

Land Use Change and Urban Impermeability in Dibrugarh City, Assam

Suntoo Das^{1*}, Dr. Mala Dutta²

¹Assistant Professor, Jagiroad College, Morigaon district, Assam, India

²Associate Professor, Cotton University, Guwahati, Assam, India

¹ORCID id: <https://orcid.org/0000-0002-6102-8977>

¹suntoo321@gmail.com and ²mala.dutta@cottonuniversity.ac.in

Corresponding Author: suntoo321@gmail.com

HOW TO CITE:

Suntoo Das and Dr. Mala Dutta
(2026). Land Use Change and Urban
Impermeability in Dibrugarh City, Assam.
International Journal of Special Education,
41(10s), 368-378.

COPYRIGHT STATEMENT:

Copyright: © 2026 Authors. Open access
publication under the
terms and conditions of the
Creative Commons Attribution
(CC BY)
license (<http://creativecommons.org/licenses/by/4.0/>).

ABSTRACT:

This study is an attempt to assess the impermeable surfaces in the Dibrugarh municipal area with the help of land use change analysis. The Dibrugarh municipal area, which comprises only 15.44 sq. km, is not suitable for land use change detection using freely available satellite images such as Landsat or Sentinel images, which have very low spatial resolution compared to the study area. Buying higher-resolution satellite images from Planet Labs, Airbus, or Maxar is quite expensive and cannot be accessed easily due to security reasons. On the other hand, Google Earth images, which are freely available and provide clear views of buildings and roads, can be easily used for on-screen digitization and hence utilized in this study for land use change detection, as they also provide historical images. The study revealed that built-up areas have increased by 10.13 percent from 2013 to 2023, which also increases the runoff coefficient from 0.54 to 0.61, making the city more vulnerable to flooding.

Keywords: *Land use change, impermeability, urban flood.*

INTRODUCTION

Though flooding is a major hazard in both rural and urban areas worldwide, but it is in urban areas that the risks to people and the economic impacts are most severe (Manson et al, 2018). Urban flooding or flooding in urban environment is the accumulation of floodwaters that results where inflow of storm water exceeds the capacity of a drainage system to infiltrate waters into the soil or carry it away. Flooding in urban areas caused by intense and prolonged rainfall which overwhelms the capacity of the drainage system is one of the principal hazards

in modern towns and cities (Ochoa et al, 2010). Major cities around the world have suffered urban flooding, both in developed or developing countries (Pitt, 2007, Rafiq et al, 2016, Zheng et al, 2016, Rainey et al, 2021).

The process of urbanization increases the risk of flooding. Urbanization increases impervious areas and decreases rainwater seepage, which results in an increased surface runoff, flood peaks and flood volumes (Surya et al, 2012). Surface runoff is precipitation that does not infiltrate into the soil and runs across the land surface into surface waters (streams, rivers, lakes

or other reservoirs) (Perlman, 2016). Singh et al, (2019) has also revealed that unplanned urbanization leads to city congestion, land use land cover change which transforms bare surface areas to paved surface areas and because of this rainwater infiltration dwindles and surface runoff increases, which results in the occurrence of urban flood. According to Blum et al, (2020), 1% impervious pavement development (e.g., roads and parking lots) will cause the average flood incidents per year to rise by 3.3%. The encroachment along the drains and wetlands by land use land cover change also results urban flooding. For example, decreasing size of Deepor Beel is unable to contain the additional surface runoff generated from the Guwahati city which results in urban flooding (ASDMA, 2014). Such problems are severe in physically uneven urban spaces with higher gradient of slopes. For example, according to a report, "Estimating sediment and water yield from hills of Guwahati city" (2017), prepared by the Indian Institute of Technology, Guwahati, stated that "Sediment yield and high runoff generation from the hilly terrain of Guwahati City is one of the important factors responsible for urban flooding of Guwahati City." Simultaneously, drainage routes are often altered in cities, which results in reduced capacity for excess water. Further, the growing urban population and degree of urbanization puts great pressure on the existing drainage systems (such as drainage system choked with garbage dumping and siltation, encroachment along the drains etc), increasing the likelihood of them being overwhelmed (Singh et al, 2023). Asiedu (2020), reviewed 45 literature from all over the world regarding urban flooding and found out that among the 45 literature sources, the highest frequency of urban flood occurrence is because of excessive or intense rainfall (62%), followed by increased paved surface (40%), inadequate or poor drains (33%), poor waste management which led to blockage of drains (31%), unplanned and haphazard development (24%), climate change (9%) and lack of drainage facilities (2%).

In many cities of Assam, poor drainage systems often cause heavy waterlogging during rains. This not only makes it hard for people to go about their daily lives but also creates serious health problems, such as the spread of malaria and other waterborne diseases. Roads, buildings and other public places also get damaged, which harms the health, safety and cleanliness of the whole community. Assam has the largest urban population in Northeast India, with 4.3 million people (Census, 2011). Big cities like Guwahati (968,549), Silchar (229,136), Dibrugarh (154,296), Jorhat (153,889) and Nagaon (142,736) have all faced urban flooding many times in recent years. In Guwahati, eight people lost their lives in floods on June 23, 2014 and four more died in another flood in June 2017 (Das, 2021). Silchar has also seen serious floods in recent times. Towns like Dibrugarh, Jorhat and Nagaon often suffer from waterlogging, especially in the summer, making floods a regular problem for these cities.

Dibrugarh, one of Assam's most important cities, has faced repeated urban floods in recent years with major incidents in 2015, 2019, 2020 and 2024 disrupting the lives of its residents (Scroll.in, 2020, Saikia, 2020, Hub news, 2024, Dutta, 2024; 2025). While numerous studies have investigated urbanization and land use changes in Dibrugarh (Acharjee et al, 2013, Neog and Gogoi, 2016, Neog et al, 2020; 2022, Mehzaheen, 2023, Saikia & Gogoi, 2024), there remains a gap in research addressing the urban impermeability and urban flood occurrence in Dibrugarh city.

This study is an attempt to investigate implications of land use change on urban impermeability in Dibrugarh city. First, land use change has been analysed to monitor the growth of impervious surfaces, which is directly related to the increasing runoff coefficient of the city. Many studies have already carried out land use conversion and urban growth patterns in all over the world using multispectral satellite images of different time periods (Bikis et al, 2014, Nath et al, 2021, Rana & Sarkar, 2021, Oli et al, 2025). All these studies have utilized Landsat satellite

images of different time periods to investigate land use land cover change by using image processing techniques such as supervised or unsupervised classification. Landsat images have been downloaded from <https://earthexplorer.usgs.gov/> where images are freely available. However, these images have certain limitations of their own. All of Landsat images provides different band resolutions ranging from 30 to 80 meters from various sensors such as Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), etc. which have very coarse resolution for studying a small municipal area like Dibrugarh which comprises only 15.44 sq. km. In case of Indian Remote Sensing Satellite imageries like LISS-4, which have been available on <https://bhoonidhi.nrsc.gov.in/bhoonidhi/home.html> portal since 2013 with a resolution of 5.8 meters, it is very difficult to accurately perform supervised or unsupervised classification as these images only have 3 spectral bands which are green, red and near-infrared (NIR). In case of Dibrugarh municipal area vegetation and open space areas emits the similar spectral signature, which poses further challenge for image classification. To overcome these limitations, the researcher can obtain high resolution satellite images with a spatial resolution of less than 2 meters from Indian Remote Sensing Satellite such as Cartosat-2 or US and European based company such as Planet Labs, Maxar and Planet Labs, however, imagery from these organizations is not open sourced and is quite expensive.

Therefore, a different approach has been taken in this study to investigate land use conversion in small urban areas like Dibrugarh municipality by utilizing freely available Google Earth Pro imagery which has a spatial resolution of less than 1 meter (Jacobson et al, 2015, Malarvizhia et al, 2016). In Google Earth Pro, one can explore small urban areas with high resolution images, easy to identify different objects like buildings, roads, vegetation, water bodies, open

STUDY AREA

space areas etc. Historical images are also available, which helps to detect changes. However, Google Earth images don't have the original multispectral band data which means in these images, it is not possible to obtain the actual pixel numbers or reflectance values. Therefore, image classification using supervised or unsupervised classification techniques cannot be carried out. But due to its higher resolution and distinctiveness of the objects on the ground, the researcher can easily import these images into GIS software (after downloading and performed georeferencing) such as ArcGIS, ERDAS IMAGINE, ENVI, QGIS etc. to identify and digitize these features for preparing land use maps and detecting change (Malarvizhia et al, 2016). Besides this, another important feature in Google Earth Pro is that a researcher can perform on screen digitization in the Google Earth Pro itself by creating different folders for different classes in KML format (Neog et al, 2020). Once the digitization process is completed, KML files can be imported directly into GIS software and by converting these KML files to shapefile format, land use statistics can be extracted and land use maps can be easily prepared. In this study, land use classes for two different time periods (2013 and 2023) directly digitized in Google Earth Pro in KML format and later imported into QGIS, converting KML format to projected shapefile for land use statistics and land use map preparation. Hence, in many micro level urban related studies, Google Earth images have already been utilized for land use change detection (Malarvizhia et al, 2016, Neog et al, 2020, Neog, 2022).

Secondly, in order to understand the impact of land use conversion on flooding in Dibrugarh city, the study also calculated runoff coefficient, which is an important parameter which indicates what amount of precipitation doesn't infiltrate into the soil (Subramanya, 2017). This study will help planners and policy-makers in future planning, management and development of the city.

Dibrugarh is an administrative district of Assam, situated in the north eastern part of India. The total geographic area is 3381sq km with a population of 1327748 (Census of India, 2011). It extends from 27°0' N to 27°45'N latitude and 94°30' E to 95°30' E longitudes. The heart of the Dibrugarh district is Dibrugarh city, which comprises of 22 wards. The city is located at the

intersection of 27°28' N latitude and 94°35' E longitudes and at 104.24 meters above mean sea level. Total area of the municipality is 15.44 sq. km and the total population is 139547 (Dibrugarh Municipal Board, 2020). The city of Dibrugarh receives its maximum rainfall during the summer (April-September) whereas in winter lowest amount of rainfall is recorded.

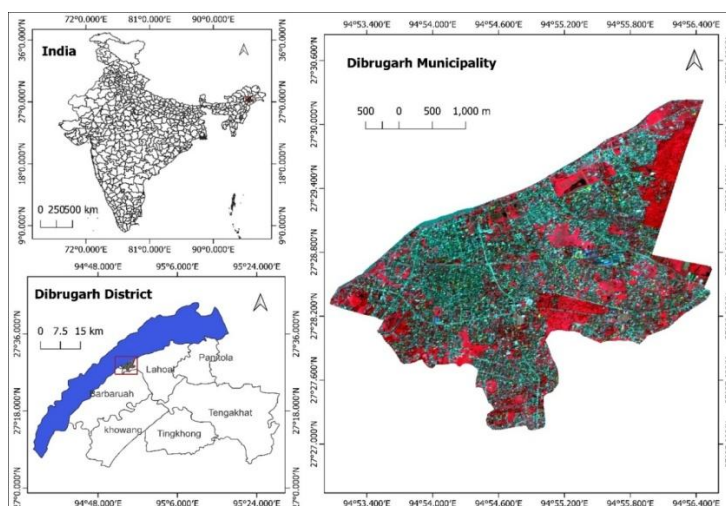


Fig. 1: Location of the study area

MATERIALS AND METHODS

Land use change

In this study, Dibrugarh Municipal Boundary map was collected from the Town and Country Planning Office in Dibrugarh. Then it was georeferenced using image to image rectification technique in QGIS where Google Satellite image was used as a reference. For image-to-image rectification, recognizable landmarks that were visible on both the municipal map and the

Google satellite image such as road intersections and railroad crossings were utilized. The municipal and ward boundaries were then digitalized and converted from a QGIS shapefile to a Google Earth compatible format (KML). In order to digitize and mark the municipal boundary, this KML file was opened in Google Earth Pro. This study selected the years 2013 and 2023 for ten years change detection and these images were accessed through historical imagery option.

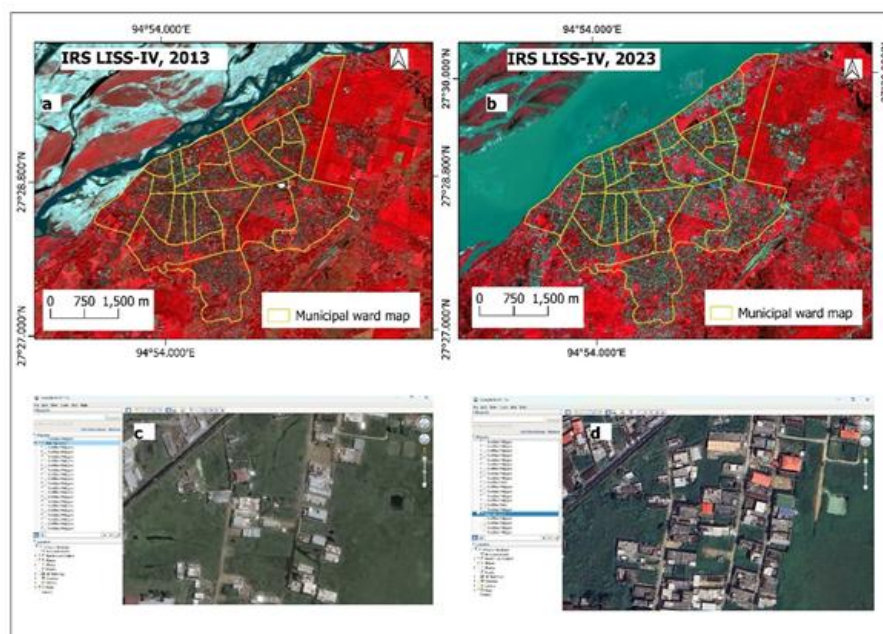


Fig. 2: LISS-IV images in standard FCC used as a reference for digitization (a & b) and (c & d) digitization in Google Earth Pro 2013 & 2023

Before digitizing, different folders were created for each land use class such as built up, vegetation, water body, agriculture, open space etc. With the help of draw polygon feature in Google Earth Pro, land use classes were digitized in KML format and saved in respective folders. The digitized KML files were imported into OGIS and converted into shapefile format which further converted to EPSG:32646-WGS84 / UTM zone 46N projected coordinate system in order to extract land use statistics and prepare land use maps. The study also used LISS-4 imagery from the same years 2013 and 2023, in a standard false colour composite as reference image for digitization and cross-checking Google Earth images while digitizing various land use classes. Land use classes that were taken into consideration for the present study were built up, vegetation, tea garden, water body and open space. The built-up area includes various types of buildings such as residential, commercial and industrial as well as transportation and communication infrastructure like roads and railways. Vegetation in the area consists of trees and grasslands. the trees situated among the houses are also categorized as vegetation. Tea gardens can be seen in the western and southwestern parts of

the municipality. The agriculture class includes paddy cultivation. Water bodies consist of ponds and open spaces are free from any sort of agriculture and other activities.

Ward-wise land use statistics were extracted using the dissolve and intersection features in QGIS. First, each land use class was dissolved into a single unit, then intersected with the ward map to obtain ward-wise land use data for calculating ward wise runoff coefficient.

RUNOFF COEFFICIENT

To investigate the increasing impermeability in Dibrugarh City, the study estimated runoff coefficient of the city based on land use statistics. The Runoff Coefficient or C is an important parameter that symbolizes the amount of precipitation that does not infiltrate and rather flows over the surface (Goel, 2011). It is a fraction which is used to determine the quantity of rainwater that will enter the stormwater drainage system by multiplying it with the total rainfall. Determining the runoff coefficient is essential for rational method, which estimates the peak discharge rate of an urban catchment area. The value of runoff coefficient ranges from 0 to 1, where $C=0$ represents the entire incoming water falling on

the surface is lost in soil or atmosphere and when $C=1$, it represents the entire incoming water falling on the surface that does not infiltrate but becomes runoff (Kuichling, 1889).

However, it is very difficult to assess runoff coefficient (C) as it varies based on factors like land use, soil type, slope and even the time of year (BASMMMA, 1999, Shuster et al, 2005, Sabzevari et al, 2024). Therefore, to calculate runoff coefficient (C), it is important to choose runoff coefficient (C) values for different land use classes from a runoff coefficient table. Several runoff coefficient tables are available in various hydrological textbooks (Das & Saikia,

2014, Subramanya, 2017) but when it comes to choosing particular runoff coefficient values for different classes in an urban area it poses further challenge as it depends on local hydrological conditions. Hence, it requires proper judgement from an experienced engineer (Urban Drainage and Flood Control District, 2016). Based on a similar study conducted in the Jorhat municipality area (Gogoi, 2019), a modified runoff coefficient table was adopted for Dibrugarh municipality from the Hydrologic Design Manual, 2019 of Texas Department of Transportation as it is best suited for the study area.

Table 1 Simplified Runoff Coefficients table for urban areas

Sl. no.	Land use	Runoff Coefficient (C)
1	Paved surface areas (stones, bricks and blocks along with the buildings and houses of such types: residential, industrial, commercial administrative plots)	0.85
2	Forest & wooden areas and areas with larger proportion of trees, plantation etc.	0.1
3	Open ground, unpaved streets, rail, roads, yards etc	0.2
4	Parks, lawns, meadows	0.18
5	Cultivated land	0.15
6	Water bodies, swamps, wetlands	0
7	Stone brick and block pavements	0.6
8.	Water tight roof surfaces (tin roof etc)	0.95

Source: Hydraulic Design Manual, 2019

Bases on the table 1 runoff coefficient values and land use statistics of Dibrugarh, a composite

runoff coefficient value (C) was calculated by using the following equation.

$$C = \frac{A_1 C_1 + A_2 C_2 + \dots + A_n C_n}{A_1 + A_2 + \dots + A_n}$$

$$= \frac{\sum A_i C_i}{\sum A_i} \quad (i = 1, 2, 3, \dots, n) \quad (1)$$

Here, $A_1, A_2, \dots, A_n$ are the areas of various land use units

$C_1, C_2, \dots, C_n$ are various runoff coefficient for different land use classes

RESULTS AND DISCUSSIONS

Land use change

Table 3: Land use change from 2013 to 2023.

Sl no	Land use classes	Area in sq. meters (2013)	Area in % 2013	Area in sq. meters (2023)	Area in % 2023	Net change
1	Agriculture	38404.62	0.25	38404.62	0.25	0.00
2	Built up	8539580.10	55.30	10133092.04	65.62	10.32
3	Open space	4484021.07	29.04	3306446.51	21.41	-7.63
4	Tea garden	1064393.65	6.89	1064393.65	6.89	0.00
5	Vegetation	1274510.65	8.25	883493.33	5.72	-2.53
6	Water body	41287.52	0.27	16367.46	0.11	-0.16
	Total	15442197.60	100.00	15442197.60	100.00	

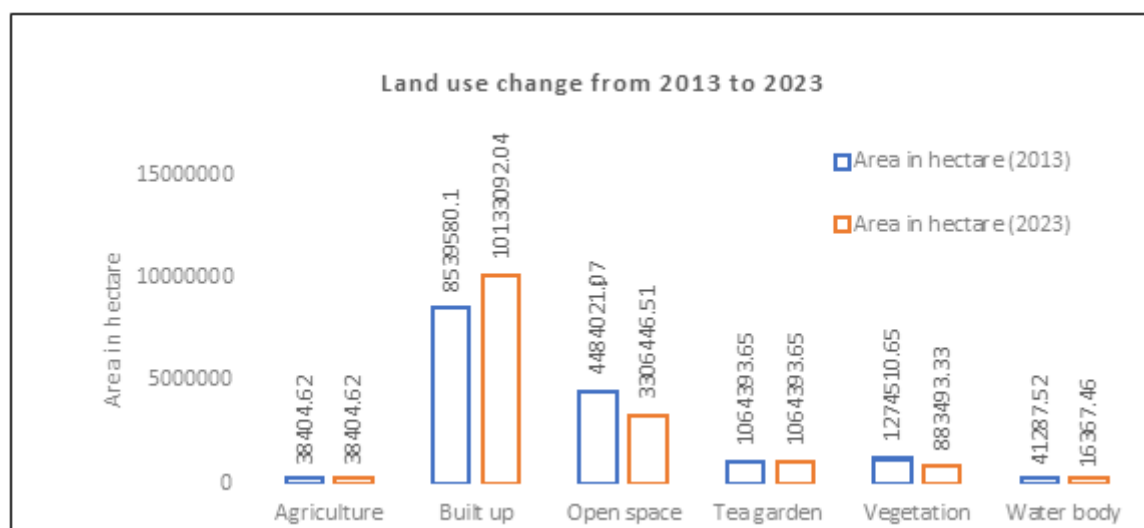


Fig. 4: Changes in land use classes from 2013 to 2023

Table 2 showed significant land use conversion from 2013 to 2023 during the span of 10 years. The built-up area has been increased by 8539580.10 sq. meters to 10133092.04 sq. meters, rising from 55.30% to 65.62%. There has been a significant decline in open space area from 4484021.07 sq. meters (29.04%) to 3306446.51 sq. meters (21.41%) while vegetation

cover has decreased from 1274510.65 (8.25) sq. meters to 883493.33 (5.72%) hectares due to the growth of urban built-up areas. Water bodies on the other hand, declined slightly from 41287.52 (0.27%) sq. meters to 16367.46 sq. meters (0.11%). There has been no change in agricultural land and tea gardens during this period.

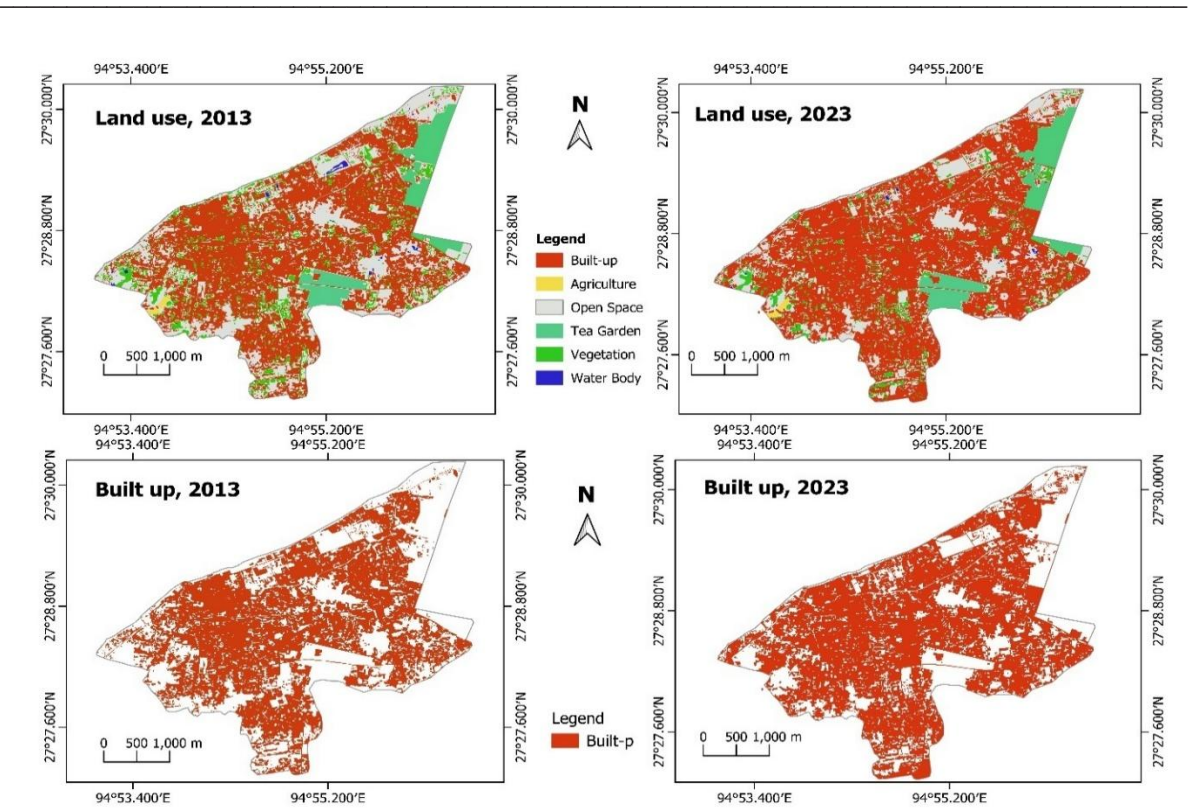


Fig. 5: Land use and built-up map for 2013 &2023

Built-up and runoff coefficient

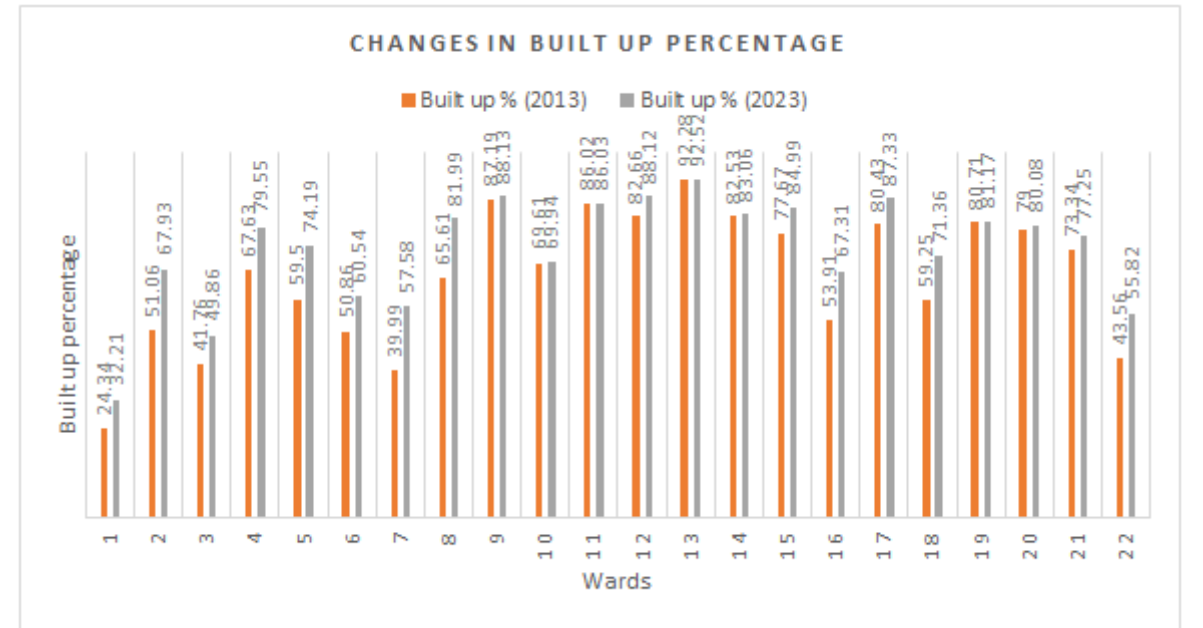


Fig. 6: Ward wise built-up percentage for 2013 & 2023

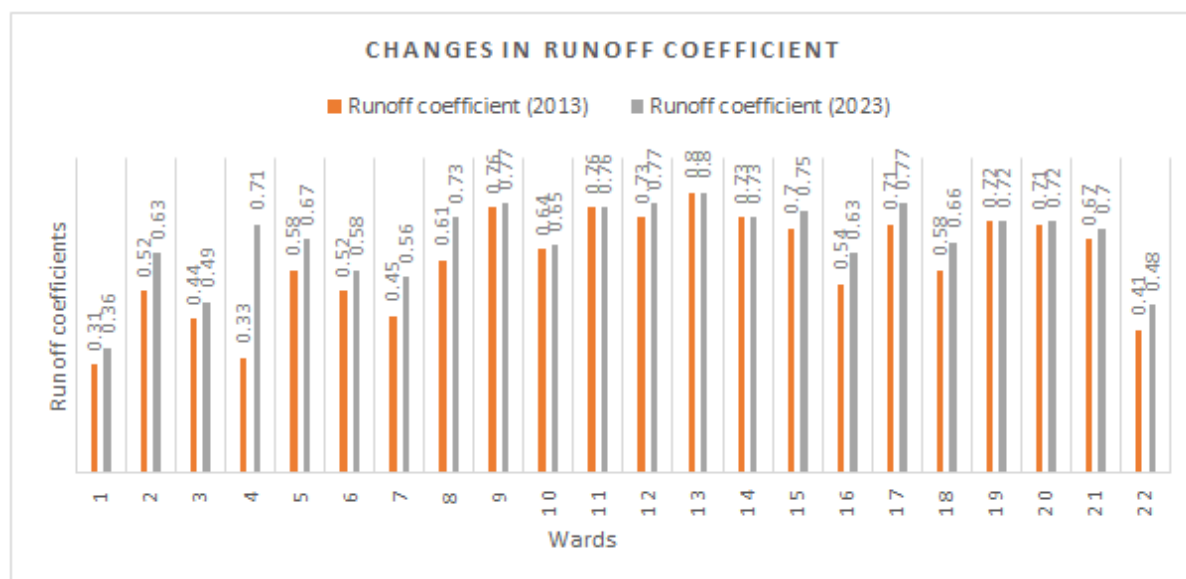


Fig. 7: Ward wise runoff coefficient for 2013 & 2023

From figure 5 & 6, it can be clearly observed that there is a trend of increasing built up areas and runoff coefficients from 2013 to 2023. The runoff coefficient for the entire municipal area has increased from 0.54 to 0.61. Between 2013 and 2023, most wards indicated a positively increasing trend in built-up areas. This increase was evident particularly in peripheral wards such as 4, 5, 7, 8, 17 and 18. In contrast, core wards like 9, 11, 13, 14, 19 and 20 indicated very minimal change as they were already highly urbanized in 2013. The increase in impervious surfaces have contributed to increased runoff coefficients in most wards and the greatest increases were observed in wards 4, 7 and 8. As of 2023, the highest runoff values overall for result produced in the densest wards (9, 12, 13 and 16). Most of the wards with low built-up percentages (1 and 3) continue to show low runoff. In general, the results show rapid urbanization in peripheral (< 75% built-up) wards and signs of saturation in the central (> 75% built-up) wards, as made evident by increasing runoff coefficients and increasing potential for urban flooding. These results

coincide with the numerous flood events in Dibrugarh city that have occurred recently and validate the impact of urban impervious surfaces on flood occurrence.

CONCLUSION

The study shows there have been significant transformations of land use in the Dibrugarh municipal area from 2013 to 2023. The pattern of the land use change shows increasing urban built-up areas at a rapid rate of 10.32 percent during the span of 10 years, which impacts the hydrological characteristics of the city. As the built-up areas increase, the runoff coefficient also increases, which can generate more surface runoff during a heavy downpour and makes the city more vulnerable to flooding.

ACKNOWLEDGEMENTS: The authors gratefully acknowledge the Municipal Office and the Town and Country Planning Office, Dibrugarh, for providing the essential data.

FUNDING SOURCES: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

- Acharjee, S., Goswami, U., & Saikia, R. (2013). Visual change detection study of some of the urban areas of Assam, India using remote sensing. *International Journal of Geomatics and Geosciences*, 3(3), 500–510.
- Asiedu, J. B. (2020). Reviewing the argument on floods in urban areas: A look at the causes. *Theoretical and Empirical Researches in Urban Management*, 15(1), 24–41.

- Assam State Disaster Management Authority (ASDMA). (2014). *Urban floods in Guwahati*. Retrieved August 5, 2025, from <https://asdma.assam.gov.in/sites/default/files/Guwahati%20floods.pdf>
- Bay Area Stormwater Management Agencies Association. (1999). *Start at the source: Design guidance manual for stormwater quality protection*. Forbes.
- Bikis, A., Engdaw, M., Pandey, D., & Pandey, B. K. (2025). The impact of urbanization on land use land cover change using geographic information system and remote sensing: A case of Mizan Aman City Southwest Ethiopia. *Scientific Reports*, 15(1), 12014.
- Blum, A. G., Ferraro, P. J., Archfield, S. A., & Ryberg, K. R. (2020). Causal effect of impervious cover on annual flood magnitude for the United States. *Geophysical Research Letters*, 47(5), e2020GL087091.
- Das, S. (2021). Analyzing urban flood scenario in Guwahati City, Assam. In H. Rahman & J. Baruah (Eds.), *Anwasha* (pp. 187–197). Jagiroad College Teacher's Unit.
- Dutta, R. (2024, July 2). Dibrugarh waterlogged for 5th consecutive day. *Times of India*. <https://timesofindia.indiatimes.com/city/guwahati/dibrugarh-waterlogged-for-5th-consecutive-day/articleshow/111417028.cms>
- Dutta, R. (2025, April 24). Dibrugarh faces severe water logging issues after 2nd straight day of rain. *Times of India*. <https://timesofindia.indiatimes.com/city/guwahati/dibrugarh-faces-severe-waterlogging-issues-after-2nd-straight-day-of-rain/articleshow/120594424.cms>
- Food and Agriculture Organization of the United Nations. (2014). *Compendium on rainwater harvesting for agriculture in the Caribbean sub-region: Concepts, calculations and definitions for small, rain-fed farm systems*. <https://openknowledge.fao.org/server/api/core/bitstreams/9e1e6970-26d5-4d07-94ce-7202552e4988/content>
- Goel, M. K. (2011). Runoff coefficient. In V. P. Singh, P. Singh, & U. K. Haritashya (Eds.), *Encyclopedia of snow, ice and glaciers* (pp. 952–953). Springer.
- Gogoi, P. (2019). *Drainage problem in Jorhat urban environment* (Doctoral dissertation). Guwahati University. <http://hdl.handle.net/10603/236664>
- Hub News. (2024, July 1). Assam: Waterlogging crisis worsens in Dibrugarh, Minister visits city to assess situation. <https://hubnetwork.in/assam-waterlogging-crisis-worsens-in-dibrugarh-minister-visits-city-to-assess-situation/>
- Indian Institute of Technology Guwahati. (2017). *Estimating sediment and water yield from hills of Guwahati City*. https://asdma.assam.gov.in/sites/default/files/swf_utility_folder/departments/asdma_revenue_uneecopscloud_com_oid_70/this_comm/Final%20Report%20on%20Soil%20and%20Water%20Yield%20from%20Hills%20of%20Guwahati.pdf
- Jacobson, A., Dhanota, J., Godfrey, J., Jacobson, H., Rossman, Z., Stanish, A., Walker, H., & Riggio, J. (2015). A novel approach to mapping land conversion using Google Earth with an application to East Africa. *Environmental Modelling & Software*, 72, 1–9.
- Kuichling, E., 1889. The relation between the rainfall and the discharge of sewers in populous districts. *Transactions of the American Society of Civil Engineers*, 20(1), pp.1-56.
- Malarvizhi, K., Kumar, S. V., & Porchelvan, P. (2016). Use of high-resolution Google Earth satellite imagery in land use map preparation for urban related applications. *Procedia Technology*, 24, 1835–1842.
- Mehzabeen, E. (2023). Living a flooded life: Women, city and community in North East India's Dibrugarh. *Journal of North East India Studies*, 13(1).
- Nath, B., Ni-Meister, W., & Choudhury, R. (2021). Impact of urbanization on land use and land cover change in Guwahati city, India and its implication on declining groundwater level. *Groundwater for Sustainable Development*, 12, 100500.
- Neog, R., & Gogoi, P. (2016). A GIS-based analysis of urbanisation and its impact on arable land: A study on selected municipalities of upper Assam, India. *IOSR Journal of Humanities and Social Science*, 21(5), 81–90.
- Neog, R., Lahkar, B., Baruah, J., Acharjee, S., Gogoi, B. S., Sonowal, B., Dutta, D., Chetia, D., Baruah, J., Gogoi, M., & Patar, M. (2020). An infrared thermography-based study on the variation in diurnal and seasonal land surface temperature at Dibrugarh city, India. *Modeling Earth Systems and Environment*, 6(4), 2047–2061.
- Neog, R. (2022). *Pattern of urban growth and urbanization in Jorhat District of Assam* (Doctoral dissertation). Dibrugarh University. <http://hdl.handle.net/10603/361563>

- Neog, R., Gogoi, P., Lahkar, B., Baruah, J., & Phukan, A. (2022). Understanding the influence of traffic volume on RST (road surface temperature) in Dibrugarh city of India. *Modeling Earth Systems and Environment*, 8(3), 3247–3261.
- Ochoa-Rodríguez, S., Smith, D. K. M., Aivazoglou, M., Pina, R., & Mijic, A. (2010). Urban pluvial flooding and climate change: London (UK), Rafina (Greece) and Coimbra (Portugal). *Water Science and Technology*, 62(10), 2238–2245.
- Office of the Registrar General & Census Commissioner, India. (2011). *Census of India 2011*. Ministry of Home Affairs, Government of India. <https://censusindia.gov.in/>
- Oli, D., Gyawali, B., Neupane, B., & Oshikoya, S. (2025). Assessment of land use land cover change and its impact on variations of land surface temperature in Atlanta, USA. *Environmental and Sustainability Indicators*, 100712.
- Perlman, H. (2016). *The water cycle*. USGS Water Science School. <https://www.usgs.gov/special-topics/water-science-school/science/water-cycle> (usgs.gov in Bing)
- Pitt, S. M. (2007). *Learning lessons from the 2007 floods: An independent review (Interim report)*. Cabinet Office.
- Rafiq, F., Ahmed, S., Ahmad, S., & Khan, A. A. (2016). Urban floods in India. *International Journal of Scientific & Engineering Research*, 7(1), 721–734.
- Rainey, J. L., Brody, S. D., Galloway, G. E., & Highfield, W. E. (2021). Assessment of the growing threat of urban flooding: A case study of a national survey. *Urban Water Journal*, 18(5), 375–381.
- Rana, M. S., & Sarkar, S. (2021). Prediction of urban expansion by using land cover change detection approach. *Heliyon*, 7(11), e08456.
- Sabzevari, T., Haghighi, A. T., Ghadampour, Z., Petroselli, A., & Namazi, H. (2024). Estimation of regional design runoff coefficient in the rational method. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 48(1), 467–482.
- Saikia, A. (2020, June 29). In pictures: 'Mad floods' amid a coronavirus lockdown in Assam's Dibrugarh. *Scroll.in*. <https://scroll.in/article/966018/in-pictures-mad-floods-amid-a-coronavirus-lockdown-in-assams-dibrugarh>
- Saikia, N., & Gogoi, A. (2024). Waterlogged lives: A sociological exploration of the human dimensions of urban flooding in Dibrugarh town, Assam. *International Journal of Humanities and Social Science Research*, 10(2).
- Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. R. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*, 2(4), 263–275.
- Singh, H., Nielsen, M., & Greatrex, H. (2023). Causes, impacts and mitigation strategies of urban pluvial floods in India: A systematic review. *International Journal of Disaster Risk Reduction*, 93, 103751.
- Singh, M., & Upmanyu, V. (2019). Urban flooding: The case of drowning cities and rising vulnerability. *Down to Earth*.
- Subramanya, K. (2021). *Engineering hydrology* (pp. 155–159). McGraw Hill Education.
- Suriya, S., & Mudgal, B. V. (2012). Impact of urbanization on flooding: The Thirusoolam sub watershed—A case study. *Journal of Hydrology*, 412, 210–219.
- Texas Department of Transportation. (2019). *Hydraulic design manual*. Retrieved August 7, 2025, from <https://www.txdot.gov/content/dam/txdotoms/des/hyd/hyd.pdf>
- Zheng, Z., Gao, J., Ma, Z., Wang, Z., Yang, X., Luo, X., Jacquet, T., & Fu, G. (2016). Urban flooding in China: Main causes and policy recommendations. *Hydrological Processes*, 30(7), 1149–1160.