Analyzing Urban Spatial Patterns and Trend of Future Urban Expansion Using SLEUTH

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Abstract

With the onset of rapid urban growth in the past three decades, a developing country for instance India, China, Africa, etc. has resulted in climatic and environmental changes severely. Pace of urban growth has increased in India post 2000's because of key driving economic factors coupled with industrial development promoting job opportunities and promising better life style. This has led to cities expanding towards periphery and rural neighborhood causing urban sprawl. Continuous increase in the built-up area is also responsible for rise in the surface temperature modifying the rainfall patterns and affecting the biodiversity of the region. This communication focuses mainly on the recent urban growth challenges and changing land surface temperature by developing Indian cities with very minimum landscape to house burgeoning population, immediate strategies and action-plan required to mitigate negative environmental impacts and effects on human beings. Further, the study attempts to correlate the dynamic land use change, land cover, land surface temperature and future urban growth scenario for one of the most systematically planned city of India, Chandigarh. Analysis was performed using open source coding and software platforms such as GRASS, QGIS and shell scripting. The study elaborates land use modeling for the year 2025 by adopting cellular automata based open source SLEUTH model The documentation and source code of SLEUTH model are publically available. The model was tested and calibrated in three different modes: coarse, fine and full resolution. The calibration mode showed high spread coefficient suggesting the urban sprawl would take organic growth. Open source software and coding would help in increased scientific output as it would help researchers understand the code that is being implemented and helps in improvisation of exiting codes to variety of applications. Results of this study would help in developing necessary policy measures and sustainable actions that are required to reduce anthropogenic effects on urban and natural environment.

Keywords: Urbanization, Landuse, Land surface temperature, SLEUTH, Opensource, India, Chandigarh.

1. Introduction

Urban growth is a significant economic and social phenomena occurring at an unmatched rate and scale worldwide. The dynamicity of urban expansion leads to basic changes resulting in different impacts on the landscape structure and functions, at a large range of scales (Dietzel et al., 2005; Sun et al., 2013). Regional development is based on the infrastructure establishments such as industries, factories, construction of roads etc., and service facilities like hotels, hospitals etc., becomes gateway for promoting urbanization (Sudhira et al. 2004). Considering the global scenario, developing countries, still in transition, are more populated than the developed countries where the transformation is complete since two or three decades.

United Nations (2015) have approximated the proportion of world population living in urbanized area is about 54% as of the year 2014 in contrast with just 15% during 1900. Compared to other continents Asia has only 47.5% of people are habited in urban areas. These statistics are projected to reach 64% by the year 2050 indicating an alarming sign especially to a developing country like India, undergoing its greatest transformation phase over the past century in terms of infrastructure development. Multi-faceted impacts of urbanization are reported by researchers on ecosystem service (Song et al., 2015), vegetation degradation (Liu et al., 2015), urban floods and drought (Brian et al., 2017) local climate and environment (Bounoua et al., 2015; Mehmood et al., 2016; Muthamilselvan et al., 2016), environment quality (Cui et al., 2015; Bharath et al., 2018), agricultural land loss (Pandey and Seto, 2015), urban heat island (Gallo et al., 1995; Weng et al., 2004; Chen et al., 2006) and so on. Land Use Land Cover (LULC) alterations such as development of extensive paved surfaces incorporates transformation of land use with concretized surfaces, that lessens the evapotranspiration rates causing sensible heat to

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increase (Mojolaoluwa et al., 2018); with elevated concentration of Greenhouse gases and particulate matters due to various activities in the urban region that affects the skin temperature of the earth's surface (Land Surface Temperature) (Fathian et al., 2015). LST is an important indicator of heat and energy balance at the surface of the earth (Prasad et al., 2013). Researchers across the globe have been working on understanding the spatial pattern of urban temperature and its relationship with respect to various surface parameters (Piringer et al., 2002; Grimmond, 2006). LST is a factor of paved surface in an urban area as well as the vegetation abundance in the region (Xiao and Wang, 2007). LST affects almost all the sectors on which human life depends such as Energy, Infrastructure (Scott et al., 1990), Agriculture, Water resource (Bolin et al., 1986), Forest ecology, Air quality and Health (Raloff, 1989).

In this context, growing Indian cities are often facing criticism for lack of urban governance, policy implementation and civic challenges in handling these effects of changing land use dynamics and visualization of future growth to mitigate the effects on humans and environment. Interaction and exchange of datasets are yet a hurdle, due to lack of coordination between different government segments. Taking advantages of modern measuring and mapping technologies at spatial scales with free and open source technology and large data availability can be easily met with appropriate understanding and usage of spatial data management and modelling systems. The need of urban models to translate historic growth into future prediction has been attempted successfully by various researchers worldwide. Revolution of urban modelling gained impetus in the far end of 19th century and early 20th century. Based on the theoretical concepts laid by Von Neumann and Ulam, Mathematicians like Conway developed "game of life" (Gardner, 1970) and Wolfram started to develop algorithms, studied rules of one-dimensional CA having diverse applications (Wolfram, 1986). CA models can be defined as a class of two dimensional lattice of cells, where each cell representing a land use category tend to change its state over time depending on the local neighbourhood of every cell. SLEUTH, a CA based model takes into account both spatio-temporal aspects of urban growth trajectories for simulation and prediction. The model is developed by Clarke, using terrain mapping and land cover deltatron. The acronym of SLEUTH stands for slope, land use, excluded, urban, transportation and hillshade, the layers used as input for the model, consists of C-language, using UNIX or UNIX based operating systems (Rafiee et al., 2009). Silva and Clarke, 2005 described it as a grid space of homogenous cells, with Moore neighborhood of eight cells, two different cell (urban/non-urban states) and most importantly, five factors controlling the behavior of growth namely: diffusion, breed, spread, slope resistance and road gravity. Apart from the factors, model also considers growth rules categorized into four broad types: spontaneous growth, new spreading centre growth, edge growth and road-influenced growth. The factors can be calibrated according to the input layers provided and region under study. SLEUTH model has been extensively used because of its excellent compatibility, availability of open source files and demo data sets to execute the program (Project Gigalopolis) and better accuracy testing methods. Limitations of SLEUTH model has been addressed by various modifications such as optimal SLEUTH metric, parallel SLEUTH, SLEUTH-3r and SLEUTH-genetic algorithm (Jantz et al., 2004; Dietzel and Clarke, 2007; Guan and Clarke, 2010;). However, this paper aims to explore the potential of SLEUTH UGM model and does not compare other methods. Research work is carried out completely using open coding and free source software platforms, descriptions listed in table1. Keeping above aspects intact, this research communication focuses on three crucial objectives: a) To understand the land use dynamics of Chandigarh region from the year 1990-2017, b) To estimate land surface temperature, relate with historic and current land use scenario, c) To simulate future growth trends for the year 2025 considering sustainable environmental and development policy measures.

2. Study Area

Chandigarh, famously known as "The city beautiful" gets the name because of its unique urban planning and modern architecture, was designed by architect Le Corbusier for a population of about half a million. The administrative boundary is spread about 114 km^2 (of which 79.74 km^2 is covered under the jurisdiction of Chandigarh Municipal Corporation) with latitude extending between 17°12'51" N and 17°42'26" N, 78°12'34" E and 78°45'29" E as depicted in figure 1. In last 3 decades, the city has

233% rise in population. Chandigarh was chosen as it has generous economic reforms and promising infrastructural services associated with prompt administrative interventions that is also a reason for higher population growth rate.

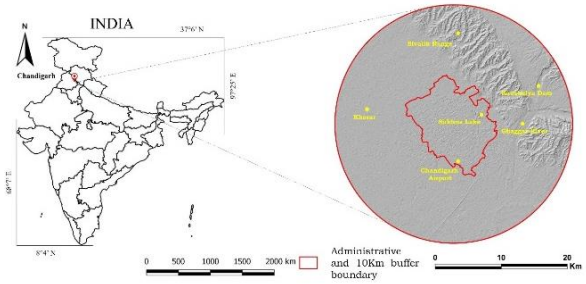

Figure 1: Study area Chandigarh, Northern India (left). Chandigarh region with administrative boundary and hill shade as a background indicating major places (right).

3. Method

Analysing patterns of urbanization and predicting future urban trends involved a four step integrated method. Figure 2 depicts a step by step approach and work flow of method adopted. Resultant layers of each sub process are indicated in green colour taken as input for CA based SLEUTH model as detailed in below sections.

3.1 Data Acquisition, Pre-Processing and Data Preparation

Historical Landsat satellite series and ASTER DEM images were collected from public repository of USGS over the time 1990-2017. Satellite data were geo-corrected and pre-processed for any distortions. Slope (in percentage) and hill shade maps were derived from DEM. Further, road layer, restricted and excluded area digitization were carried out on topographic maps, city development plan (CDP) supported by secondary data accessed using Google earth and Bhuvan. Chandigarh administrative boundary was extracted from CDP and geo-corrected toposheet. Satellite images and other raster layers were masked considering 10km buffer form administrative boundary to understand future dynamics beyond existing core urban areas. Data used are tabulated in table1.

3.2 Land Cover Analysis

LC was performed to understand the condition (density) of vegetation in the study region during the study period. NDVI (Normalized difference vegetation index) was quantified as it is considered as one of the most suitable indices to analyze the live green vegetation in the region. It is represented as shown in equation 1.

$$NDVI = \frac{NIR\ (DN) - Red\ (DN)}{NIR\ (DN) + Red\ (DN)} \quad (1)$$

Table 1: Software/website used for analysis and description

Software/ Website	**Authority**	**Description**
Google earth	Google Inc.	Virtual earth data system
Bhuvan	National remote sensing center.	Web mapping service application developed with the help of open layers and embedded map data
GRASS GIS	OSGEO	Image processing, raster and vector data management, visualization, spatial modelling
Quantum GIS	OSGEO	Helps in visual interpretation, manage, edit, analyze data, and compose printable maps.
Cygwin	Cygnus Solutions (Now Red Hat, Inc.)	It has a large collection of GNU and Open Source tools which provide functionality similar to a Linux distribution on Windows. Serves as a backbone to process SLEUTH codes.
Project Gigalopolis	UCSB	Open source project. Extends and refines the SLEUTH model to predict urban growth at local, regional and global scales.

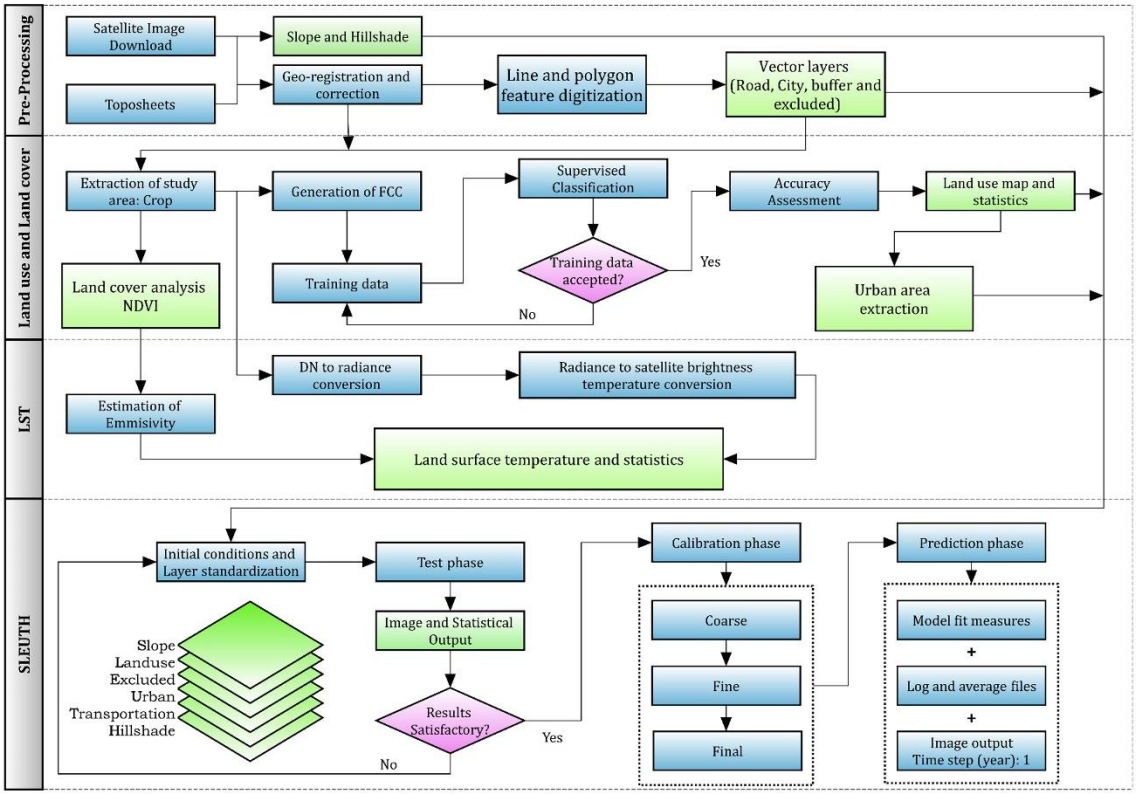

Figure 2: Method adopted to analyse urban spatial patterns

NDVI value ranges from -1 to +1. A zero value of NDVI indicates presence of water body, negative values indicates built up, soil, open area, mining activities, etc. Positive values from 0.1 – 0.3 indicates sparse vegetation (scrubs, trees with some distance, shrubs, etc.), 0.3 – 0.6 indicates moderate density of trees and 0.6 – 0.8 indicates dense vegetation. As the value of NDVI approaches to one, the vegetation cover becomes denser.

3.3 Land Use Analysis

Land use image classification was based on supervised Gaussian maximum likelihood classifier (GMLC). Initial procedure to carry out land use assessment involves stacking satellite bands. In this context, Green, Red and Near infrared bands were stacked and assigned false colour coding to form false colour composite (FCC) image. FCC helps identifying heterogeneous features in landscape with ease (Bharath et al., 2018). Training polygons were digitized on FCC covering the entire study area uniformly (with at least 15% per each class) under four broad categories. These polygon extents were loaded to pre-calibrated GPS to verify ground truth data by visiting field. Inaccessible places during field visit were verified from Google earth. GMLC is a superior supervised algorithm which considers four aspects to classify an image: mean, co-variance, probability density and cost functions (Ramachandra et al., 2012; Duda et al., 2000). Error matrix or confusion matrix is widely used to understand correctly classified pixels, omission error, commission error and overall accuracy. Overall accuracy takes into account only the diagonal elements whereas the Kappa statistic or K-hat also considers the off diagonal elements to cross validate two images (Congalton and Green, 2008; Lillesand etl al., 2012).

3.3 Land Surface Temperature

In order to quantify LST the method involved was followed as shown in Shafia et al., 2018. It is a three-step process: 1) Conversion of DN into Radiance, 2) Conversion of Radiance into At-satellite brightness temperature and 3) Computation of LST using emissivity and At-satellite brightness temperature.

3.4 Urban modelling using open source code - SLEUTH

3.4.1 Input data set preparation

The six input layers for SLEUTH model were acquired from various data sources (table 2).

Slope and hill shade maps derived directly from digital elevation models of ASTER satellite data. Slope is expressed in terms of percentage whereas hill shade map is used as a background layer for visualization purpose. Further, urban extent layers were obtained by reclassifying land use images. Transportation or road layers digitized for most recent years using toposheets, open source maps, Google street data and Bhuvan data keeping land use maps as background to correlate between urban extents and road layers. Excluded layers were created by referring to CDP, existing and proposed land use plans, provides area of importance to be protected, for instance: heritage sites, open spaces, green spaces, parks and forest, defence area, recreational zones, afforestation zones etc. These layers are collectively taken into single directory and were ensured of identical rows and columns, same projection, same map extent and standard resolution at 30m as specified by Dietzel and Clarke, 2004. Layers have to be compiled, reclassed, cropped, resampled and exported as greyscale 8-bit gif's in three different resolutions: coarse, fine and full for the purpose of three modes of calibration. Each SLEUTH run depends on scenario file where most of the variables and settings are written in accordance with derived layers.

Table 2: Input layers used and source for SLEUTH analysis

No.	Layer name	Source
1	Slope and Hill shade.	Processed from ASTER DEM (raster)
2	Land use and Urban extent	Classified from Landsat series images (raster)
3	Transportation (Roads)	Street data (OSM, Bhuvan and Google maps) updated with classified images (originally vector, rasterized).
4	Excluded map	CDP and other plans (originally vector, rasterized).

3.4.2 Model test, calibration and prediction

Details of SLEUTH general structure and work flow is depicted in figure 2. For model test phase, full resolution images (30m) are used. Scenario file holds the information about path directory information, log file preferences, Monte Carlo iterations, coefficient range and step values, output statistics etc. can be modified from source file as per the formatted study region specifications. Calibration phase involves rigorous iterations to narrow down the range of best and optimum suitability of coefficient values required to predict urban growth. During coarse calibration, entire dynamic range of coefficient values for diffusion, breed, spread, slope resistance and road gravity can be explored by adjusting start, step and stop values in scenario file. The statistical log output file would be considered along with Lee-salee metric, a goodness of fit measure, arranged in decreasing order to find range values for further calibration. With input data of 60m and 30m resolution images, fine calibration and final calibration phase can be started respectively. Top Lee-salee metric are selected to obtain five unique coefficient values responsible for urban growth. After each run, the model returns a total number of 13 metrics to evaluate the goodness of fit. These metric value changes according to the study area considered and various other factors. Urban researchers have used Lee-Salee, compare, population, clusters, edges, slope, product and weighted sum of all 13 metrics to achieve region specified calibration results (Silva and Clarke, 2002; Jantz et al., 2004; Yang and Lo, 2003; Dezhkam et al., 2014).

4. Results

4.1 Land Cover and Land Use Analysis

Land cover analysis was performed using NDVI and results are as shown in figure 3. Statistics of land cover classes were tabulated as in Table 3 indicates the vegetation and non-vegetation cover. The gradual increase in the green areas over the decades can be understood as sustainable urban initiations within the city like city greening, development of city forest in institutional open spaces, wasteland afforest ration, peoples' nursery, agro forestry and parks, planting of trees along the road sides which would help in absorbing the emission pollutants. The major change was observed near Sukteri and Kuranwala region. Relevant tree species that exhibited biodiversity and bio-aesthetic attributes were used for afforest ration in both urban and rural areas. Nurseries were initiated focusing on development of urban poor who will the prime beneficiaries and will be infra-structurally supported by the Horticulture department. For better understanding of the region, land use analysis was performed and results are as shown in figure 4 and 5 and land use statistics is tabulated in table 4.

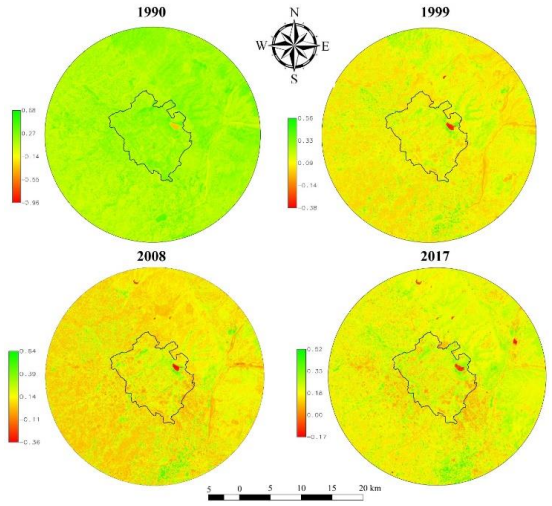

Figure 3: Land Cover of Chandigarh with 10km buffer

There has been a considerable increase in the urban areas and vegetation down the decades. Significant jump in urban expansion can be observed during the period 2008-2017 with 67.41 % mainly due to strong economic and administrative base, high profile living environment with efficient service delivery mechanism and varied employment opportunities. Nearby smaller villages and towns for instance, Kharar, Zirakpur and Panchkula have evolved as larger urban clusters and many new settlements can be recognized along the transport corridors. Water body has also seemingly increased in 2017; this can be understood on basis of visualization (temporal scale on Google earth) as well. Major development has been happening in the proximity of Aerocity road and Jagatpura bypass road with new construction sites coming up. Zirakpur, Panchkula extension and Sahibzada Ajit Singh Nagar has witnessed the major land use change for construction of residential purpose on the cost of agricultural fields and open area. Industrial area and residential complexes have been coming up in Mohali region. These alterations in urban landscape plays an important role in increasing the built up area and are responsible for the sprawl happening in Chandigarh causing micro climate change. Table 4 shows the kappa coefficient and overall accuracy of the classification. Land use and land cover assessment was performed using open source image processing and visualization Geographic Resources Analysis Support System (GRASS) and Q-GIS software.

Table 3: Percentage Vegetation and Non-vegetation

Year	Vegetation (%)	Non- vegetation (%)
1990	18.74	71.26
1999	18.95	81.05
2008	22.7	77.3
2017	20.08	79.92

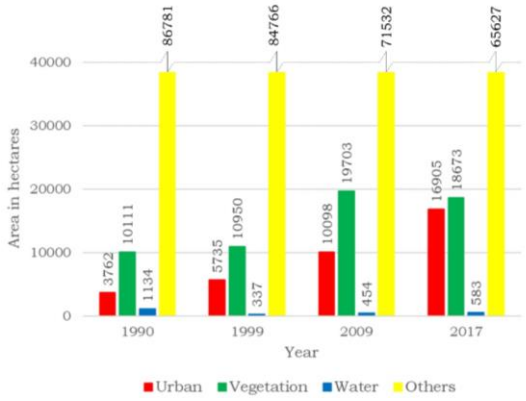

Figure 4: Quantitative change in land use over last three decades

Table 4: Land use analysis and accuracy assessment.

Year	Land use categories				Accuracy assessment	
	Urban	Vegetation	Water	Others	Kappa statistic	Overall accuracy (%)
1990	3.70	9.93	1.11	85.26	0.79	92.68
1999	5.63	10.76	0.33	83.28	0.73	91
2008	9.92	19.36	0.45	70.28	0.86	94.10
2017	16.16	18.34	0.57	64.47	0.82	90.75

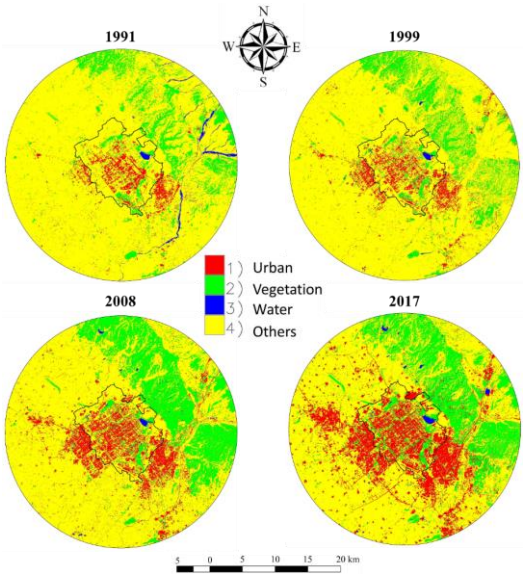

Figure 5: Land Use of Chandigarh from 1990 to 2017

4.2 Land Surface Temperature

LST for Chandigarh city with 10km buffer was quantified as shown in figure 6 and temperature statistics for all the land use classes as illustrated in figure 7. The average surface temperature for the study area has been increasing since 1991 which can be inferred due to increased urban structures and formation of new residential colonies and industries. Urban category shows a mean temperature rise by 11.31˚C. There are number of plantation activities carried out near Karoran region but still the temperature of vegetation has shown an increase. Water bodies and others class also experienced increment in mean surface temperatures. The growing industrial and residential areas in the city and in vicinity has altered the surface temperature and changed the net solar influx. The surface temperature has increased by 12-18˚C creating a huge imbalance in the climate, rainfall pattern, crop yield, etc.

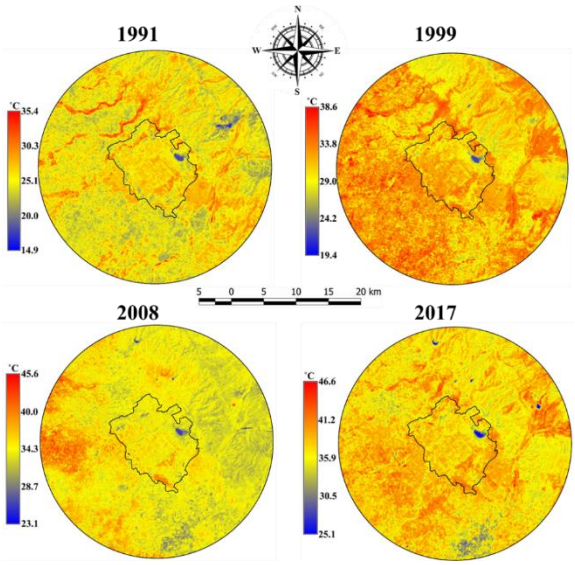

Figure 6: Temporal Land Surface temperature analysis for Chandigarh.

4.3 SLEUTH

Test mode was successfully run for Chandigarh region data set with full resolution. Further, calibration phases were run with coarse, fine and final. Results of calibration values and time step taken for each coefficient in all phases of calibration are shown in table 5.

Based on Lee-Salee metric, the final values obtained for prediction showed least chance of diffusion (1) and breed (2). Medium range value was observed for slope resistance (17) indicating no chances of development towards northeast and southeast direction from Chandigarh city that is Sivalik range. Spread (50) and road gravity (64) showed a higher value suggesting the possibility of spreading urban growth type from already existing centers along highway roads. Keeping hillshade as background, figure 8(a-d) depicts SLEUTH urban growth prediction for the year 2025, with annual probability of urban growth ranging from 50-100%, higher value suggests more likely urbanization.

Chandigarh region has followed historical urban growth pattern with infill and leapfrog as major types. Urban extent in 2017 was 169 km^2 and was predicted as 421 km^2 in 2025 suggesting the necessity of immediate policy intervention to curb urban growth at the cost of green spaces, agriculture land and protected areas. Spreading type urban growth can be seen in Kharar region, it is important to note that NH-95 passes this location further connecting to Ludhiana (figure 8a), spontaneous growth concentrated with road gravity is evident in New Chandigarh region (Eco city) with detached individual urban areas along Kurali-Chandigarh highway road (figure 8b). Organic growth type is visualized in figure 8c in Pinjore and Kalka region mainly due to tourist attraction of nearby Kaushalya reservoir and also Zirakpur-Panchkula-Shimla highway road (NH-22) from Ambala. Diffusive and spread of new growth center can be observed near Chandigarh international airport area (figure 8d). Zirakpur and JLPL industrial area. Performance of SLEUTH is assessed by fitness measure. A total number of six metrics were selected to judge model fitness based on literature, they are: compare, population, edges, clusters, cluster size and Lee-Salee metric. Of these, population, edges, clusters and cluster size showed excellent fitness values of greater than 0.85 for all three phases of calibration sufficing the prediction result validation, whereas compare and Lee-Salee metric were ranging from 0.4 to 0.66 that is within acceptable range indicating success of near perfect calibration procedure.

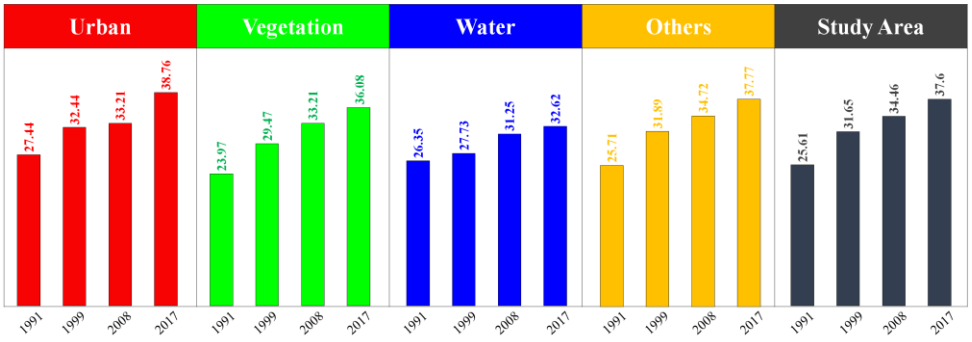

Figure 7: Temperature Statistics for various LU classes (values in ˚C)

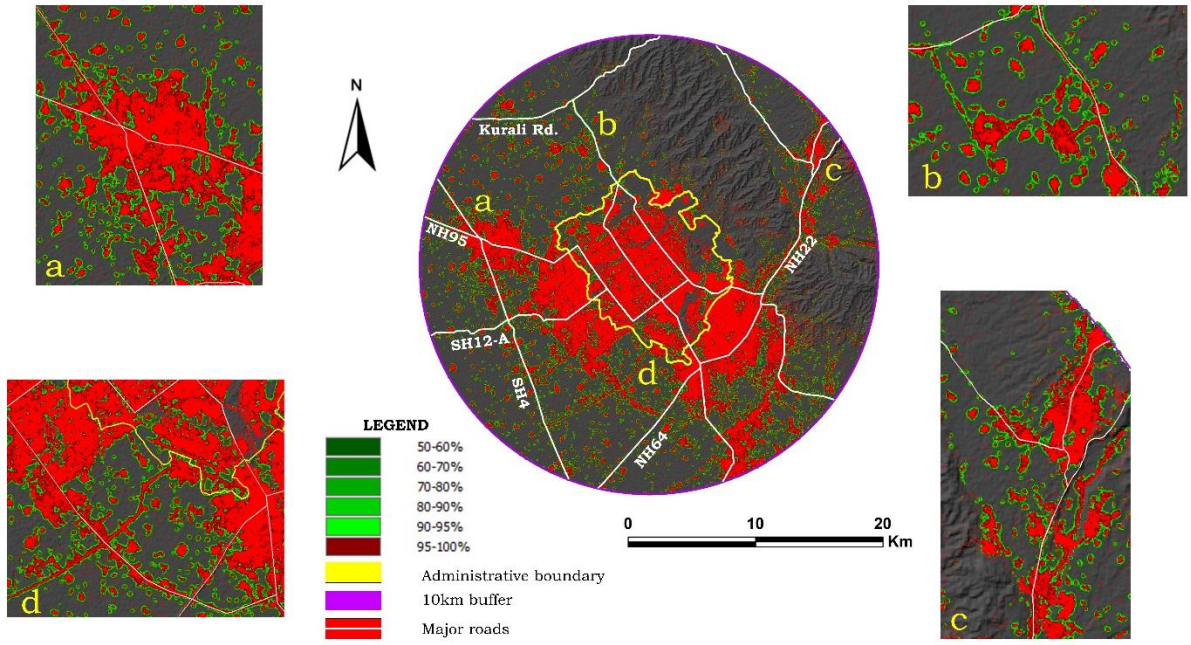

Figure 8 (a-d): SLEUTH modelled output along with major road network of Chandigarh region, 2025.

Table 5: Coefficient range and step values for various phase of calibration

Parameters	Calibration Phase						
	Coarse		Fine		Final		Prediction
	Range	Step	Range	Step	Range	Step	Value based on Lee-Salee
Diffusion	0 to 100	25	1 to 25	5	1 to 5	1	1
Breed	0 to 100	25	1 to 25	5	1 to 5	1	2
Spread	0 to 100	25	50 to 75	5	50 to 55	1	50
Slope	0 to 100	25	1 to 25	5	15 to 20	1	17
Road gravit	0 to 100	25	50 to 75	5	60 to 65	1	64
Monte carlo iterations	5		8		10		100

5. Conclusion

Recent studies on urban growth in India have tried to address urbanization process as a whole. In this communication we have revisited the perspective of urban growth trajectory and employed an integrated technique of analysing land use and land cover supplemented by LST and CA based SLEUTH model. Land cover results clearly depict consistency in vegetation category and a slight increase from the year 1999 to 2008, which is seldom seen in Indian cities. To support land cover analysis, results of land use analysis indicate fivefold increase in urban category from the year 1990 to 2017. These factual figures highlights Chandigarh being one of the exceptionally well-planned cities, is no different from other metro areas in terms of urban growth and urban sprawl. LST results signify that even though the city has planned structure, the concretization has caused a rise in surface temperature. Few of the urban developments such as Sahibzada Ajit Singh Nagar, Chandigarh International Airport, etc. shows highest temperature. Results from SLEUTH highlights pattern of urban growth in the periphery. A case of four regions within the designated 10km buffer boundary is taken to understand future urban dynamics at a very microscopic scale. Visualizations from model further highlighted the

process of accumulating urban areas in the hinterland with growth types: spontaneous, diffusive, spread, organic and road influenced. Urban areas have consistently been increasing towards the periphery along the highroads and railway networks which proves good transportation modules helps boosting in regional economy as well as they try to attract more number of people from non-urban areas. At the same time, the results also send out a clear message to regional planners and governmental agencies to address and revise the regions land use policy. The research article has successfully implemented open source data sets, tools and software platforms to address the linkage between historical land use trends, LST and future urban growth. The study also insists on the need of focus towards multi-dimensional aspects of problem solving approaches, that includes socio-economic, culture and ecosystem-oriented measures to ensure harmony between human beings and surrounding environment accounting for sustainable future. This paper also exhibits Free and Open Source Software can provide extensive detailed analysis based on user's needs and has versatility of handling various tasks of modern day geo-informatics

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Open source web resources used

Bhuvan: http://bhuvan.nrsc.gov.in; Earth explorer: http://earthexplorer.usgs.gov/;Grass GIS: https://grass.osgeo.org/ ; Quantum GIS:https://qgis.org/en/site/
Municipal Corporation Chandigarh:http://mcchandigarh.gov.in/cdp.pdf
Open Street Map:https://www.openstreetmap.org/
Project Gigalopolis:http://www.ncgia.ucsb.edu/projects/gig/index.html

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