Monitoring of Urban Trajectories Using Remote Sensing and GIS

A Case Study of Udaipur Complex

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Abstract

The unprecedented combination of economic and population growth in the last two decades has led India to be in transition from a largely rural society to a predominantly urban one. Progressive concentration of population in urban units affects land cover as well as brings various negative impacts on the environment. When built up area grows up in the form of dense and continuous belt, it engulfs the available forest cover, agricultural land and open spaces. Vast green cover of the landscape is significantly converted into concrete jungles.

Therefore, monitoring of the spatial-temporal patterns of urban sprawl and their impact on the environment is of critical importance for future urban planning and sustainable development, especially in developing Indian cities such as Udaipur City. Past researches demonstrated that the combined approach using Remote Sensing, Geographic Information System and urban modeling is a powerful tool, and it will be a productive new direction for the improved understanding, representation, and modeling of the spatiotemporal forms due to the process of urbanization. The present paper is one of the few unique studies which used Land Change Modeler (LCM) to monitor urban land and use land cover for Udaipur City over the last 37 years (1976 to 2013).

Research results showed that the built up area in the city grew from 5.78 km² in 1976 to 83.42 km² in 2013; in total, 77.64 km² of non-built up land was converted into urban area at the cost of other non-built up area, showing a significant transformation of urban land scape. The present study also identified a spatial trend in land transformation process i.e. tree cover was first converted into open scrub, and then the open scrub into cropland and fallow land. Finally, cropland and fallow land converted into builtup land. This kind of development can potentially eat the natural vegetation cover, open spaces and agricultural land as it may end up with no vacant space left over.

The findings of the present study can be used by Department of Town Planning, Department of Land and Environment and Udaipur Urban Improvement Trust in the preparation of sustainable and livable Urban Planning of Udaipur City.

Keywords: Urban growth, Spatio-temporal pattern, Remote sensing and GIS, Monitoring, Urban Planning, Udaipur city.

Introduction

The land use/land cover pattern of a region is an outcome of natural and socio-economic factors and their utilization by man in time and space. Knowledge of land cover and land use change is important for many planning and management activities (Lillesand and Kirfer 1999). Land use is the human use of land and land cover refers to physical and biological cover on the surface of land (Rimal 2011).

Land use and land cover changes (LULC) have been recognized as an important driver of environmental change on all spatial and temporal scales (Adepoju et al., 2006), Also they are emerging as a key environmental issue and, on a regional scale, one of the major research endeavours in global change studies. These changes encompass the greatest environmental concerns of human populations today, including urban heat island, climate change, biodiversity loss and the pollution of water, soils and air. Monitoring and mediating the negative consequences of LULC while sustaining the essential planning has therefore become a major priority of researchers and policymakers around the world. In this context, it is much needed to monitor and analyze the land use changes over the time and predict the future scenario of Udaipur city. The main objective of this study is to analyze relevant remote sensing data from 1976 and 2013 and identify the locations, types and trends of the main land cover changes in the last 37 years using Land Change Modeler (LCM) method. This kind of analytical study can be remarkable in creating the prediction maps of the future LULC for sustainable development.

Study Area and Data Description

Study Area

Geographically, the area of Udaipur Complex is situated between 240 24' 58" N and 240 42' 01" north latitude and 730 34' 30" E to 730 57' 15" east longitude. The total area of Udaipur Complex is 57,486 hectare (574.86 km2) with a maximum north-south length of about 32 km2 and east-west distance of about 37.9 km2. The Municipal Corporation Limit of Udaipur city covers an area of 64. 28 sq. km. with an extension of 240 31' 46" to 240 37' 53" N latitude and 730 38' 57" to 730 45' 55" E longitude (Figure-1).

Udaipur city is within the Girwa Tehsil of Udaipur district. Udaipur complex comprises Urban Notified Area and the Urban Notified Area consists of Municipal Corporation Limit and its nearby 62 villages. In this research, the investigator used "Udaipur City" and "Udaipur Complex" as synonyms for each other.

The name Girwa denotes a basin like land morphology wherein water flows from the surrounding hills (Gir=hills, Wa=flow of water).Udaipur City has a unique geomorphological setting and is known as the city of Lakes; Venice of the East. It is in a bowl-shaped basin located on the eastern flank of the Aravalli mountain ranges in southern Rajasthan at 576 m above the mean sea level. Its geographically bowl-shaped position and rugged terrain created favourable site condition for the settlements in terms of natural defense and microclimate. Lakes are the distinctive feature of the city that form important infrastructure and give visual/psychological relief in its hot dry environment.

Udaipur is a main political and administrative center, a major tourist station and economically strategic location in the region. The city has a great potential to convert into a big industrial city as its environs are rich in various mineral resources i.e. zinc, marble, soap stone and rock phosphate. Construction of new broad-gauge railway tracks and national highways has provided a solid base to the city and proliferated the commercial activities in last some years.

Udaipur, a bowl shaped city, is drained by Ahar river and its tributaries. The elevation in the study area ranges from 436 to 929 meters above the sea level. Almost 86 per cent part of the study area has slope greater than 8 per cent, while 44 per cent of the land has slopes greater than 8 per cent slope. Even though 13.5 per cent of the study area is levelled land in the form of basins situated among the small hillocks including surface water bodies. But this land is fragmented in small patches and not in the contagious pattern, having less area for physical expansion (Figure-1). Therefore, the future urban planning is a very challenging task for Udaipur city due to its complex topography.

Udaipur is the fifth largest urban center in Rajasthan. The city has shown a non-uniform pattern of urbanization in the last 130 years. The population of Udaipur city increases annually by about 3 per cent. In 2011, the population in the Municipal Corporation Limit already counted 4,51,735 people. Besides, 1,19,833 people were living outside the Municipal Limit. Because of demographic uncertainties, such as net migration, and natural population increment, the exact number of inhabitants is not really known. It is estimated that population will increase up to 8.30 lakhs in 2022 with 38.56 per cent growth rate and need more area for spatial expansion. Moreover, in 1971 the UIT area was only 17.40 km2, which increased drastically approximatly up to 574 km2 showing a significant spatial expansion. Therefore, monitoring the spatial-temporal patterns of urban sprawl and their impact on the environment is essential for urban planning and sustainable development for fast developing city like Udaipur.

Data

The data used in the present study are given in the Table-1. The satellite data used are Landsat MSS and TM acquired in 1976 and 1990 respectively. The resolution of the images is 58 and 30 meters respectively. They were obtained from the United States Geological Survey (USGS) portal. RESOURCE-SAT-2 L4FMX and IRS-P6-L4MX data with spatial resolution of 5.0 meters were also used to substantiate the study. CARTOSAT-1 PAN-A and PAN-B stereo data with spatial resolution of 2.5 m was used to generate Digital Elevation Model (DEM) of the study area. Moreover, the images are projected to WGS_1984_UTM_Zone_43N Coordinate System.

In order to substantiate the findings and detect the changes on the surface, it is necessary to use additional data including other high resolution imageries, topographic maps, socio economic and environmental data, physiographic and climate data. For this study, as ancillary data, CARTO DEM and existing land cover maps of the area, Google maps and Google Earth, and population data (Census Handbook 1951-2011) were integrated. All these ancillary data have been used during sample collection for image classification and accuracy assessment.

Methodology

The researcher produced maps of the study area from satellite images to monitor urban trajectories. Data pre-processing and image classification with the applications of remote sensing techniques have been performed. Object oriented image classification has been employed. Validation of classification results is an important process after image classification procedure. Hence, the classified images were then validated. The validation was done both in eCognition, sample based validation. Moreover, validation was done based on the reference map. In both cases, Kappa coefficient has been found to be above the minimum threshold. For the past 37 years, 1976-2013, Udaipur City has been undergoing extensive land cover change.

The classification of multi-temporal satellite images of four different time periods, i.e. 1976, 1990, 2005 & 2013, into tree cover, open scrub, crop land, fallow land, barren land and built-up land cover classes has resulted in a simplified representation of the study area. LUCC detection quantification and analysis for the four classified images of the study area with descriptive statistics have been performed. A cross classification procedure is a fundamental pairwise comparison technique used to compare two images of qualitative data (Eastman 1995). IDRISI Selva software offers efficient tools for rapid assessment of land cover change and its implications based on cross classification principles. The Land Change Modeler (LCM) allowed using the classified land cover maps from 1976-1990, 1990-2005, 2005-2013 and 1976-2013 as input parameters and identifying the locations and magnitude of the major land change, land persistence, and transitions between land cover categories in the study area.

Results and Discussion

The research results of urban trajectories showed a clear pattern of increased urban expansion prolonging both from urban center to adjoining non-built up areas (other land cover classes) in all directions mainly in the north, north-east, east and south-east direction alongside major transportation corridors (Figure-2). The synoptic analysis of spatio-temporal land cover change revealed that urbanization has significantly transformed the urban landscape of Udaipur City. The built up area in the city has grown from 5.78 km² in 1976 to 83.42 km² in 2013 at an average growth rate of 14.36, 14.04 and 6.73% per annum during 1976-1990, 1990-2005 and 2005-2013 study periods respectively. In total, 77.64 km² of non-built up land has been converted to urban area. By analyzing the different classes, it became clear that removal of tree cover did not result in any direct increase in the builtup areas. Rather, the process was more staged. Tree cover was first converted to open scrub, and then open scrub to cropland and fallow land. Finally, cropland and fallow land became builtup land. Likewise, open scrub land class was first converted to cropland and fallow Land and then cropland and fallow land became builtup land. This process was an important finding for arriving at the conclusions about the process leading to deforestation in the area. Once the amount of changes has been identified, the locations undergoing this change are mapped.

The graphic Figure-3 produced by the LCM indicates change of land use measured from the two images between 1976 and 2013. The Land Change Modeler allows the users to change these analysis settings to analyze either each land use change individually, or all the land use changes together. The above graphic shows a scenario where we are trying to compare all the changes at once. The Gains/Losses per class are shown. This allows one to summarize the changes in land use to understand whether there have been significant gross changes in the time period or not.

The graphic Figure-4 tells us about the change in Tree Cover, Open Scrub and Fallow Land areas. These three classes have reduced by almost 17,005 hectares during 1976-2013. There also seems to be an almost corresponding gain of nearly 17,005 hectares in Builtup, Cropland and Barren Land classes.

Open scrub occupied the largest area during the whole time period. In addition, tree cover shrank at annual rate of -1.6% during 1976-2013. Open scrub decreased at a rate of -0.79%, from 28,926.99 ha to 20,447.23 ha, during the whole study period. Fallow land showed a decline of around 69% with annual losses of -1.87%, resulting in a decline in fallow land from 7653.96 ha to 2338.32 ha during these 37 years. Other classes experienced an increase. Barren land reflected a large increase from 176.76 ha in 1976 to 4,738.42 ha in 2013, resulting in roughly a 27 fold increase, at an average annual growth of 69.47%. In addition, builtup and cropland classes increased with annual growth rates of 36.19% and 0.99%, respectively from 1976-2013. Our data showed a corresponding 15.0 and 1.3 fold expansion in the builtup and cropland classes (Table-2).

During the whole study period, major changes occurred in the conversion of tree cover to open scrub, open scrub to crop land, barren land, builtup land and then in the conversion of fallow land to builtup and cropland. Contribution net change from tree cover to open scrub, barren land and crop land were 2568, 296 and 166 ha respectively, between 1976-2013. In the same fashion, contribution net change from open scrub to cropland, barren land, builtup and fallow land were 4190, 3879, 2429 and 578 respectively, during 1976-2013.

It is possible to see the pattern of urbanization in the Udaipur Complex from the transition map (Figure-5). Moreover, there is a mapping tool developed for Spatial Trend of Change. Since, the main concern of the study is urban area; the analyst has computed the trend of the urban growth within the study area. With the same tool, in order to see the sprawling trend of the Udaipur Complex, three polynomial orders have been tested. They have revealed a similar result that the built up is expanding to the East and South. The more appropriate polynomial order for linear function, which is the 3rd order, has been chosen and the cubic spatial trend of change result has been obtained. This interpolation result is more acceptable as stated by Eastman (2006), choosing the lowest-order function produces an acceptable result. A third order polynomial function is a linear function chosen to best fit the interpolated trend result with the input image. The parameters for the trend surface modeling function are the degree of polynomial surface (in this case it is 3 for a cubic polynomial) and the data frame with no data (the background) is omitted.

The Spatial Trend of Change result was based on the change of all the land classes to the Built up area, and it has shown a trend of sprawling of built up to the east and south.

Conclusion

The results of the present study show that Udaipur City has been undergoing sprawling pattern of urban growth. This is witnessed by a continuous decrease in the vegetative cover, agricultural land and open spaces. This kind of development can potentially eat into natural vegetation cover, open spaces and agricultural land as it may end up with no vacant space left over. Public open spaces and green areas have indispensable socio-economic and environmental value for the development of a city and for the quality of air in urban areas. If the infilling development process continues in the future, the Udaipur Complex will no doubt be 100% built up area without leaving vacant land for open spaces. Thus, at this point it is important to think about the future of open spaces and green areas in the city center. Policy makers and planners should critically think about the issue and come up with a planning scheme that protects the existing green belt, fringe area and open spaces from encroachment or restrict any more merging of patch in the future.

The Markov Chain Analysis embedded in the LCM is an effective approach for calculating the land use transition probabilities and simulating the scenarios of future urban developments and therefore providing the policy options for sustainable urban planning. The findings can provide valuable information to support decision-making by the expected users of the output, specially, Department of Town Planning, Department of Land and Environment; and Udaipur Urban Improvement Trust.

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Figures

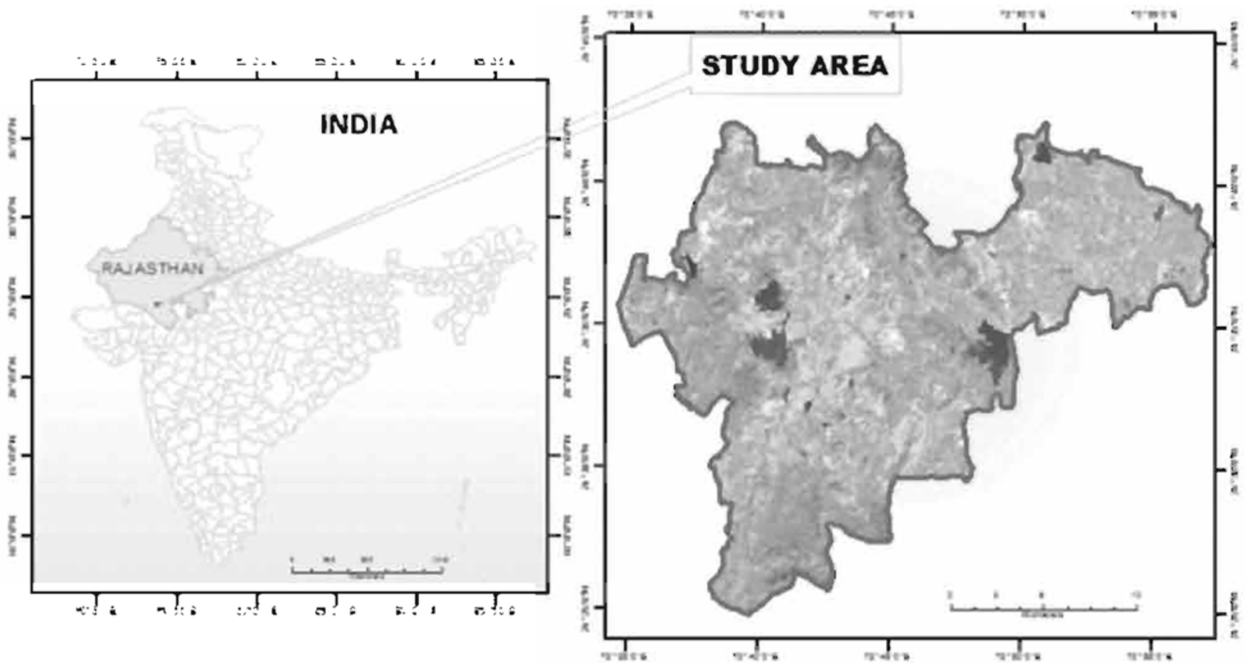
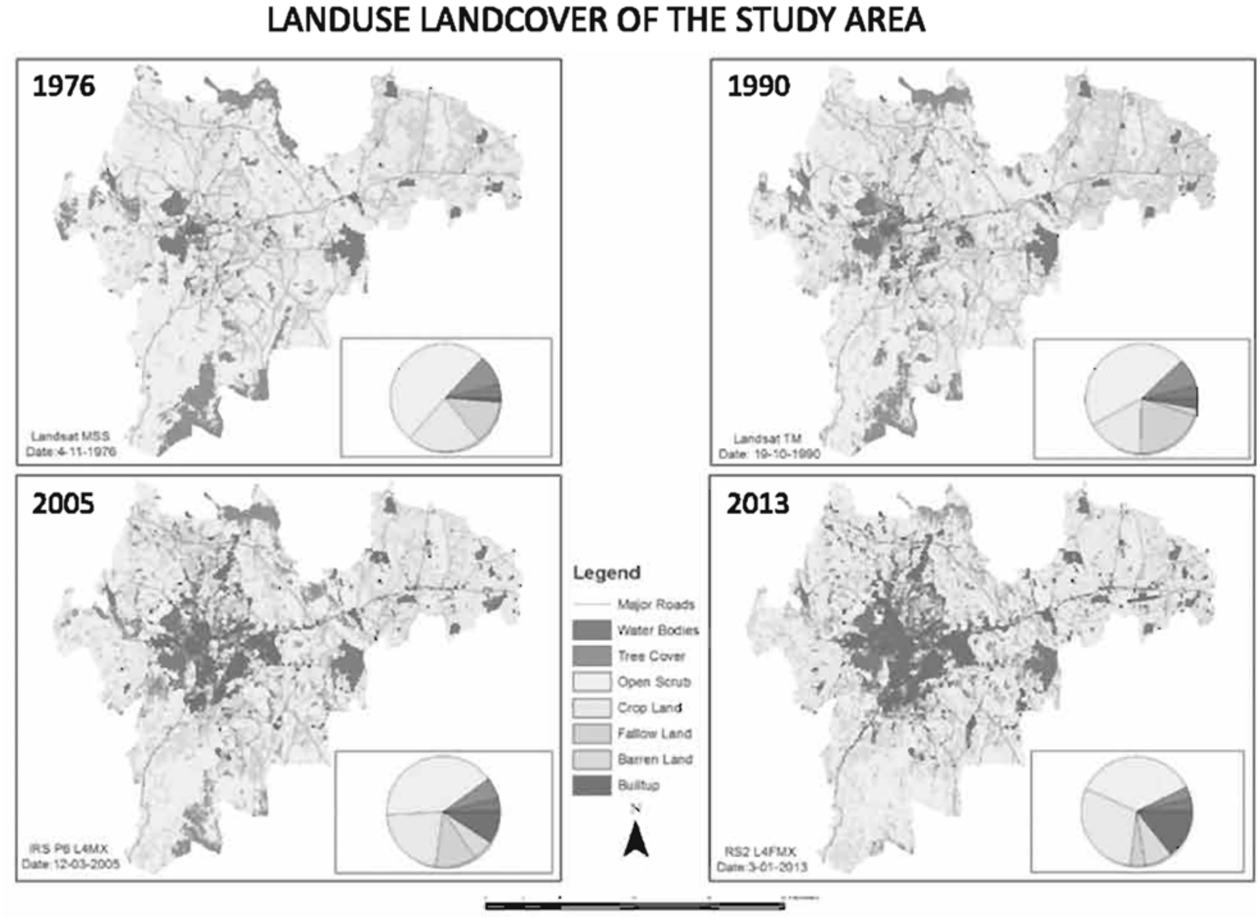


Figure -1 Location of the Study Area



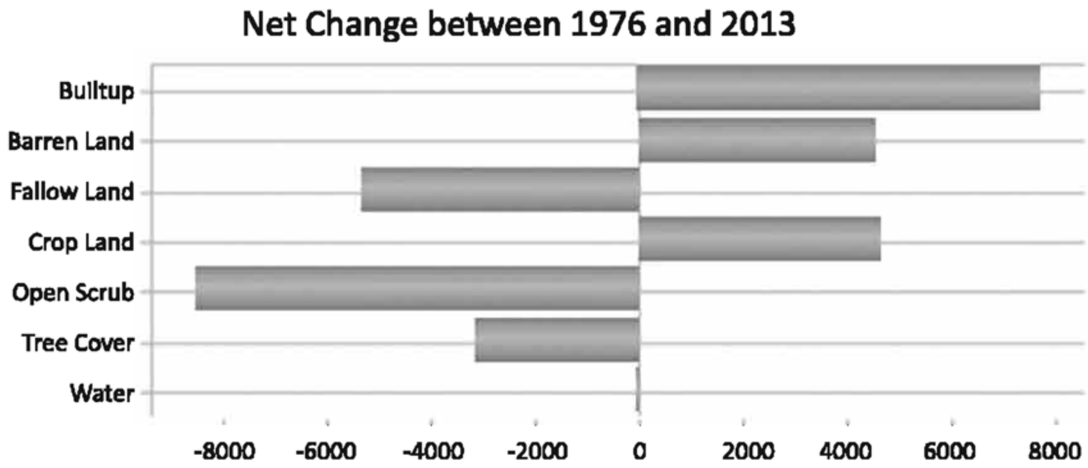


Figure 3 : Change Analysis Showing Gains and Losses (in ha)

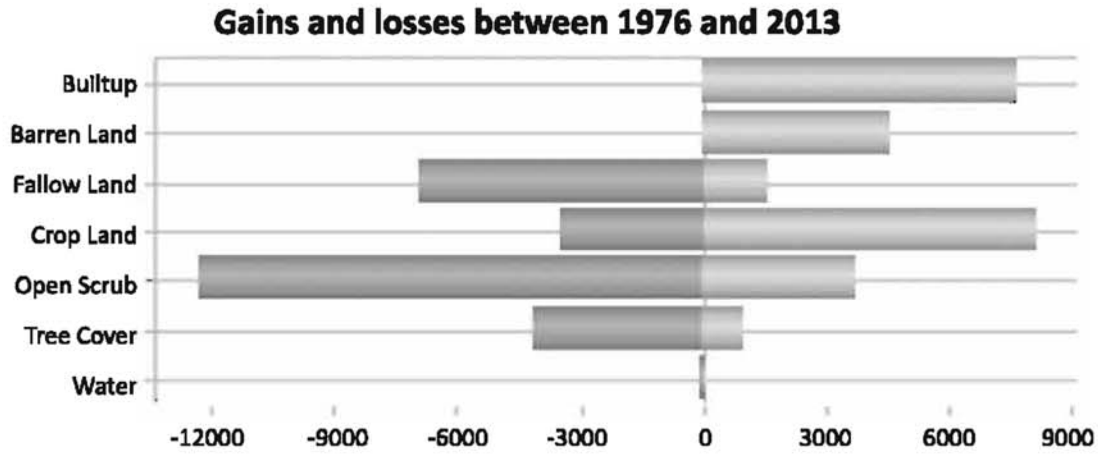


Figure 4 : Change Analysis Showing Net Change by Category (in ha)

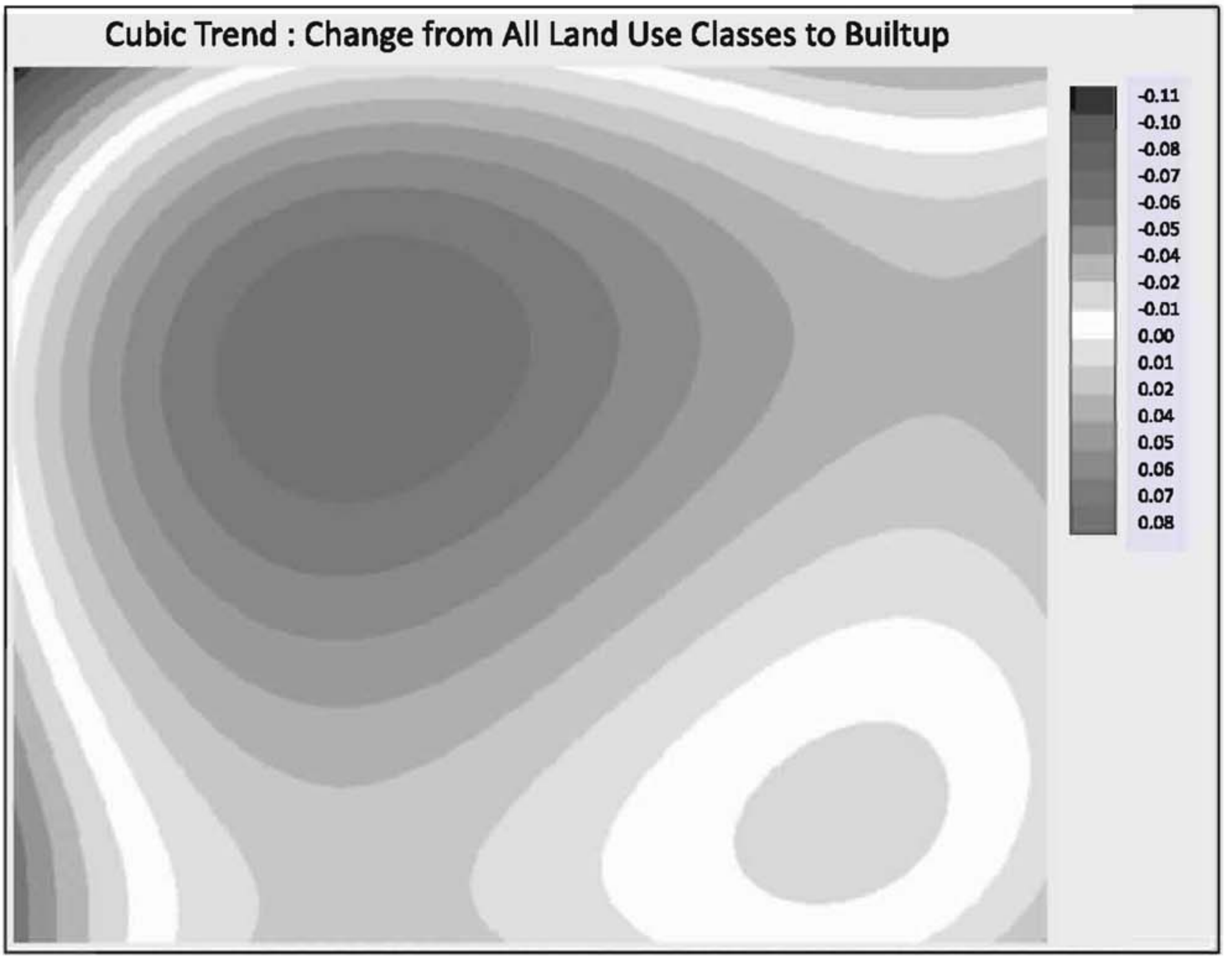


Figure 5 : Map of the Spatial Trend of Change of the Udaipur Complex (1976-2013)

Table-1 Characteristics of Satellite and Other Data Used

S.No.	Sensor	Acquisition Date	Path/Row No.	Spatial Resolution	Used For
1	LANDSAT-MSS	04-11-1976	159/043	58 m	LULC Mapping
2	LANDSAT-TM	19-10-1990	148/043	30 m	LULC Mapping
3	RS2-L4FMX	3-1-2013	D-093-54	5 m	LULC Mapping
4	RS2-L4FMX	3-1-2013	C-094-054	5 m	LULC Mapping
5	IRS-P6-L4MX	12-3-2005	2-3-042	5.4 m	LULC Mapping
6	CARTOSAT -1	24-10-2008	512-284	2.5 m	Digital Elevation Model
7	SOI Toposheets (1:50,000)	45H/6-10-14-7-11-15		Preparation of Point Database files for village and other important locations.	
8	GPS	Primary Data Collection for Classification and Data Validation			
9	Google Earth	Support for site data, Delineation of road network			
10	UIT Master Plans (2022 & 2031)	Digitization of polygons of greenbelt and fringe area Study of urbanizable area as proposed in the plan 2031			

LULC TYPE	1976-1990		1990-2005		2005-2013		1976-2013	
	Change (%)	Annual rate(%)	Change(%)	Annual rate(%)	Change (%)	Annual rate(%)	Change (%)	Annual rate (%)
Water Bodies	-3.16	-0.23	3.61	0.24	0.37	0.05	0.71	0.02
Tree Cover	-6.88	-0.49	-26.50	-1.77	-42.11	-5.26	-60.38	-1.63
Open Scrub	-9.54	-0.68	-11.03	-0.74	-12.17	-1.52	-29.31	-0.79
Crop Land	-24.13	-1.72	32.40	2.16	36.18	4.52	36.80	0.99
Fallow Land	54.20	3.87	-42.47	-2.83	-65.56	-8.19	-69.45	-1.88
Barren Land	519.96	37.14	213.97	14.26	37.72	4.72	2580.72	69.75
Builtup	201.14	14.37	210.61	14.04	53.86	6.73	1339.15	36.19