

Urban Land Cover Mapping and Change Detection Analysis Using High Resolution Sentinel-2A Data

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ARTICLE INFO

Received: 31 May 2018
Received in revised:
23 Jul 2018
Accepted: 8 Aug 2018
Published online:
5 Oct 2018
DOI: 10.32526/ennrj.17.1.2019.03

Keywords:

Land cover map/
Unsupervised classification/
Sentinel-2A/ Natural
resources/ Change detection/
Urban sprawl

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ABSTRACT

Land cover information is essential data required by urban planners and policy makers to understand existing development and to protect natural resources in a city or town. With the availability of high resolution satellite images from Sentinel-2A, it is now possible to prepare accurate land cover maps and the present study is an attempt in this direction. An approach based on unsupervised classification plus a post-classification editing (recoding) by referring to Google satellite images is proposed in this study and has been tested for the city of Chennai, India. An unsupervised classification using ISODATA technique with 150 clusters and 36 iterations was carried out first and then Google satellite images were used on the background to assign each cluster to a particular land cover type. The proposed approach is very promising as the overall accuracy was found to be 96% with Kappa coefficient of 0.94. It was found that the proposed approach performs well when compared to the supervised and object based classification. The land cover map from Sentinel-2A was compared with the topographical map of 1971 and it was found that there was a fourfold increase in built-up area over the years. Built-up area was induced to develop in proximity to important highways in Chennai as ribbon type of sprawl is noticed. The results showed that the availability of green space is only 7.626 m² per person in Chennai against the recommended value of 9 m². It was also found that almost 6 km² of water bodies have disappeared in Chennai and buildings were constructed over them illegally. The government should ensure proper land use planning and control built-up area development in order to protect the natural resources in the city.

1. INTRODUCTION

Increasing population in cities is a major concern to urban planners, especially in developing countries like India as it results in unprecedented growth of cities in recent decades. More people are migrating from rural to urban areas for better job opportunities and living conditions and this is one of the major reasons for urbanization in the country. Urbanization is inevitable in a developing country like India. However, if urbanization is not controlled properly, it may result in decrease in agricultural land and productivity, cutting down of trees, crowded habitats, air and noise pollution, water distribution problems, public health issues, road traffic congestion, etc. Accurate and up-to-date urban land cover information is an essential data required by urban planners and policy makers for various purposes such as detection of human encroachment on natural resources, urban infrastructure facilities planning, preparation of

master plan and detailed development plans, identification of open and green spaces, selection of suitable site for solid waste disposal, etc. In recent years, high resolution satellite data are increasingly being used for urban land cover mapping and monitoring of natural resources as it is possible to differentiate among various earth surface features due to high spatial and spectral resolution (Gaur et al., 2015; Akay and Sertel, 2016; Malarvizhi et al., 2016; Thanvisitthpon, 2016; Salako et al., 2016; Mondal and Debnath, 2017; Guan et al., 2017; Goldblatt et al., 2018; Ongsomwang et al., 2018). Sentinel-2A launched on June 23, 2015 by European Space Agency (ESA) as part of Copernicus Programme is a milestone in the field of satellite remote sensing as it provides high resolution satellite images at free of cost for a wide range of applications. Out of 13 spectral bands of Sentinel-2A, the four bands (B2, B3, B4 and B8) in the visible and near infrared region has a high spatial

resolution of 10 m with a high revisit period of 5 days and hence could potentially be used for various urban related applications (Topaloglu et al., 2016; Abdikan et al., 2016; Elhag and Boteva, 2016; Djerriri et al., 2017; Marangoz et al., 2017; Hansen et al., 2017; Sekertekin et al., 2017; Clerici et al., 2017; Schlaffer and Harutyunyan, 2018).

In many studies, it is reported that the use of Sentinel-2A for land cover classification yields better results than using Landsat-8 (Topaloglu et al., 2016; Sekertekin et al., 2017). For example, Topaloglu et al. (2016) reported that the overall accuracy of land cover classification by Landsat-8 is in the range of 71% to 82% whereas the classification accuracy of Sentinel-2 is in the range of 76% to 84%. Sekertekin et al. (2017) found that the overall accuracy of land cover map derived from Sentinel-2 is 89% whilst that of Landsat-8 is only 84%. This shows that Sentinel-2 is superior to Landsat-8 in land cover classification. However the maximum accuracy reported by existing studies is only 89% (Sekertekin et al., 2017). None of the reported studies on the use of Sentinel-2A optical data for land cover map preparation reported more than 89% accuracy. This was the main motivation behind the present study, i.e., to propose an image classification approach which can give accuracy more than what has been reported in the existing studies. The unsupervised classification plus a post-classification editing (recoding) by referring to Google satellite images was proposed in the present study for land cover map preparation using optical data of Sentinel-2A. The land cover map prepared was then checked for its overall accuracy and Kappa coefficient using randomly generated points. After that, land use/land cover change detection analysis was carried out by comparing the land cover map prepared using Sentinel-2A with the land cover map of 1971 prepared using Survey of India topographical maps. The analysis of land cover maps will help to ascertain the level of urban growth over the years. The direction-wise urban growth analysis was also carried out to find the direction in which the urban growth is oriented. The fundamental question behind the present research work is, "How can the open source satellite data like Sentinel-2A and Google images be best utilized to prepare accurate land cover maps and perform change detection analysis?" The specific objectives of the research work are: (1) to propose an image classification

approach for accurate land cover map preparation using Sentinel-2A and Google satellite images. (2) to perform change detection analysis to understand how the city grew over the years, in what direction, the causative factor behind its growth and the type of urban sprawl. (3) to analyze the impact of urbanization on water bodies.

2. METHODOLOGY

Chennai (formerly called Madras), the capital of the Tamil Nadu state in India is the fourth largest metropolitan city of the country. For land cover map preparation using Sentinel-2A data, Chennai Corporation which extends to an area of 430 km² was taken into account. Figure 1 shows the areal extent of Chennai Corporation and its location in Tamil Nadu and India. The Chennai Corporation is headed by a Mayor and it comprises 15 zones and 200 wards. Until 2011, Chennai Corporation covered only an area of 176 km². After that, several municipalities, town panchayats and panchayat unions adjacent to the city which were expanded along with the city were merged with the corporation and hence its areal extent has been increased from 176 km² to 430 km².

The Sentinel-2A data were acquired, processed, and generated by the European Space Agency and repackaged by U.S. Geological Survey (USGS) into 100 km × 100 km tiles. The Sentinel-2A satellite data acquired on August 24, 2016 was used in the present study to extract the land cover information. The satellite data was downloaded from USGS Earth Explorer (USGS, 2018). As the revisit frequency is 5 days, a large number of images acquired at different dates were available for download. However, selecting an image without any cloud cover was difficult as the percentage of cloud cover was high in most of the images. The satellite image taken on August 24, 2016 had a cloud cover of only 0.41% and hence the same was considered in the present study for land cover map preparation. The processing level of the downloaded image was Level-1C which includes radiometric and geometric correction, ortho rectification and spatial registration on a global reference system, namely, the WGS84 datum and Universal Transverse Mercator (UTM) Projection. There are 13 spectral bands in Sentinel-2A which extends from visible and near-infrared (VNIR) portion to Short-wave infrared (SWIR) portion. Out of 13 bands, four bands have 10 m

spatial resolution, six bands are at 20 m resolution and the remaining three bands at 60 m resolution. Since the purpose of the present study is to prepare urban land cover map, an image with high spatial resolution is generally preferred. Hence only the three bands of the Sentinel-2A data were considered. They are green (Band 3 at 560 nm), red (Band 4 at 665 nm) and near-infrared (Band 8 at 842 nm). The classical blue (Band 2 at 490 nm) was not considered as only green, red and near-infrared is sufficient for generating the false colour composite (FCC). After downloading Sentinel-2A data, clipping of the image

within the study area was carried out as the downloaded image is of 100 km × 100 km size. The next step of generation of FCC was done by assigning band-3 (green) to blue, band-4 (red) to green, band-8 (near-infrared) to red. In the present study, four land cover classes were considered, namely, built-up, open land, vegetation and water bodies. The built-up area includes all buildings and roads; open land includes rocky, barren, scrubland, play grounds and residential layouts; vegetation includes parks, forest and agricultural lands; water bodies consist of lakes, rivers, ponds and tanks.

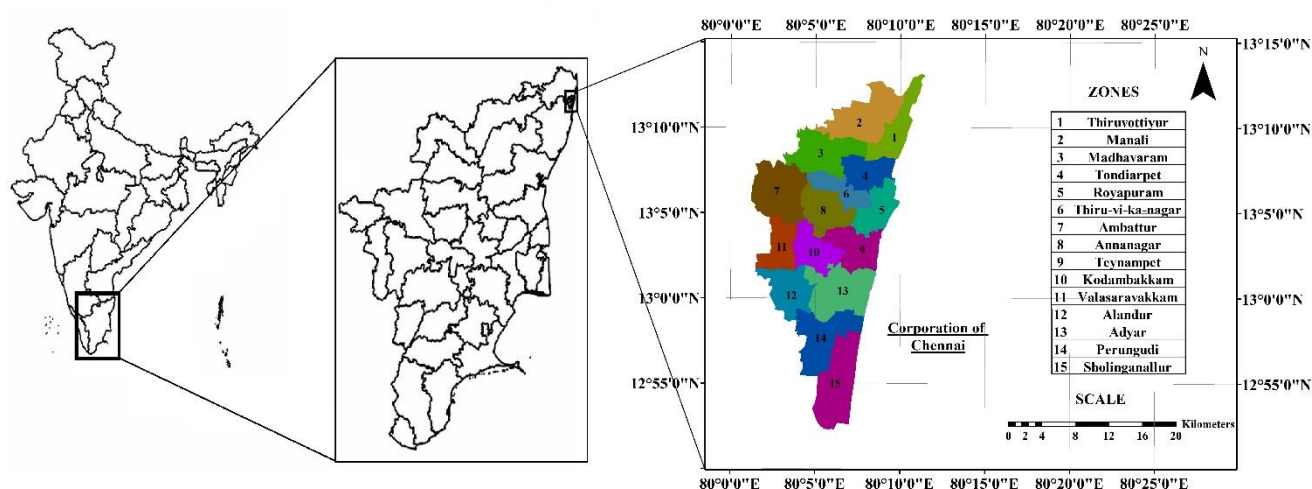


Figure 1. Map showing the location of Tamil Nadu state in India (left), location of Chennai Corporation in Tamil Nadu (middle) and Chennai Corporation (right)

In the present study, digital image processing using one of the popular unsupervised classification techniques called ISODATA was applied first and then visual interpretation using Google satellite images was carried out. The Iterative Self-Organizing Data Analysis Techniques Algorithm (ISODATA) is basically a clustering algorithm that uses an iterative procedure to group image pixels into spectrally similar clusters based on their position in the spectral space. The algorithm begins with an initial clustering of the data and the calculation of cluster means. During each iteration, the algorithm compares the spectral distance of each pixel to the cluster means and assigns them to the cluster whose mean is closest. Once all pixels are assigned, the cluster means are recalculated, and the pixels are again compared and clustered based on spectral distance to the cluster means. This process is repeated until the maximum number of iterations is reached. In the present study, ISODATA

classification was applied with 150 clusters or classes and 36 iterations. After running the ISODATA algorithm using ERDAS Imagine software, the classified image was obtained with 150 classes. In order to assign each of these 150 classes to a particular land cover type, the traditional approach is to see the original satellite image used for classification and identify which land cover a particular cluster belongs to. But the problem with this approach is sometimes we may wrongly assign a cluster and this may happen especially in situations where the spatial resolution of the image is low. Even though the present study uses high resolution Sentinel-2A data of 10 m for classification, however, it may not be possible to see individual buildings, roads, etc. on the image. Hence it has been decided to use the satellites images from Google maps on the back ground to identify the land cover type of a given cluster as it is possible to see buildings, roads, etc. very clearly on the Google maps because of its

high resolution images. An open source software called Portable Base Map Server (PBMS) was used to get the Web Map Tile Service (WMTS) link of Google Maps and the link was used in ArcGIS software to bring the Google maps in background while assigning each cluster to a particular land cover type. Finally the land cover map with four classes, namely, built-up, open land, vegetation and water bodies was checked for its accuracy using 100 points generated randomly over the classified map using 'Create Accuracy Assessment Points' tool in ArcGIS software. For each of the random point generated, the type of land cover from classified image was compared with that of the actual land cover identified from Google maps satellite image to get the overall accuracy and Kappa statistic. A comparison with the supervised classification and object based classification was also attempted to check the performance of the proposed approach in land cover map preparation.

For preparing the land cover map of 1971, four toposheets, namely, 66C4, 66C8, 66D1 and 66D5 of 1:50000 scale covering Chennai corporation

was obtained from Survey of India and then scanned & georeferenced using known ground control points and projected to the UTM Zone 44N. The land cover map was obtained by on-screen digitizing of built-up, open land, vegetation and water bodies in the toposheets within the study area. The areal extent of various land covers were found and compared with that of the land cover map prepared using Sentinel-2A to assess the urban growth. The direction-wise urban growth analysis was also carried out by calculating the built-up area in 16 cardinal directions (N-NNE, NNE-NE, etc.) using the land cover maps of 1971 and 2016. The direction-wise analysis helped to find the direction in which the urban growth was oriented. The results are discussed in the following section.

3. RESULTS AND DISCUSSION

The land cover maps of 1971 and 2016 are shown in Figure 2. The results of accuracy assessment of land cover map prepared using Sentinel-2A is presented in Table 1.

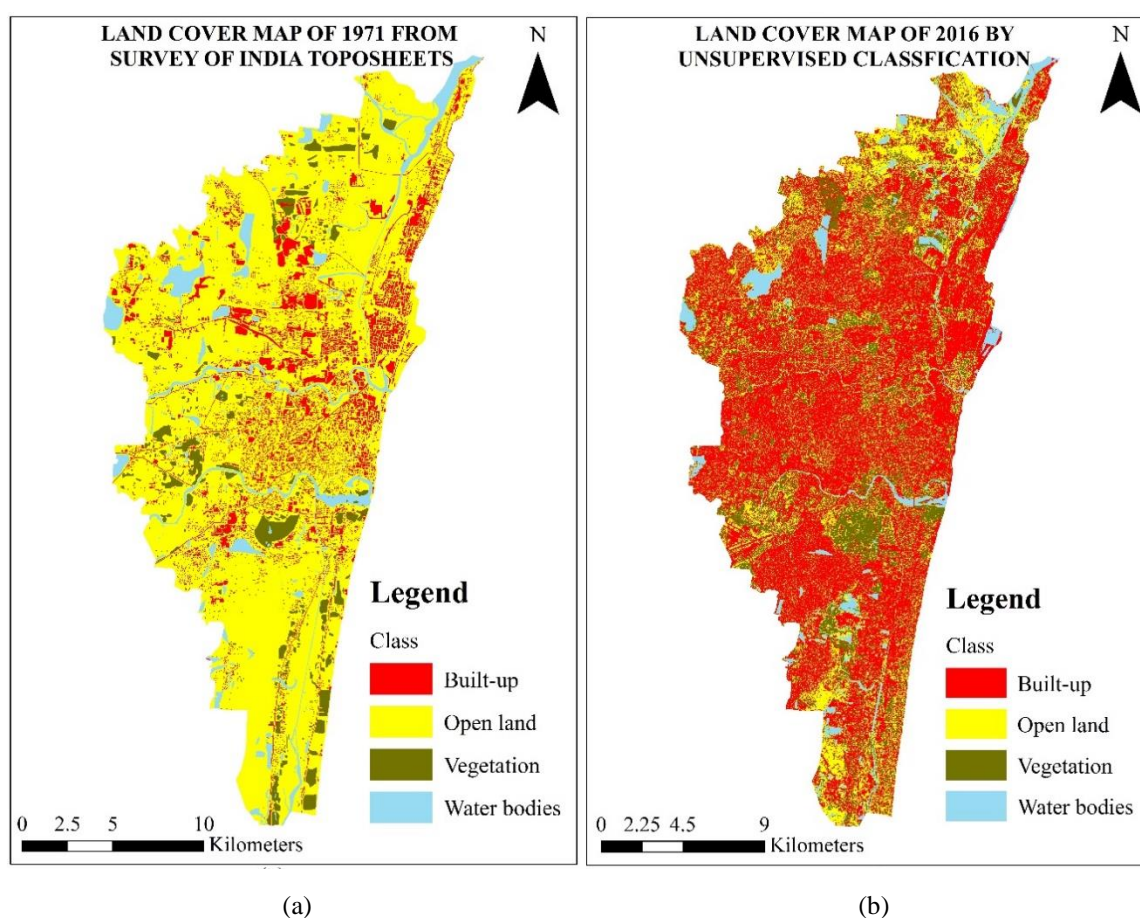


Figure 2. Land cover map of (a) 1971 (b) 2016

Table 1. Accuracy assessment results

Class	Built-up	Water bodies	Open land	Vegetation	Total	User accuracy	Kappa
Built-up	50	1	2	1	54	0.93	0.00
Water bodies	0	10	0	0	10	1.00	0.00
Open land	0	0	24	0	24	1.00	0.00
Vegetation	0	0	0	12	12	1.00	0.00
Total	50	11	26	13	100	0.00	0.00
Producer accuracy	1.00	0.91	0.92	0.92	0.00	0.96	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.94

It can be seen from Table 1 that the overall accuracy was found to be 96% and Kappa coefficient was calculated as 0.94. According to Congalton and Green (2009), an overall accuracy of 85% is the cut-off between acceptable and unacceptable results. As the overall accuracy is 96% in the present study, it indicates that the proposed approach of unsupervised classification using Google satellite images on the background is acceptable and well suited for classifying the land covers in Sentinel-2A data. A comparison with supervised and object based classification methods was also attempted. For supervised classification, Maximum Likelihood Method (MLM) was used by creating 50 training samples for each land cover category. The MLM method calculates the probability function for each land cover class using the training data given. It assumes Gaussian or normal distribution for the training dataset. Each unknown pixel in the image is assigned to a class that has the highest probability or maximum likelihood. For object based classification,

image segmentation was carried out first by segmenting the original image into objects using IDRISI image processing software. Then the objects were used to create training samples for various land cover classes. Finally the MLM method of supervised classification was applied to prepare the land cover map. The results are shown in Figure 3. The accuracy assessment results are presented in Tables 2 and Table 3. An overall accuracy of 77% and 81% was obtained for supervised classification and object based classification respectively. Similarly the Kappa values are 0.65 and 0.70 for supervised and object based classification respectively. The result of accuracy assessment shows that the proposed method of unsupervised classification using Google satellite images on the background is superior to the supervised and object based methods as the overall accuracy of the proposed method is 96% with Kappa coefficient of 0.94.

Table 2. Accuracy assessment results of supervised classification

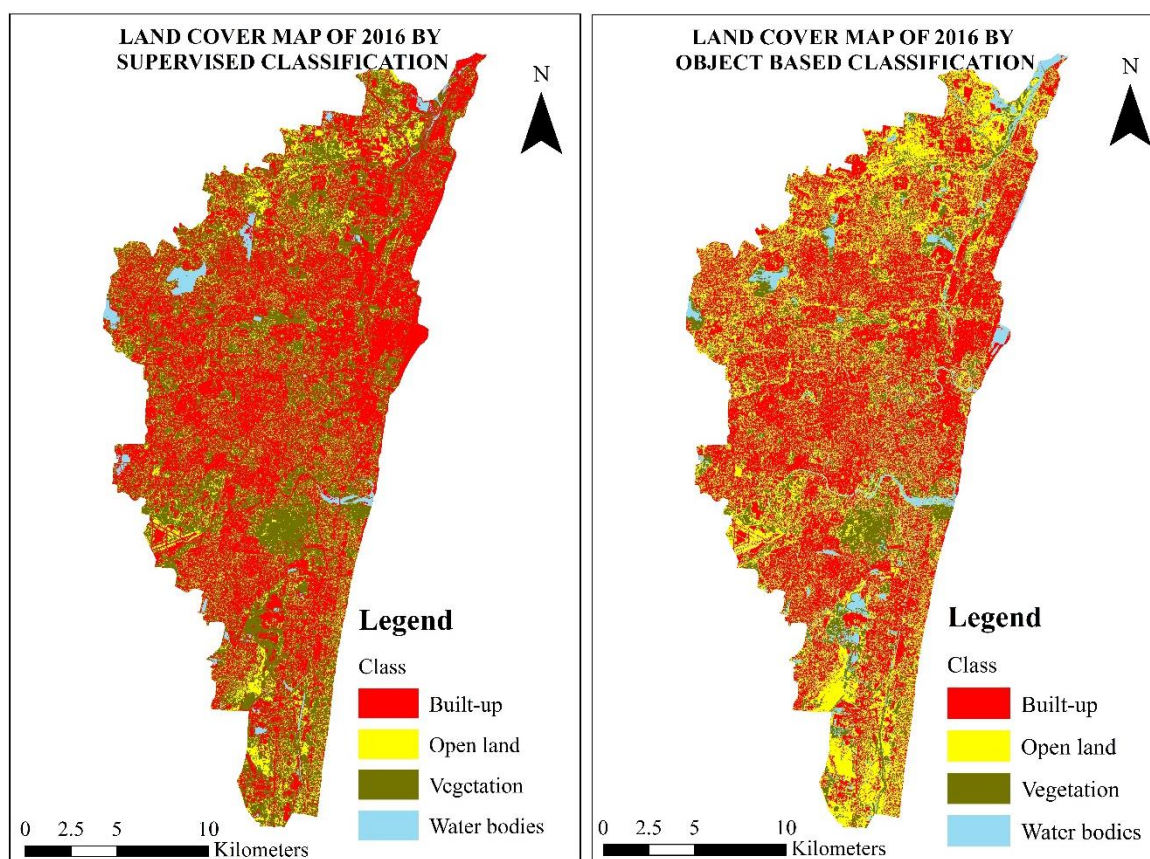
Class	Built-up	Water bodies	Open land	Vegetation	Total	User Accuracy	Kappa
Built-up	40	3	3	0	46	0.86	0
Water bodies	0	7	1	0	8	0.87	0
Open land	3	0	11	1	15	0.73	0
Vegetation	6	3	3	19	31	0.61	0
Total	49	13	18	20	100	0	0
Producer accuracy	0.81	0.53	0.61	0.95	0	0.77	0
Kappa	0	0	0	0	0	0	0.65

Table 3. Accuracy assessment results of object based classification

Class	Built-up	Water bodies	Open land	Vegetation	Total	User Accuracy	Kappa
Built-up	39	0	6	0	45	0.86	0
Water bodies	3	3	1	2	9	0.33	0

Table 3. Accuracy assessment results of object based classification (cont.)

Class	Built-up	Water bodies	Open land	Vegetation	Total	User Accuracy	Kappa
Open land	3	0	30	1	34	0.88	0
Vegetation	1	2	0	9	12	0.75	0
Total	46	5	37	12	100	0	0
Producer accuracy	0.84	0.6	0.81	0.75	0	0.81	0
Kappa	0	0	0	0	0	0	0.70

**Figure 3.** Land cover map by (a) supervised classification (b) object based classification

The overall accuracy of 96% as reported in the present study is more than what has been reported in the existing studies (Elhag and Boteva, 2016; Topaloglu et al., 2016; Clerici et al., 2017; Hansen et al., 2017; Marangoz et al., 2017; Mishra and Singh, 2017; Sekertekin et al., 2017; Schlaffer and Harutyunyan, 2018). Even the studies which combined the Sentinel-2A optical data with Sentinel-1A SAR data (Clerici et al., 2017; Schlaffer and Harutyunyan, 2018) reported a maximum overall accuracy of only 89%, whereas the present study which is purely based on optical data achieved a highest overall accuracy of 96%. Some studies have used both 20 m and 10 m bands of Sentinel-2A by resampling the 20 m band data to 10 m×10 m before

they apply the classification (Topaloglu et al., 2016; Clerici et al., 2017). In such cases also, the reported accuracy were in the range of 76% to 89%. But in the present study, only three bands which are at 10 m resolution were considered and reported an overall accuracy of 96%. In existing studies using Sentinel-2A, the visual interpretation of the satellite image and training sample collection were done before digital image processing. This is one reason why the reported accuracy is less in existing studies because only representative samples for each land cover classes can be given during training sample collection. But in the present study, digital image processing using ISODATA unsupervised classification technique was applied first and then

visual interpretation using Google satellite images was carried out. By this way the entire classified output is thoroughly checked using the background Google images. As the present approach offers many advantages and yields high accuracy, the same can be used by researchers for urban land cover classification using Sentinel-2A data.

The area occupied by four land cover classes in 1971 and 2016 is shown in Figure 4. It can be seen from Figure 4 that in the year 2016, built-up land tops in the list with maximum area of 245 km² which accounts for about 57% of the total area. As Chennai is one of the well-developed metropolitan cities in the country, it is obvious that one could expect high proportion of built-up land compared to

other classes as witnessed in Figure 4. It was found that between 1971 and 2016, there was a fourfold increase in built-up land, which is the highest recorded change when compared to other land covers. This fourfold rise in 45 years indicates that the built-up land has doubled in every decade. It can be seen from Figure 2 that in 1971, one could see built-up areas mainly in the eastern and northeastern side of Chennai in places like Mylapore, Triplicane, Nungambakkam, Theagaraya Nagar, George Town, Purasavakkam, Kilpauk and Alandur. While in 2016, except at a few places in the north and south, all of Chennai is occupied by mostly built-up land as shown by red colour in Figure 2.

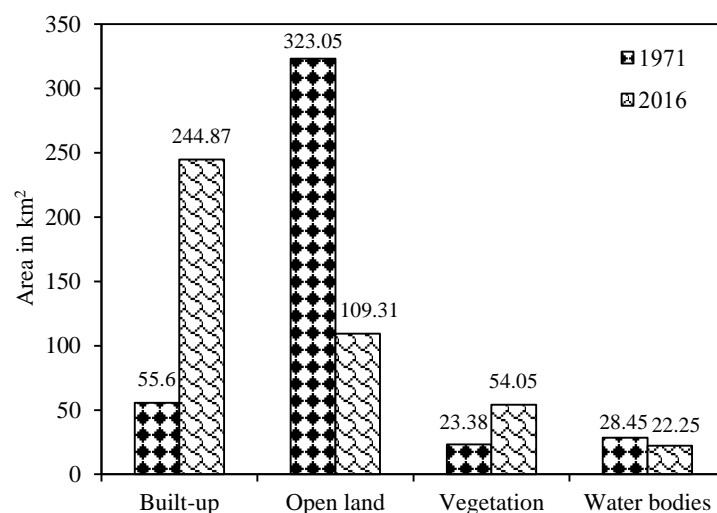


Figure 4. Area of various land cover types in 1971 and 2016

The land covered by vegetation in Chennai is only 13% of the total area in 2016. It was found that this 13% area is mostly reserved forests and parks without any agricultural land. Availability of green spaces is vital for any city as it forms the fundamental component of an urban ecosystem. They help to provide clean air and play a key role in reducing temperature in urban areas. Even though the green cover has increased from 23.38 km² to 54.05 km² (Figure 4) between 1971 and 2016, but still it is less than what is recommended by World Health Organization (WHO). According to WHO, a city should have a minimum of 9 m² of green space per person (WHO, 2010). The population of Chennai from census data is found to be 7.088 million in 2011. According to WHO standards, the total green space required is 63.792 km² in Chennai but the

green space available is only 54.05 km² (Figure 4). That is, 7.626 m² of green space is available per person in Chennai which is less than the recommended value of 9 m² per person. This shows that more green spaces are required in Chennai to meet the WHO standards. This can be achieved by constructing more parks which not only provide recreational facilities for the public but also helps to maintain the ecological balance and supply quality oxygen.

From Figure 4, one can notice that the water bodies in Chennai have been reduced from 28.45 km² in 1971 to 22.25 km² in 2016. This shows that almost 6 km² of water bodies have disappeared over the study period of 45 years. The lack of maintenance and encroachment are the major reasons for the reduction in the proportion of water

bodies in Chennai. Figure 5 shows the past and present situation of tanks and lakes in Chennai. The land cover maps of 1971 and 2016 which are registered in the same datum (WGS84) and coordinate system (UTM Projection Zone 44N) were used to extract the past and present situation of water bodies. As seen in Figure 5, tanks and lakes, once waterbodies in the topographical map of 1971, were completely disappeared in 2016 and buildings were constructed over them. Some remains of the water bodies can be seen only in Konnur Tank and

Velachery Lake, whereas all the remaining tanks and lakes were replaced by buildings and roads. This conversion of water bodies to built-up area is one of the major reasons for recent floods in Chennai as the buildings constructed on water bodies affect the natural flow of rain water and thus causes flooding and water logging. To avoid all these things, the civic authorities should take stringent action against encroachments on water bodies and should not grant permission for residential layouts or building plan approval on lands located on water bodies.

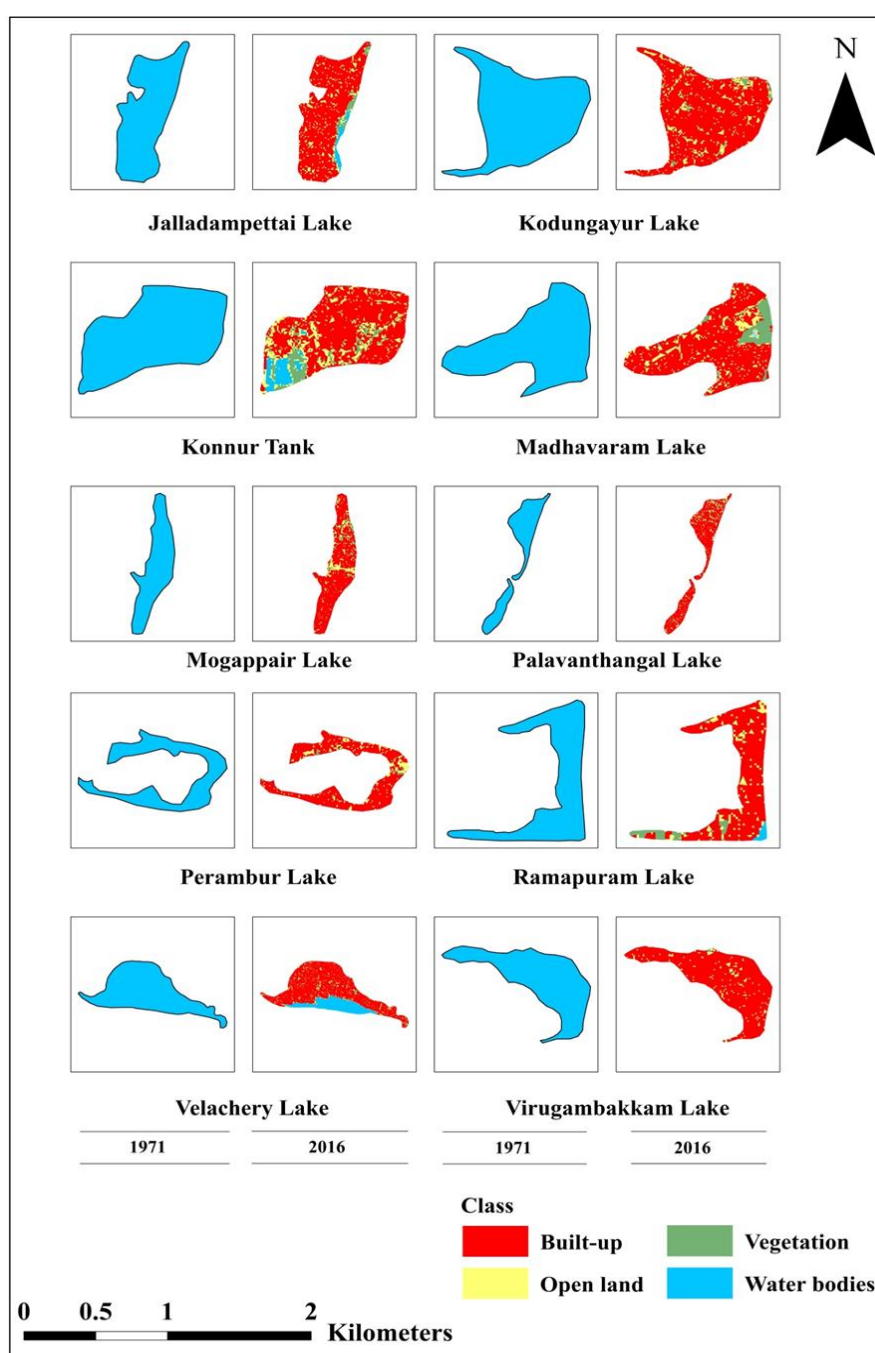


Figure 5. Past and present situation of water bodies in Chennai, India

In order to find the direction in which the urban growth has taken place, sixteen cardinal directions (N, NNE, NE, NEE, E, etc.) were plotted and placed over the built-up area map of 1971 and 2016 as shown in Figure 6. The originating point for the sixteen directions was located at Fort St. George because this is the place from where the Chennai city

has grown over the years. The portion from NNE to S in clockwise direction (7 segments) was not considered as it's basically the coastal area (Bay of Bengal) and hence there is no built-up land as seen in Figure 6. The built-up area within the remaining 9 segments (N-NNE, S-SSW, SSW-SW, etc.) in 1971 and 2016 was extracted and shown in Figure 7.

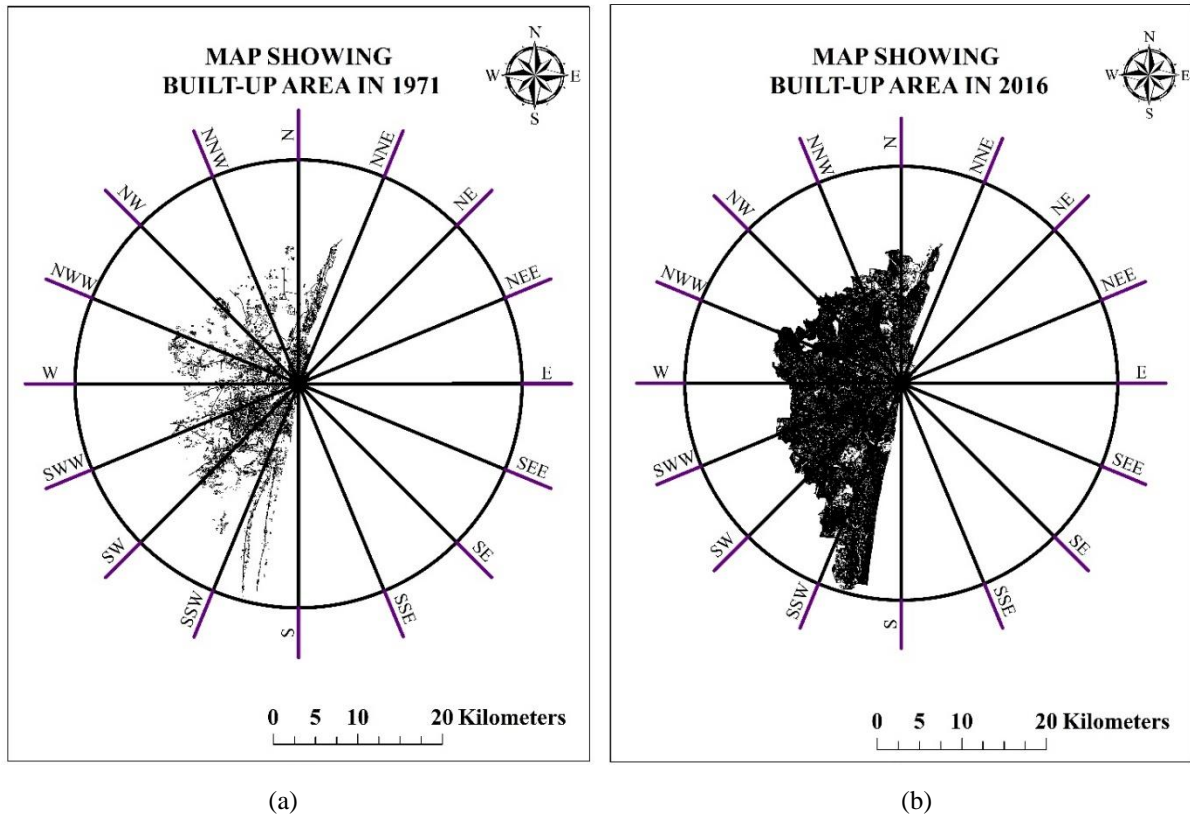


Figure 6. Built-up area in (a) 1971 (b) 2016

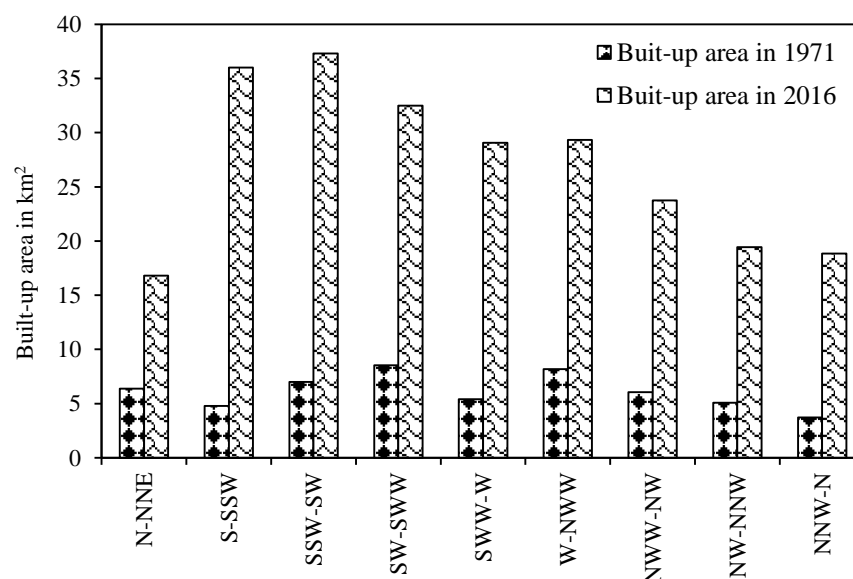


Figure 7. Direction-wise built-up area in 1971 and 2016

It was found that the direction SSW-SW experienced the maximum built-up area development with an enclosed area of 37.31 km² in 2016. Next to that, S-SSW and SW-SWW showed maximum growth with an area of 36.02 km² and 32.5 km² respectively. In terms of difference between the built-up areas of 1971 and 2016, the above said directions stands in the top with 31.25 km², 30.31 km², and 23.97 km² for S-SSW, SSW-SW and SW-SWW directions respectively. The reason for urban growth along these directions is that the major highways in Chennai, namely, Mount road, Grand Southern Trunk (GST) road, Old Mahabalipuram road, East Coast road, Velachery-Tambaram road and Mount Poonamallee road are all located along S-SSW, SSW-SW, SW-SWW directions. Proximity to the highway induced the built-up area to develop along these highways over the years. Such type of urban growth or sprawl is called ribbon sprawl or linear sprawl as sprawl takes place along the highways in outward direction from urban centre. As it was found that the urban growth in Chennai is influenced by major roads, there are more chances that if a new road is constructed, residential layouts, commercial establishments and industries may come up along the road which may lead to haphazard or uncontrolled urban growth with mixed land use and increase of land prices too. Hence the government should ensure proper land use planning and control built-up area development on both the sides of the proposed new roads in Chennai.

The land cover map prepared using Sentinel-2A in the present study can be used in urban heat island (UHI) studies as the land cover plays a dominant role in formation of heat islands in a city. The land surface temperature (LST) from the recently launched Sentinel-3 can be used to prepare UHI map and the UHI map can be correlated with the land cover map to identify the most influencing land cover type. Spatio-temporal variations of heat island and its relationship with land cover can also be done as both Sentinel-2A and 3 has very high revisit frequencies. Another area where there is a good scope for further research is the prediction of future urban sprawl using models like Cellular automata or Markov chains. The land cover maps of the past and present can be used to predict the areas of likely growth in the future. An in-depth investigation of various contributing factors of urban sprawl such as population, distance from roads,

availability of basic amenities, infrastructure facilities, etc. and developing mathematical models to explain the urban sprawl phenomenon is another potential direction for further research.

4. CONCLUSIONS

Urbanization is a serious problem in most of the cities in developing countries and India is no exception to this. In order to have a control on urbanization and protect natural resources, it is essential for an urban planner to have accurate and up-to-date urban land cover information. As Sentinel-2A is providing high resolution satellite images free of cost to the public, it is now possible to prepare accurate and up-to-date land cover maps and the present study is an attempt in this direction. An approach based on unsupervised classification plus a post-classification editing (recoding) by referring to Google satellite images was proposed in this study for land cover map preparation using Sentinel-2A data. The proposed approach yielded accurate results and hence can be used by urban planners to prepare land cover maps using Sentinel-2A data and further use it for change detection analysis. The advantages of the proposed approach are simplicity, accuracy and it requires only open source data for preparation of the land cover map.

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