Impact of Land Dynamics on Agricultural Land

Sathees Kumar*, Nisha Radhakrishnan**, Samson Mathew**

Abstract

Land use Land cover (LULC) change has taken place in Tiruchirappalli city in Tamil Nadu, India over the past two decades due to induced industrialization and urbanization. In this article, the impact of land dynamics on agricultural land was studied by the combined use of remote sensing, geographical information system (GIS) and stochastic modeling technologies. The different land use categories and their spatial and temporal variability in Tiruchirappalli city has been studied over a period of five years (2007-2012), from the analysis of CARTOSAT – 1 images for the year 2007, 2009, 2011 and 2012 using ArcGIS 9.3 and ERDAS Imagine 9.1 software. Maximum Likelihood Algorithm was employed to detect the LULC types. Based on the results of classified images, the agricultural land coverage area was observed to have reduced from the year 2007 to 2012 by 4.42 %, while the area under settlement increased from the year 2007 to 2012 by 7.12 %. An attempt was made to project the LU/LC change for the future using Markov model. The forecasted results indicated that, the area of agricultural land would maintain the decreasing tendency in future. The study demonstrates that the integration of satellite remote sensing and GIS was an effective approach for analyzing the temporal and spatial pattern of LU/LC change. The further integration of these two technologies with Markov modeling was found to be beneficial in describing and analyzing land use change process.

Keywords: CARTOSAT, GIS, Land use, Markov, Remote Sensing.

Introduction

The history of land use and urban growth indicates that urban areas are the most dynamic places on the Earth’s surface. Despite their regional economic importance, urban growth has a considerable impact on the surrounding ecosystem. Land use Land cover (LULC) change is a dynamic, widespread accelerating process which, in turn, drives changes that would impact natural ecosystem to a great extent, leading to urbanization. There are several factors responsible for these changes, mostly being the unprecedented population growth and migration from rural areas and smaller towns. Planning and development of urban areas usually require extensive and accurate information on how land has been utilized and updated information on area, direction and pattern of LULC changes available in the form of maps and statistical data.

*Department of Civil Engineering, Mohamed Sathak Engineering College, Kilakarai, Tamil Nadu, India.
**Department of Civil Engineering, National Institute of Technology, Trichy, Tamil Nadu, India.
Correspondence to: Mr. Sateesh Kumar, Mohamed Sathak Engineering College, Kilakarai, Tamil Nadu, India.
Email Id: satheeskumar@msec.org.in

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However, the traditional methods are work intensive, time consuming, and unable to detect the spatial patterns at the large scale, and grasp changes that occur over a long period of time. Large data base that is involved in LULC assessment is usually uncoordinated and uncorrelated at municipality level and not well updated. In the recent years, Remote Sensing data, in conjunction with Geographic Information Systems (GIS), has been recognized as an effective tool in quantitatively measuring landscape patterns and their changes over a large area in a timely and cost-effective manner [1]. In the present study, geospatial technology integrated with stochastic models is applied to analyze and understand the impacts of land dynamics on agricultural land as well as its spatial distribution and patterns along Tiruchirappalli city, in the state of Tamil Nadu, India.

**Study Area**

The study area is Tiruchirappalli city, Tamil Nadu (Fig. 1), one of the famous historical and cultural cities in India. The spatial extend of the study area is between 10°44’ 46” to 10°52’ 46” N Latitude and 78° 39’ 11” to 78° 44’ 13” E Longitude. The study covers an area of approximately 13833 ha. The average annual rainfall is 821.4 mm. The mean maximum and minimum temperature range from 41.10°C and 18.60°C respectively [2]. The area has been experiencing remarkable LULC changes due to urban expansion and population pressure (Fig. 2). Its environs are abundant with economic and social activity facilitated by rapid developments in residential, educational, commercial, industrial, recreational and traffic and transportation sectors [3]. So, it is necessary to monitor the impacts of land dynamics on agricultural land for understanding the current scenario and to plan the future development of the city. In this, the latest Geospatial technology is required to simulate current and future changes for the study area.

![Figure 1. Location of Study Area](image-url)
Methodology

Data

To study the dynamic changes in LU/LC in Trichy city, Indian Remote Sensing Satellite (IRS) CARTOSAT – 1 images were used (Table 1). A base map of Tiruchirappalli city was provided by Local Planning Authority of Tiruchirappalli for preparing the study area boundary. Remote sensing image processing was performed using ERDAS Imagine 9.1 software. IRS data of years 2007, 2009, 2011 and 2012, Survey of India (SOI) Toposheet 58 J/9 (1:50,000) were used to find the spatial and temporal changes and its impacts on agricultural land in the study area, during the period of study.

LULC Classification

LULC classification schemes were developed by careful refinement of the Anderson classification scheme - 2001 and LULC classification system devised by National Remote Sensing Agency (NRSA) [4].

In this study, based on thorough visual interpretation, ground truth and the classification systems, six LULC classes were defined, namely Agricultural Land, Built-up Land, Grass, Vegetation, Waste Land, and Water Bodies. A supervised approach for classification of the image was adopted with the maximum likelihood rule used as a parametric rule [5, 6].

LULC Change Analysis

The classified images are shown in Figure 3 and the area statistics of different LULC classes in Tiruchirappalli city from 2007 to 2012 are shown in Table 1. The trend of LULC change in the city from years 2007 – 2012 is shown in the Fig. 4. From years 2007 to 2012, the built-up land area has been observed to have increased by 7.12%. On the other hand, waste land, agricultural land and vegetation have decreased by 5.32%, 4.42% and 3.18%, respectively, suggesting that the dynamic growth of built-up land has been at the expense of the waste land, agricultural land and vegetation.
Figure 3. LULC Classified Images of Tiruchirappalli City

Table 1. LULC of Tiruchirappalli City from Years 2007 to 2012

<table>
<thead>
<tr>
<th>LULC Classes/Code</th>
<th>Area in hectare (ha)</th>
<th>Change in percentage (+/-)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2009</td>
</tr>
<tr>
<td>Agricultural (1)</td>
<td>2534</td>
<td>2260</td>
</tr>
<tr>
<td>Built-up Land (2)</td>
<td>3032</td>
<td>3333</td>
</tr>
<tr>
<td>Grass Land (3)</td>
<td>1409</td>
<td>2048</td>
</tr>
<tr>
<td>Vegetation (4)</td>
<td>2016</td>
<td>1869</td>
</tr>
<tr>
<td>Waste Land (5)</td>
<td>3753</td>
<td>3402</td>
</tr>
</tbody>
</table>
The accuracy of the results obtained depends on the selection of the training sets involved in the classification of the classes. To assess the accuracy of classification, a GPS field survey was employed as ground truth data. The overall accuracy of the images of years 2007 and 2009 were observed to be 85.47% and 88.27% respectively and the corresponding kappa coefficients were 0.85 and 0.89.

**Markov Forecast and Validation**

After doing LULC assessment, the next step is forecasting land use change. Markov Model was considered for the study to forecast the LULC in Tiruchirappalli city. It is a convenient tool for simulating LULC change when changes and processes in the landscape are difficult to describe [7-11]. Markov model is a stochastic model which can describe LULC change from one period to another and can used to simulate the future dynamic changes by analyzing the initial state of a system known as the primary matrix, P(0) as well as the probabilities of change from one state to another, i.e., transition probability matrix. The model for future forecasting is given by the equation

\[ P(n) = P(n-1).P_{ij} = P(0).P_{ij}^n \]

Where \( P(n) \) – state of probability of any time, \( P(n-1) \) – preliminary state primary matrix and \( P_{ij} \) – transition probability matrix [12].

For the study, year 2007 was considered as the base year to form the primary matrix. The six LULC classes were considered, namely Agricultural Land, Built-up Land, Grass, Vegetation, Waste Land, and Water Bodies and their areas in hectares were extracted from CARTOSAT-1 image of the year 2007, to give the primary matrix as \( P(0) \). The transition probability matrix that records the probability that each land cover category will change to the other category was derived between years 2007 and the immediate later image, i.e., year 2009 (Table 2). In table 2, it can be seen that the diagonal matrix values are not equal to one, except for the built-up land. This is because the built-up area seldom transfers to other land uses. Thus, the transition probabilities of the built-up state to other states are given as “zeros”. Modelling using this model predicts the future changes based on the assumptions that the rates and patterns of change will be reflected based on the current and recent trends. The Transition probability matrix between the year 2007 and 2009 is taken as the trend change for simulating the future growth. Figure 5 shows the simulated change trends of LULC in Tiruchirappalli city for the year 2011, 2013 and 2015.
Table 2. Matrix of Transition Probability of LULC Types in Tiruchirappalli City during Year 2007–2009

<table>
<thead>
<tr>
<th>LULC classes</th>
<th>W</th>
<th>G</th>
<th>V</th>
<th>A</th>
<th>B</th>
<th>Wa</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.3609</td>
<td>0.0965</td>
<td>0.1512</td>
<td>0.1271</td>
<td>0.1558</td>
<td>0.1085</td>
</tr>
<tr>
<td>G</td>
<td>0.0206</td>
<td>0.2363</td>
<td>0.1285</td>
<td>0.1675</td>
<td>0.2009</td>
<td>0.2463</td>
</tr>
<tr>
<td>V</td>
<td>0.0580</td>
<td>0.1339</td>
<td>0.2579</td>
<td>0.2123</td>
<td>0.1523</td>
<td>0.1855</td>
</tr>
<tr>
<td>A</td>
<td>0.0620</td>
<td>0.1669</td>
<td>0.1807</td>
<td>0.2028</td>
<td>0.1626</td>
<td>0.2249</td>
</tr>
<tr>
<td>B</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>1.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Wa</td>
<td>0.0304</td>
<td>0.1367</td>
<td>0.0861</td>
<td>0.1476</td>
<td>0.2856</td>
<td>0.3136</td>
</tr>
</tbody>
</table>

W - Waste land; G - grass; V – Vegetation; A - Agricultural land; B - Built-up land; Wa - Water bodies

The forecasted results based on model indicate that the area of Built-up land would be 4385 ha in the year 2015. On the other hand, agricultural land has decreased by 690 ha. For validating the model, LULC area of year 2011 was compared with the actual area interpreted from the year 2011 satellite image (CARTOSAT-1) and tested with actual values using $\chi^2$ test in order to ensure suitability of the model (Table 3). From the result, it was observed that the assumptions considered for the study are justifiable.

Table 3. Forecasted Value vs. Expected Value

<table>
<thead>
<tr>
<th>LULC Classes</th>
<th>2011 (Forecast) Area (km$^2$)</th>
<th>2011 (Expected) Area (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Land</td>
<td>21.86</td>
<td>20.11</td>
</tr>
<tr>
<td>Built-up Land</td>
<td>36.97</td>
<td>37.38</td>
</tr>
<tr>
<td>Grass land</td>
<td>20.16</td>
<td>22.39</td>
</tr>
<tr>
<td>Vegetation</td>
<td>17.99</td>
<td>17.10</td>
</tr>
<tr>
<td>Waste Land</td>
<td>32.57</td>
<td>32.32</td>
</tr>
<tr>
<td>Water bodies</td>
<td>8.78</td>
<td>8.91</td>
</tr>
</tbody>
</table>

For validating the results, years 2007 and 2012 CARTOSAT-1 images were taken and clipped as shown in Figure 6 (a) and (b). The two clipped images were compared with each other to find the impact of land dynamics on agricultural land. It shows that agricultural land in 2012 clipped image has decreased when compared to 2007 clipped image. It conforms that, the future development in Tiruchirappalli city can take place in the agricultural areas which is derived from the LULC change analysis. Based on the study, it is recommended to develop a
proper urban planning for the city to protect the agricultural areas. Accuracy result also show that it is feasible to simulate LULC change for Tiruchirappalli city integrating the considered remote sensing images, GIS and Markov model.

Figure 6. (A). Clipped Image 2007 (B). Clipped Image 2012

Conclusions

From the observations and results obtained, the following conclusions can be drawn:

- From years 2007 to 2012, the built-up land area has been observed to have increased by 985.05 ha. On the other hand, waste land, agricultural land and vegetation land have decreased by 736.91 ha, 613.42 ha and 441.29 ha respectively.
- The overall accuracy of the images of years 2007 and 2009 were observed to be 85.47% and 88.27% respectively and the corresponding kappa coefficients were 0.85 and 0.89.
- The study showed that areas under agricultural and land is being cleared for human settlements. This indicates that anthropogenic disturbances are the main drivers of LULC Change.
- The forecasted results based on Markov model indicate that the area of Built-up land has increased by 9.77% and on other hand agricultural land has decreased by 4.99%.
- The simulated values estimated from the model was validated by comparing the forecast LULC areas of 2011 with the expected areas interpreted from 2011 satellite image and result tested with expected values using χ2 test. There is no significant difference between forecast value and expected value, suggesting the model for urban planning of a city.

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