Urban Sprawl Analysis Using Remote Sensing Data And Its Impact On Surface Water Bodies: Case Study Of Surat, India

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Abstract. Urbanization is the process in which population shifts from rural to cities or urban centers for an improved standard of living due to economic growth and development. As the migration rate increases, urban cities undergo major changes in land use and land cover which trigger several negative effects such as overcrowding, water scarcity, air pollution, loss of productive agricultural lands and forest cover. Remote sensing and Geographical Information System (GIS) are used for monitoring the emerging urbanization of the cities using satellite images. In this study, the land use land cover classification of Surat city has been studied for 26 years (1993-2019). The results showed that the urban built-up area in the city has increased by 175.2% over the years. In this study, the contemporary situation of surface water bodies of Surat city was examined by the intersection of urban land use areas and the digitized surface water bodies. The result reveals the reduction and disappearance of surface water bodies due to the encroachment of urban land-use. This study is done to raise the awareness paid for surface water management issues during the urban expansion process.

1. Introduction

Rapid industrialization and economic growth in major cities cause migration of population from rural to urban centers for employment and to improve their standard of living. As the migration rate increases, urban cities underwent major changes in land use and land cover which trigger several negative impacts such as overcrowding, water scarcity, air pollution, loss of productive agricultural lands and forest cover over the decades. According to the 1901 census, the population in urban cities of India was 11.4%, which gradually raised to 28.53% (2001 census) and then increased to 32.73% as per the 2011 census, currently 43% of the population live in the urban centers. The cities are expanding spatially to accommodate the migrated population. The expansion of cities in the outskirts of the urban region along the highways and over rural areas is defined as sprawl [1]. Normally sprawl occurs in urban fringe areas. Due to the lack of prior planning in the urban development process, cities face a shortfall of basic infrastructure facilities like water, sanitation, and electricity. Urban sprawl leads to the absence of productive agricultural land, open green space, reduction of groundwater and loss of surface water bodies [2]. Sprawl is a multifaceted phenomenon that has both ecological and social impacts which leads to hazardous situations. This unpremeditated urbanization process has induced several hydrological impacts in terms of influencing the nature of surface runoff, erosion,
encroachment in riparian zones, delivering pollutants to rivers, depletion of groundwater and other hydrological characteristics [3]. In this paper, an attempt has been made to explore the relationship between the increase in urban land use (built-up area) with the reduction and disappearance of surface water bodies.

The conventional topographical surveying and mapping techniques are expensive and time consuming for recognition of urban sprawl and its pattern. Remote sensing is an inexpensive technology used for the investigation of urban sprawl in these days. Geographical information systems (GIS) together with Remote sensing data are used for monitoring the emerging urbanization of the cities using digital satellite images and temporal data. From the earliest imagery (Landsat-MSS-1973) having more than 70 m resolution to the present higher (IRS-P6 LISS-III) imageries having finer (5.8 m) resolution, it has been proved proficient in sensing the changes in land-cover and urban sprawl [4] [5]. The Gaussian Maximum Likelihood classifier is an empirical classification algorithm employed in the processing of satellite images. Urban growth modeling studies have been attempted in many developing countries [6]. In this study, the spatial phenomenon is studied geometrically using supervised classification techniques for the analysis of urban growth patterns and impervious built-up area.

2. Study Area

Surat is the largest city nearby the Tapti river in the west Indian state of Gujarat. The city is located at 21°10′N and 72°50′E and it is the 8th largest populated city in India. The population is about 44,66,826 as per the 2011 Census. Surat district covers a total area of 4,418 sq. km with a population density of 13,680 per sq. km. Figure 1 shows the study area. Surat city is the secretarial capital of the Surat district. Surat is the center for diamond cutting and polishing. Surat enjoys a tropical climate and receives abundant rainfall during the monsoon period. Table 1 shows the population growth in Surat metropolitan city over the decades.

![Figure 1. Study area.](image)

Since Surat is located in between the Tapti river, it has an enormous number of surface water bodies such as lakes, ponds within its administrative boundary. The total areal extent of Surat city is 327 sq. km. Surat city has undergone rapid urbanization due to socio-economic and industrial
development over the decades. The latitude and longitude of the Surat city center are 21°11'51" N and 72°49'29" E. For this study, a buffer zone of 15 km radius is considered around the Surat district’s Central Business District (CBD). Hence the study region considered covers an extent of 706.87 km². The area covered under the buffer region is considered to derive the urban sprawl in urban fringe areas and also to find the extent of conversion from rural to urban areas.

3. Collection of Data

For this study, data has been collected from primary and secondary data sources. The data collected from the primary sources include Survey of India (SOI) topo-sheets (scale, 1:25,000) and multi-spectral Landsat TM images for the years 1993, 2000, 2010 and 2019. The data collected from the secondary source include demographic data from the Census of India (1991, 2001 and 2011). The administrative boundary of Surat is extracted as shape-file from the Open street map. Table 2 shows the data used for the study. 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.

| S. no | Type of data used                     | Scale/Resolution | Years          |
|-------|--------------------------------------|------------------|----------------|
| 1     | Survey Of India (SOI) Topographical maps | 1:25,000         | 2011           |
| 2     | Landsat 4-5 Thematic Mapper C1 Level-1 | 28.5 m           | 1993, 2000 and 2010 |
| 3     | Landsat 8 OLI/TRIS C1 Level -1        | 30 m             | 2019           |
| 4     | Census data                          | decadal          | 1991, 2001 and 2011 |

These data sets were used for the land cover and land use classification analysis. Table 3 shows the path and row details of satellite images. For the study purpose, the cloud-free satellite images were chosen in the same month of each year to reduce the discrepancy of images due to periodical or seasonal changes.

| Year | Month | Path, row |
|------|-------|-----------|
| 1993 | March | 148, 45   |
| 2000 | March | 148, 45   |
| 2010 | March | 148, 45   |
| 2019 | March | 148, 45   |

Table 1. Population growth of Surat district by 2011 census

| YEAR | POPULATION  |
|------|-------------|
| 1991 | 14,98,817   |
| 2001 | 24,33,835   |
| 2011 | 44,66,826   |
4. Methodology

Geographical information systems (GIS) together with remote sensing data are used for scrutinizing the emerging urbanization of the cities using digital satellite images. Basic satellite image processing procedures like layer stacking, image enhancement, and improvement process are done for the raw satellite images to obtain clear pixels for performing classification analysis [7]. 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. Methodology.

4.1. Satellite Image Processing
GIS and remote sensing data are used in analyzing the progression, pattern, and extent of urban sprawl. For this study, the satellite imageries are taken and image pre-processing was done [4]. The standard image processing like layer stacking, image enhancement, and improvement is done for better identification of pixels to perform further analysis [3]. The satellite imageries and the extracted administrative boundary of Surat were projected to WGS 1984 UTM zone 43N.

Land Use and Land Cover (LULC) changes were performed by supervised classification method and the imageries were classified as urban, water, agriculture, vegetation, and barren land use classes during this study period. [8].

4.2 Geo Processing of Topographic Map
Survey of India (SOI) topographical maps are considered for abstracting surface water body features of Surat city [9]. Topographical survey maps are available in Open Street Maps (OSM) and Survey of India (SOI). These maps are referred by their topo-sheet number and OSM number. These images are then geo-referenced to their coordinated system projected to UTM WGS 1984. For this study, eleven topo-sheets were mosaicked into a single new raster. Mosaicking is a process of combining data of different layers and then grouped into a single image. [7]. The Surat city area is then clipped from this mosaicked image. The water body feature classes are then extracted by digitizing polygon over the surface of water bodies in the topographic map. Figure 7 shows the surface water bodies extracted from the topographic survey map.

4.3 Extraction of Urban Lands Surface Data of Surat City
From the classified images, the urban land surface data (built-up area) can be extracted for the study purpose. The extraction of urban raster from the classified image is carried out for the year of 2019. This data which is in the raster format is to be converted into vector format of shape-file for conducting overlay analysis. Since overlay can be performed only for the same type of data sets. Figure 8 shows the extracted urban land surface data in vector format.

4.4 Overlay Analysis
The intersect overlay analysis was performed for the urban land surface data and the water body feature class which was extracted from the topographic map to determine the extent of urban encroachment on surface water bodies. This intersection operation of two feature maps was carried out to derive the intersected features which represent the urban land transformation over the surface water bodies.

5. Result and Discussion
5.1 LULC Classification of Surat City
The classifications of the satellite images were done for three decades to find the spatial changes concerning the years 1993, 2000, 2010 and 2019. The supervised classification algorithm technique is followed to do the Land Use Land Cover classification of each class into their pixel group. The results of the classified images are shown in Figures 3, 4, 5 and 6. The results show changes in the land surface pattern, it is observed that there is a drastic expansion in urban areas due to urbanization. Table 4 shows the LULC classification of Surat city. An accuracy assessment is performed over the data sets to check the certainty of results. The classification was obtained with an accuracy of 84%, 90.1%, 93.3%, and 90% for the years 1993, 2000, 2010, and 2019 respectively.

The total extent of Surat city in 1993 is classified into 5 main classes viz. urban land (59.91 sq.km) cultivated land (239.95 sq. km), vegetation (28.56 sq. km), barren land (148.73 sq.km) and water bodies (9.70 sq. km).
In the year 2000, the urban area expanded by 29.5% from the year 1993. During this decade, the city had initial industrialization which leads to an increase in migration of population from rural. Results show that there is a reduction in the area of the water body to 21.05 sq.km. This reduction in surface water bodies is the major evident of urbanization impacts on the environment. During this year the city faced a drought situation where the cultivated land had decreased unexpectedly in many places which probably increases the barren land.

In the next decade, the city suffered great pressure in need of land for accommodation of the migrated population. The urban built-up area was increased by 31.3% from the year 2000. In the year 2019, the Surat city has undergone major economic and population growth due to urbanization. The need for build-up lands to accommodate the overwhelming population results in lands being converted for urban use from other diversities which leads to an imbalanced environmental situation. In this decade, the urban built-up area increased by 47.7%.

Table 4. Land Use and Land Cover classification of Surat city

| CLASS          | 1999 Area (km²) | 2000 Area (km²) | 2010 Area (km²) | 2019 Area (km²) |
|----------------|-----------------|-----------------|-----------------|-----------------|
| URBAN          | 59.9157         | 77.571          | 112.993         | 164.923         |
| WATER          | 29.709          | 21.0546         | 21.0357         | 17.6733         |
| CULTIVATED LAND| 239.953         | 99.7686         | 141.47          | 231.793         |
| VEGETATION     | 228.562         | 227.209         | 215.748         | 95.3595         |
| BARREN         | 148.736         | 281.272         | 215.628         | 197.126         |
| TOTAL          | 706.875         | 706.875         | 706.875         | 706.875         |

Figure 3. LULC classification of Surat city 1993.

Figure 4. LULC classification of Surat city 2000.
5.2. Intersection of Water Body Features and Urban Land Features Using Overlay Analysis.

An overlay creates a compound map by combining the geometries and attributes of the input data sets. In this study, the water body feature classes are extracted by drawing polygons over surface water bodies from the topographic map of Surat (2011). These extracted features which are in vector format of shape-file represent the existence and shape of water bodies for the year 2011. The urban land use raster is then extracted from the LULC classified image of Surat city (2019) to observe the current situation by the urban land extending over the surface water bodies during this study period.

Intersect overlay analysis was executed to the urban land use features and water body feature class. The outcomes of this analysis indicate the reduction and disappearance of surface water bodies of about 0.812 sq.km of the area during 2011-2019 by urban expansion activities. Figure 9 shows the disappeared surface water bodies of Surat city in 2019.
Figure 9. Disappeared surface water bodies of Surat city in 2019.

6. Conclusion
From the year 1993 to 2019 there are extreme changes in land use that can be found in Table 4. It is identified that the urban area in the city has expanded by 175.2% over the study period. The change in the overall extent of urban over the decades indicates the drastic expansion of urban land mainly in the city center and fringe areas. The urbanization process has various negative impacts on the environment. This unpredictable urbanization is to be governed in a well-planned manner for the conservation of natural ecological value and to provide basic infrastructure facilities to the densely populated city. The urban expansion process acquires lands from other diversity of land use, mostly from agricultural/cultivated lands or by encroachment in riparian zones of water bodies and from barren lands. About 0.812 sq.km of shallow water bodies have been transformed into urban built-up from 2011 to 2019. Most of the conversions were on lakes to the built-up area and river beds to agricultural land. Improper management and depletion of water bodies to land encroachment on boundaries of lakes and rivers lead to flooding. More detailed attention is needed to be paid for the spatial requirements of water bodies while planning for urban developments. Water scarcity, lack of rainwater catchment and the stagnation of surface water run-off are other factors that are being affected by depletion of surface water bodies. Therefore preventive measures and conservative policies are to be developed in urban planning for proper urbanization without any impacts on the environment.

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