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Quantification Of Urban Growth Dynamics Using Entropy Approach

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Abstract

Expeditious and unchecked urban expansion has significantly altered the urban environments. This has warranted the need of understanding, monitoring and analyzing the spatial patterns of urban growth. Relative Shannon Entropy is widely used metrics for assessment of pattern and the extent of urban growth in cities. Thereupon, this research paper pertains to quantify and monitor the patterns and dynamics of urban growth using Relative Shannon Entropy with integration of Geospatial technology in the city of Haldwani, Uttarakhand. In this study, land use land cover maps were extracted using satellite imageries of LISS IV and Sentinel II for 2005-2019 time periods. Subsequently, built-up, road network and the core of the city were extracted from the satellite data for the years 2005, 2008, 2013 and 2019. Eventually, Relative Shannon entropy (RE) was computed with reference to the core and the major roads for 2005-2008, 2008-2013 and 2013-2019 time periods. It has been observed that the obtained RE values exhibits that the pattern of urban growth in the city was a compact in the earlier period (2005), which in due course of time (2019) has changed to a dispersed pattern of urban expansion concerning both the core and the roads of the city. This research work thus enables in understanding the spatio-temporal pattern of urban growth in the city for effective land use planning in the city for sustainable urbanism.

Keywords*: Urban Growth, Relative Shannon Entropy, Spatial Patterns*

Introduction

Cities are complex systems of interactive elements (Ramachandran, 1989) of population, location and infrastructure and their association with the built-up and non-built-up environments. These interactions and interdependence of all the elements is primary for pertinent functioning of the system. Any significant change in the inter-related elements of urban growth disrupts the urban system, as a whole. The dynamic attribute include Population growth and migration that forms the foundation of an urban system. Rapid change in the dynamics of the attributes induces urban expansion. Unregulated urban expansion alters the physical environment on varied scales and magnitude. Excessive urban growth in fact is considered as menace to urban system and is critical to the quality of life of the population of the city. This necessitates the need to understand the intricacies and implication of uncontrolled urban expansion and analysis of the spatial patterns of urban growth in the city.

The spatial pattern of urban growth characterizes the physical configuration of built-up environment and the population. It ascertains the dynamics of the physical, environmental, economical characteristics of urban centers over time. Preliminary recognition, monitoring and analysis of urban patterns facilitates in effectual land use planning and resources management; affirming sustainable development.

The spatial patterns of urban growth can be detected, monitored and analyzed using geospatial technology (Barnes et al., 2001) and statistical metrics (Gar-On Yeh et al., 1998). Entropy based approaches are effective in quantifying urban sprawl patterns in Geographic Information System (GIS) domain. Shannon Entropy (Sudhira et al., 2004; Joshi et. al., 2006; Sun et al., 2007; Sarvestani et al., 2011) serves as a significant measure of spatial order. Generally, it is used to evaluate the spatial distribution pattern of urban centers. It is indicative of spatial concentration or dispersion (Yeh and Li 2001). In fact, it is based on informative theory. It regulates the degree of compactness or dispersion of urban expansion (Lata et al., 2001).

Thereupon, this research work endeavors to monitor and evaluate the urban growth patterns for the study area using Relative Shannon Entropy in conjunction with the geospatial technology for affirming sustainable urbanism.

Study Area

Haldwani planning area has been considered to carry out this research. The study area has a geographical extent of 79° 27' 55.34" E to 79° 32' 21.06"E longitude and 29° 09' 22.83" N to 29° 17' 31.9" N latitude. It is located along the banks of the Gaula River in the Bhabar Belt of the foothill plains of Himalayan mountains in Nainital district of Kumaun region of Uttarakhand. Haldwani has an areal coverage of 48.2 square kilometres and is the largest city in the district. It is one of the fastest growing class I city of the state.

Materials and Methods

Data

This study has incorporated multi-spectral satellite imageries of LISS IV and the Copernicus Sentinel II for the time period of 2005-2019. LISS IV and Sentinel II data were acquired from National Remote Sensing Centre (NRSC) and European Space Agency respectively. The LISS IV data has a spatial resolution of 5.8m operating in three spectral bands B2 (Green), B3 (Red) andB4 (NIR). While Sentinel 2 imagery has 10m spatial resolution with 4 spectral bands- B2 (Blue), B3 (Green), B4 (Red) and B8 (Near Infrared). The planning boundary was extracted from the Master Plans from Town and Country Planning Organization (TCPO), Uttarakhand.

Methodology

Understanding the dynamism of the urban growth and the patterns developed due to expansion necessitates the need to comprehend primarily the land use land cover (LULC) of the study area and then evaluation of the patterns evolved over time. The methodology flowchart is given in the Figure 1.

Land Use Land Cover Characterization

Land Use Land Cover classification is the fundamental step in pursuing geospatial analysis. It is the process of assignment of pixels to particular classes. In this study, LISS IV and Sentinel II data were classified into major classes of built-up, vegetation, agricultural and fallow lands, open spaces, road networks, and river and water bodies. Eventually, land use land cover (LULC) maps were generated using Maximum likelihood **classification** (**MLC**) algorithm for the study area for

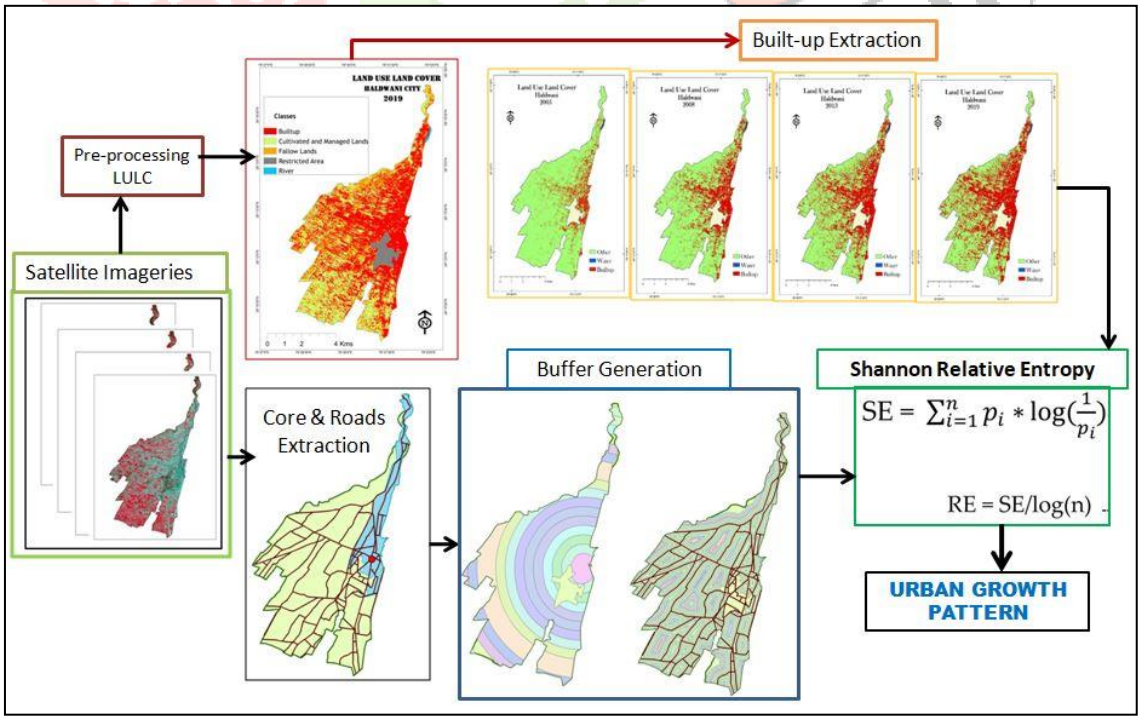

Figure 1 Methodology flowchart for the study undertaken

the years 2005, 2008, 2013 and 2019 respectively. The classification accuracy for the classified images of 2005, 2008 and 2013 and 2019 was done using overall and kappa statistics. The overall accuracy was found to be 89% (2005) 89.2%(2008), 89.5%(2013) and 91 %(2019), respectively. While the overall kappa statistics of the classified images were 0.9, 0.89, 0.94 and0. 91 for the years 2005, 2008, 2013 and 2019 respectively. The cantonment and the river was exclusionary from the study area as growth in this areas were restricted.

A significant indicator of urban growth is the percentage of an area covered by impermeable surfaces (built-up)(Barnes et al., 2001). The higher proportion of built-up coverage specifies higher urban expansion and vice versa. Hence, two major classes namely, Built-up and Non-Built-up were generated for the study area for 2005, 2008, 2013 and 2019 years.

Eventually, the roads and the core of the city were also extracted for the study area, which forms the base of the estimation of urban growth in the study area. The major roads include National Highway 109 which passes through the city and other roads include Haldwani-Kaladhungi–Ramnagar road and the Kathgodam-Sitarganj road. The core of the city is the center within municipal limit and is the meeting place of the major roads of the city.

Shannon Entropy Estimation

The Shannon entropy is elucidated as the measure of the degree of spatial concentration or dispersion of a geographical entity of urban growth among the zones. The Shannon entropy is postulated on the basis of concentric circles/ buffers created in the cities with the radius of 500 meters around the core of the city and 100 meters radius around the major roads.

The Shannon entropy was calculated using the Equation 1 and Equation 2 respectively.

$$SE = \sum_{i=1}^{n} p_i * \log(\frac{1}{p_i}) \text{----------Equation 1}$$

$$RE = SE/\log(n) \text{ ---------- Equation 2}$$

The relative entropy was calculated to normalize the values of Shannon entropy and was calculated using the following equation 2.

Here, pi refers to as the probability of a variable/entity occurring in the i^{th} zone. The entropy values ranges from zero (0) to log (n). The value of zero (0) indicates that the urban growth is of compact pattern whereas the value of log(n) indicates that the urban growth pattern is of dispersed type.

Results and Discussion

The land use land cover (LULC) maps of the study area manifests that the amount of built-up has exceeded at more than triple pace Figure 2. In the LULC map of the year 2005, it can be clearly seen that the built-up was concentrated only in the core and the municipal area of the city. In the year 2008, the built-up has grown more compact at the core and started sprawling towards the outer municipal limits of the city.

More urban expansion is towards the northern and western parts of the city, as visible in the LULC maps of 2008 and 2013. Following the same direction, the sprawling of urban is dominant in the LULC map of 2019.

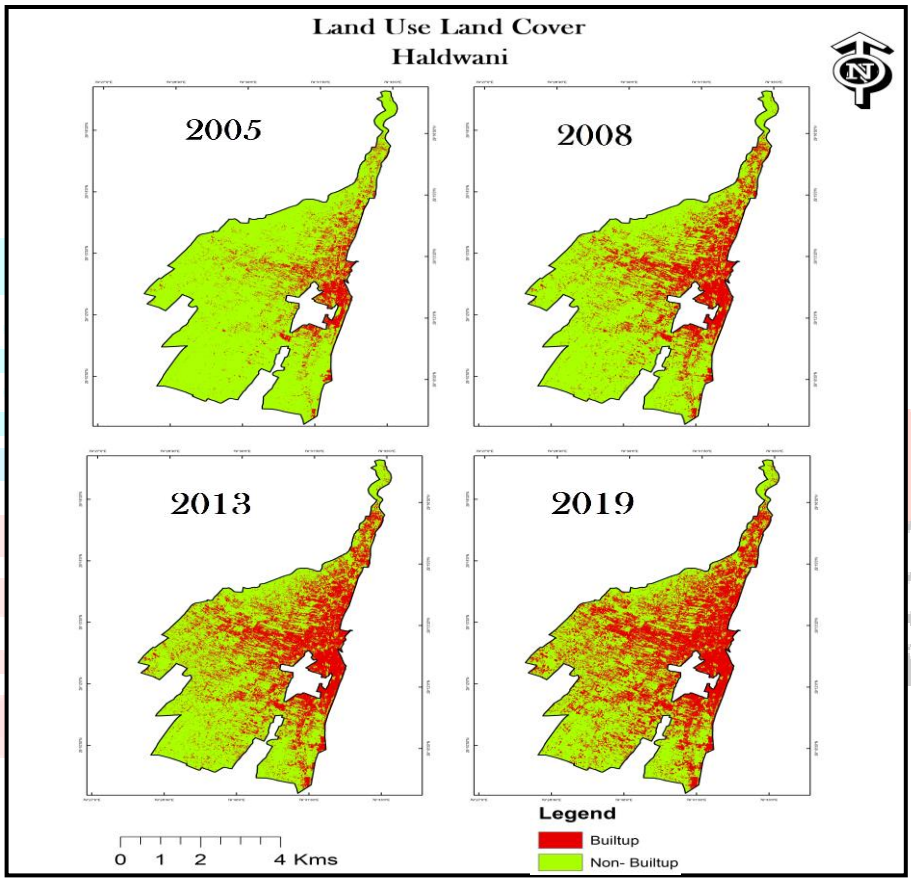

Figure 2 Land Use Land Cover Map

The built-up, which is an indication for urban growth, has grown tremendously from 6.01 square kilometers in 2005 to 20 square kilometers in 2019. There has been 41.4 percentage of areal change of built-up over 2005-2019 period. Contrarily, percentage of 58.5 of non built up has sharply declined over the same period. Non built-up in 2005 was 42.19 square kilometers which shrunk to 28.21 square kilometers in 2019(Table 1).

Class	Area (in Square Kilometers)							
	2005	2005 (in %)	2008	2008 (in %)	2013	2013 (in %)	2019	2019 (in %)
Built-up	6.01	12.47	11.56	23.98	16.035	33.26	20.00	41.49
Non-built-up	42.19	87.53	36.64	76.02	32.17	66.74	28.21	58.51

Table 1: Built-up Statistics of Study Area (2005-2019)

The directional growth of the built-up for the study area was also strived to analyze. It has been observed that the city has immensely expanded towards the north and the north-eastern parts of the city. This is resultant of the city expansion along the major roads that connects Nainital, the district's seat, to Haldwani-Kathgodam since its inception. The maximum built-up expansion of about 1.17 square kilometers in the year 2005 was extended towards the north east – east (NE-E) directions. While in 2008, 3.2 square kilometers of built-up has grown towards the north-north-east(N-NE) directions. Similarly highest built-up of 4.4 square kilometers and 5.3 kilometers for years 2013 and 2019 has grown towards north-north-east (N-NE) directions respectively. Contrarily, lowest built-up expansion was observed towards south-west-west (SW-W) for 2005, 2013 and 2019 and for 2008, east-south-east (E-SE) directions has expanded the lowest.

It is apparent from the Figure 3 that the city of Haldwani has enormously grown and it has grown towards and along the major roads and core of the city and keeping this as base city will continue to grow at radial directions.

Eventually, the Shannon entropy was estimated for the study area. The first requirement for calculation of entropy is the division of the study area into concentric circles. The concentric circles or buffers were generated with the distance of 500 meters from the core of the city extending up to several buffers till it encompasses the whole study area. The largest buffer was at the distance of 8500 meters encircling the outskirts of the city. It can also be inferred that the core with 500 meters radius had the highest amount of built-up, while the most distant buffer had the least amount of built-up. Similarly, buffers were generated along the major roads at a distance of 100 meters, which extended towards outskirts up to 1000 meters, covering the study area.

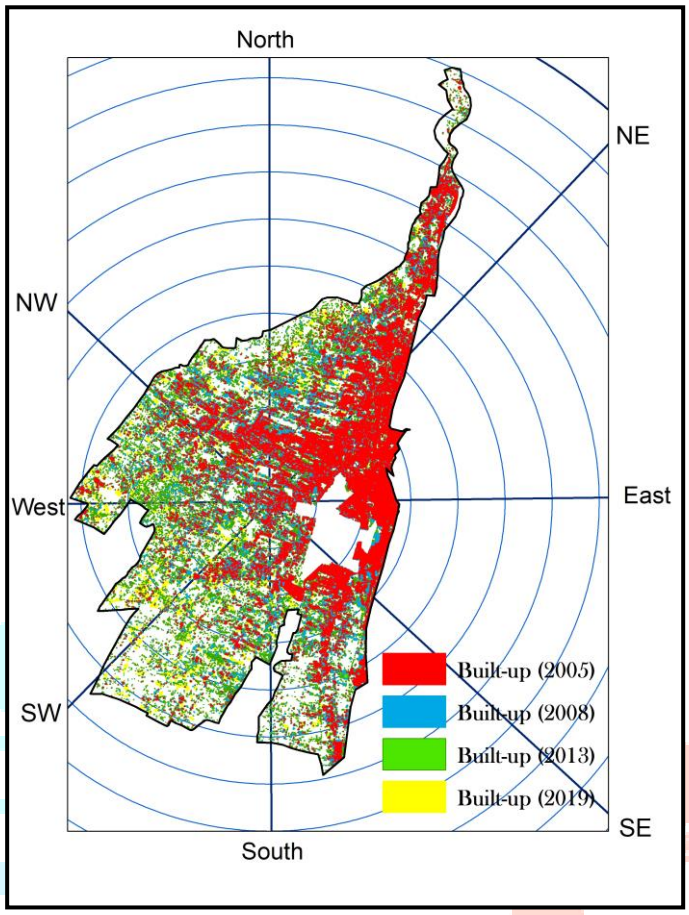

Figure 3 Directional Urban Expansion of the Study Area

The Shannon entropy was calculated using the above given equation 1. The normalization of the Shannon entropy results were done to simplify and for easy comprehensibility of the outputs, using equation 2, which is Relative Entropy. The Table 2 depicts the relative entropy (RE) values for the study area.

Time-period	Entropy along roads	Entropy alone city core
2005-2008	0.466917	0.833968
2008-2013	0.509516	0.84971
2013-2019	0.546361	0.84294
2019-2020	0.56506	0.870909

Table 2: Shannon Entropy Values along the Core and Roads of the City

The relative (RE) values of the study area along the core and the roads for the time period of 2005-2019 graphically, as given in the Figure 4. The relative entropy (RE) values along the core of the city were 0.83 (2005), 0.84 (2008), 0.84(2013) and 0.87(2019). The highest and the lowest RE values along core were found in the years 2019 and 2005 respectively. Similarly, the entropy values (RE) along the roads also exhibited the same;

lowest and highest RE values were obtained in the year 2005 and 2019 respectively. The RE values along major roads were 0.46(2005) and it increased to 0.50 in 2008, 0.54 in 2013 and 0.56 in 2019. The RE values along the core and roads both manifested an upward trend of urban expansion in the city over time. This indicates that the city was more of compact pattern in 2005, which gradually over time has moved towards dispersion. In other words, the city is of dispersed type in present than that of earlier time.

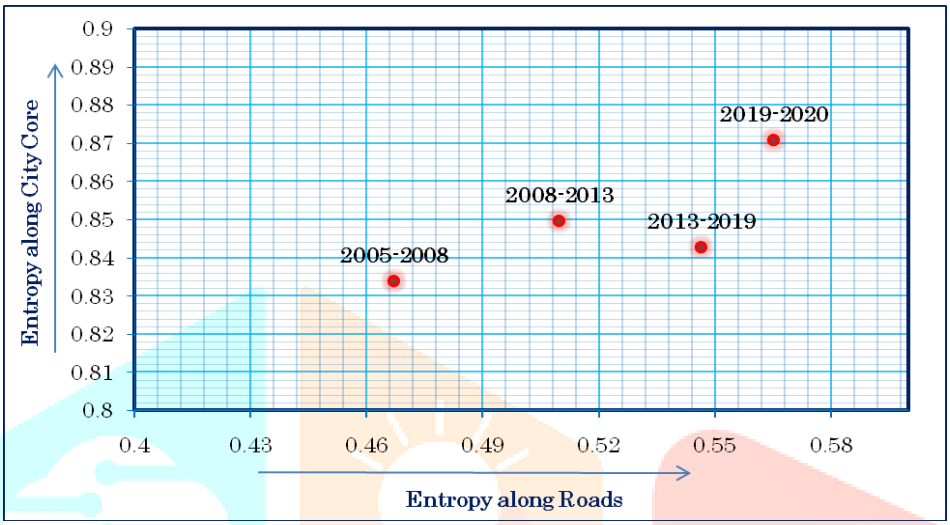

Figure 4 Shannon Relative Entropy Values along the core and major roads (2005-2019)

Additionally, the RE values along major roads were much lower than the RE values along the core of the city over the time period of 2005-2019. This evidently depicts that the built up distribution is of more compact pattern along the roads in comparison to the built-up pattern found along the core of the city.

Conclusion

The research work has undoubtedly proved that Shannon entropy coupled with geospatial technology can be a significant consideration for the urban growth and pattern analysis for a city. The results of the research work exhibit that higher the entropy values will be the higher urban expansion or sprawl and vice versa. Additionally, likewise in this study, road networks and core /CBD factors were considered; other influential factors can also be taken into consideration of entropy based analysis for urban growth pattern analysis.

Hence this research aids in providing a ‘big picture’ of the city depicting ‘where’ and ‘how’ the city is growing and at ‘what’ pace for Haldwani city over 2005-2019. This study stimulates the present growth pattern of the city and can pave for future direction framework, in order to ensure effective planning prospects for the city and sustainable urban development.

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