Assessing the spatial impact of urbanization on surface water bodies using remote sensing and GIS

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Abstract. Indian cities are expanding exponentially due to rapid and unplanned urbanization. The unprecedented pace of expansion is a major challenge for surface water management. The shrinkage of surface water bodies is considered as an important criterion by urban planners and policymakers. This research utilizes remote sensing data to address this problem for the suburbs of Chennai. The extent of urbanization is studied through remote sensing data obtained from satellite imagery at 30 m resolution for the year 2019 and land use land cover classification is also carried out to determine the urban built up. The initial surface area of the water bodies were determined using the topographical maps and was then compared with the present areal extent. The result reveals that the urbanization had a significant impact on the spatial extent of surface water bodies. The water bodies have significantly undergone reduction and disappearance due to urban expansion. Proactive land use planning and monitoring are essential to safeguard the ecological value of water bodies.

1. Introduction

Water is a very important and crucial resource needed for human existence; especially freshwater is a very essential resource for all life on earth. Freshwater constitutes only 2.5-2.75\% of the total water available on the planet. The remaining water is saline water in nature which reduces its usability to a great extent. Freshwater is utilized by human beings for drinking, farming and for day to day activities. The freshwater is available in the form of glaciers, groundwater and surface water. A vast amount of freshwater is frozen in glaciers and as ice. It is vital not to exploit those sources because of their ecological and environmental impacts. The surface water sources of freshwater include rivers, lakes, ponds and streams. The surface water bodies are the main source of freshwater for all human beings. Therefore, it is of prime importance to safeguard and utilizes the surface water responsibly and efficiently. Freshwater is a renewal and a finite resource. Freshwater can be replenished through the process of precipitation. The catchment area and the surface water bodies are the primary sources for collecting and storing freshwater obtained through precipitation.

The water bodies play an essential role in maintaining the sanity of the environment and as well as supports human life to thrive. The water bodies supply water for the human necessity for his day to day needs. The water bodies play a vital role in groundwater recharge and thereby playing a crucial role in maintaining the groundwater table of the region. Surface water bodies also act as barriers to
flooding control. The water bodies help in maintaining the greenery around them and also, play a vital part in reducing the surface temperature of the urbanized cities. The urban heat island effect on the cities can be minimized by the presence of water bodies.

With the increase in population and economic development, urbanized areas are expanding spatially and creating an ecological imbalance. The cities while expanding convert the cultivable lands, water bodies and forest into the urban structure thus leading to ecological imbalance. The immigration of people to urban areas leads to a drastic increase in the population of the cities thereby creating additional demand for land, freshwater and other infrastructure facilities. The cities stressed by infrastructure demand and lack of land at cheaper prices leads to horizontal development along the fringes. The spatial expansion of the cities stresses the surface area of the freshwater storage bodies. Several studies have been conducted to find out the extent of urbanization. During the last three decades, several Indian cities have experienced fast urbanization. The urbanization of Indian cities has been categorized by unprecedented population growth and unplanned developmental activities [1].

Spatial-temporal land use land cover changes due to urban expansion have been studied extensively [2][3]. The previous works have concentrated on loss of vegetation [4], loss of cultivable lands [5] and the pattern of urbanization [6]. Some research has been carried out recently about water bodies management concerning urbanization. Land use management of lake areas in urban fringes is analyzed using GIS [7]. The impact of urbanization and urban land expansion on the quality of water is determined [8]. The effects of land use change on lake restoration have been studied [9] and the relationship between urbanization and water environment is also analyzed [10]. The urbanization impacts on surface water bodies based on the land conversion happening around the urban area were determined [11].

In this study, an attempt has been made to investigate the relationship between the increase in urban land use (built-up area) and its spatial impact on the surface water bodies. The study aims to raise the level of attention paid to encroachment and surface water management issues in spatial planning of the urban development process. The impacts of water body deterioration may lead to a situation of water scarcity where, even the water demand for the basic need is not fulfilled. This increase in water demand is due to rapid urbanization and encroachment of water bodies due to the increasing demand for residential and commercial infrastructure. This study gives a detailed report of spatial encroachment of urban structures on surface water bodies.

2. Study Area
Chennai is the capital city of Tamilnadu. It is one of the four metropolises and the fifth most populated city in India. Chennai city corporation (Chennai District) includes sixteen municipalities, twenty town panchayats and two hundred and fourteen villages. According to the 2011 census, the city of Chennai with its suburbs has a population estimated at 9 million. This makes it the fourth most populous metropolitan city in India and the thirty-first largest urban city in the world. Chennai city lies between latitudes 12°50'49" and 13°17'24", and longitudes 79°59'53" and 80°20'12". It is flat land located on the Coromandel coast plain in southern India. Urban suburbs are considered because the suburban regions are prone to encroachments than that of the city core [12]. The urbanization of Chennai is more along the southern direction of Chennai rather than other directions. So southern suburbs of Chennai are considered for the study. Seven assembly constituencies viz. Alandur, Pallavaram, Tambaram, Sholinganallur, Sripurumudur, Chengalpatu, and Thiruporur in the southern suburbs of Chennai are considered for the study.
3. Data Collection and Methodology
Survey of India (SOI) topo-sheets (scale, 1:25,000) and multi-spectral Landsat TM for the year 2019 is considered for the study. Topo-sheets of southern suburbs of Chennai were collected from Survey of India (SOI) topographical maps (2011). Waterbody features were extracted from topographic maps which represent the geological features of the earth. Landsat satellite images were downloaded from the United States Geological Survey (USGS) a public domain that provides topographic and geographic maps of the required region in GeoTIFF format. These data sets were used for the land use and land cover (LULC) classification. The toposheets of the southern suburban region of Chennai used for the study are 57O/16, 57P/13, 57P/14, 66C/4, 66D/1, 66D/2.

| S. no | Type of data used       | Scale/Resolution | Years |
|-------|-------------------------|------------------|-------|
| 1     | Survey of India (SOI)   | 1:25,000         | 2011  |
|       | Topographical maps      |                  |       |
| 2     | Landsat 8 OLI/TRIS C1   | 30 m             | 2019  |
|       | Level -1                |                  |       |

Geographical information systems (GIS) together with remote sensing data are used for monitoring the emerging urbanization of the cities using digital satellite images. Satellite images are needed to be pre-processed to obtain clear pixels in an image to perform image classification algorithms. Land use and land cover classifications are done by a supervised classification algorithm for the satellite images.
From the classified images, the urban land features are extracted from raster to vector format. Survey of India (SOI) topographical maps are considered for abstracting surface water body features. For the analysis of urbanization impacts on surface water bodies, the extracted urban land features are intersected with the surface water body features. Figure 2 shows the methodology used for the study.

**Figure 2.** Flowchart of methodology.

### 4. Results and Discussions
The satellite image of the study area is classified into various classes such as water body, cultivated land, urban, vegetation, and barren land. The results of these classifications are shown below. The extraction of the urban raster is carried from the classified images. The water body features are extracted from geo-referenced topographic maps.
4.1. LULC Classification of Chennai City
The Landsat satellite image of 2019 is clipped using the shapefile of seven assembly constituencies boundaries. The clipped satellite image corresponding to the study region is classified using a supervised classification method. The classification was carried out for five land use categories such as waterbody, urban, cultivated land, vegetation and barren. The classified image is shown in Figure 3.

![LULC of Southern Suburbs of Chennai 2019](image)

**Figure 3.** LULC of the study region.

The area occupied by each land use class is given in Table 2. The urban land use occupies an area of 791 sq. km. This contributes to 12% of the total area of the study region. The classified image had a user’s accuracy of 90% and overall accuracy of 92%.

| LAND USE      | AREA (sq. km) |
|---------------|---------------|
| Water bodies  | 181           |

**Table 2.** LULC of the study region
### 4.2. Urban Extraction from LULC

The urban pixels for the study region were extracted from the supervised classification image containing all the five land use categories. Figure 4 depicting the urban extraction enables an easy identification of urbanization happening in a ribbon pattern in the suburbs of Chennai. The ribbon development is taking place along the major highways connecting Chennai with other districts.

![Image](遥远.jpg)

**Figure 4.** Urban regions of the study area.

### 4.3. Surface water bodies in the study region

The spatial extent of surface water bodies such as lakes and ponds in the study region is determined by digitizing the lakes and ponds from the toposheets of 2011. The digitized waterbodies are represented in Figure 5. The digitized spatial boundary represents the region designated for lakes and ponds as per the 2011 Survey of India toposheet. The digitized water bodies have a surface area of 81.77 sq.km, which is considered for the study. The total surface area covered by the surface water bodies (LULC) in the study region is 181 sq.km which includes all the water bodies in the digitized surface area. Since the area of water bodies in LULC depicts the area covered by all the water bodies and not that of designated lakes and ponds, the data was not used for the analysis.

| Type          | Area  |
|---------------|-------|
| Urban         | 791   |
| Cultivated area | 1793  |
| Vegetation    | 839   |
| Barren        | 957   |
| **Total**     | **4561** |
The digitized water bodies of 2011 were overlaid with the urban regions of 2019. The intersecting regions of the overlay analysis represent the designated water body which has been converted into urban land use over nine years between 2011 and 2019. It is determined that an area of 5.07 sq. km of water bodies have been encroached by urbanization. This represents a loss of 6.2% of the surface area of digitized water bodies. The encroached regions are represented in Figure 6. These encroachments lead to loss of surface area of water bodies and also, they impede the flow of water to the designated water bodies. The dumbing of urban waste in the water bodies lay the stepping stone for encroachments. These form bunds which are gradually utilized by humans for various purposes. These gradual encroachments must be monitored and prevented to maintain the sanity of the water bodies.

Figure 5. The spatial extent of surface water bodies in the study region.

Figure 6. Urban encroachment in the study region.

5. Conclusion
This study helps to raise concerns for the protection and improvement of surface water resources for our present and future demands. The rate at which urbanization is affecting the water resources is extremely perturbing. Urban areas occupy 18% of the total land area in the suburbs of Chennai and the urban expansion during the period of 2011-2019 has encroached 5.07 sq.km of surface water bodies in the Chennai suburbs while the water bodies have shrunk by 6.2% in these nine years due to urbanization. The sprawling or unplanned urban development usually occurs in the urban fringes of the city. The government bodies need to regulate urban growth to preserve the environmental sanity of the regions. Hence it is necessary to have an insight into the urban area planning for the future by systematic and organized planning by the urban planning authorities so that our future needs are not compromised for our present actions.
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