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Entropy Based Approach for Analysis of Spatio-Temporal Urban Growth Dynamics

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Abstract: Relative Entropy (RE) is defined as the measure of degree of randomness of any geographical variable (i.e., urban growth). It is an effective indicator to evaluate the patterns of urban growth either compact or dispersed. In the present study RE has been used for evaluating the urban growth of Dehradun city. Dehradun, the capital of Uttarakhand is situated in the foothills of Himalayas, has undergone rapid urbanization. Landsat, Thematic Mapper (TM) satellite data of years 2000, 2010 and 2019 has been used in the study. Built-up cover outside municipal limits and within municipal limits was classified for the given time period. Road network and city centre of the study area were also delineated using satellite data. RE was calculated for period 2000–2010 and 2010–2019 with respect to the road network and city centre. High values of RE indicate higher levels of urban sprawl whereas lower values indicate compactness. Urban growth pattern over a period of 19 years was examined with the help of RE.

Keywords: Relative Entropy (RE), urban growth; urban sprawl

1. Introduction

Rapid urbanization and change of landscape had been witnessed in some developing countries which is a result of fast economic development. Therefore, measurement and monitoring of land use changes in these areas is a crucial task for planning and management purpose [1]. Relative Entropy is an effective indicator to evaluate the patterns of urban growth whether compact or dispersed with regard to a factor. It measures the degree of randomness of any geographical variable (i.e., urban growth) among n zones [2,3]. Through entropy structure and behavior of different systems (i.e., urban sprawl) can be described [4]. Entropy based approaches have been widely used for measuring urban growth patterns by using remote sensing and GIS [5–9]. In the present study an attempt has been made for evaluating the urban growth using Relative Entropy of Dehradun.

1.1. Study Area

Dehradun Planning Area which consists of Dehradun city and the surrounding area, is selected as the study area. It is the capital of Uttarakhand state in India. The geographical extents are 30°15′ N to 30°25′ N latitude and 77°55′ E to 78°10′ E longitude with a total area of 360 km^2. The study area has lower Himalayas on the northern side and Shivalik mountains on the southern side. River Song and river Tons are situated in the eastern and western parts, respectively. There are number of civil and defence institutions of national levels situated in the city. It is also a vital service centre of trade, health, education, transportation and recreation (Figure 1).

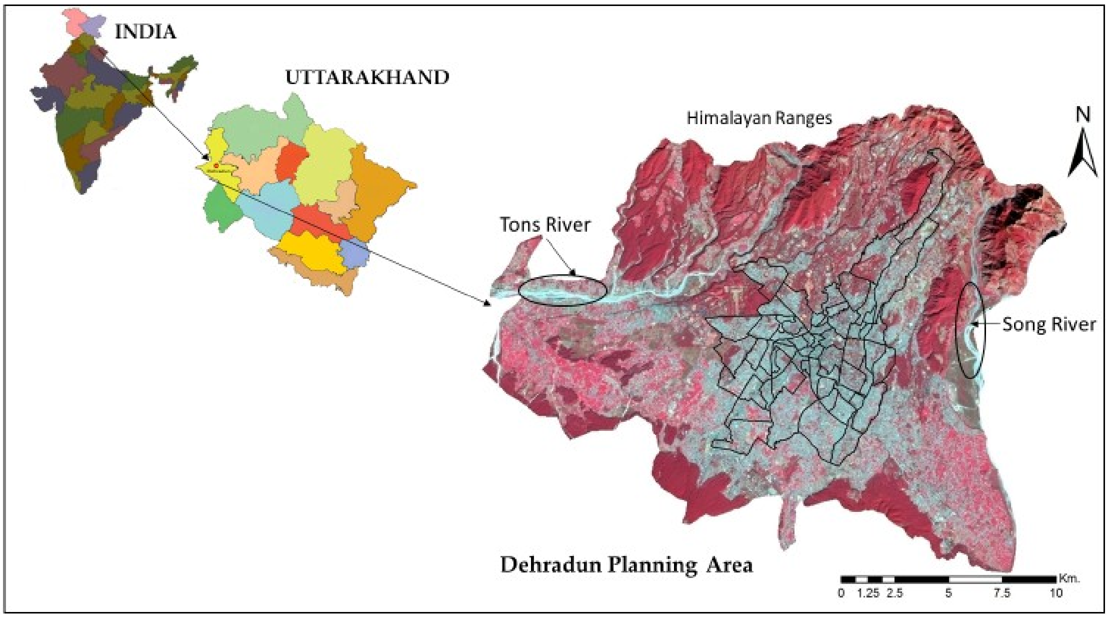

Figure 1. Location map of the study area.

1.2. Dataset

For the study Landsat (TM) satellite images of year 2000, 2010 and 2019 at a spatial resolution of 30 m were used as primary data for generation of land cover maps and road network map. The topographical maps (Sheet numbers: 53 J/3 and 53 F/15) and guide maps of the study area from Survey of India (SOI) have been used as a reference data.

1.3. Methodology

The methodology of the study is given in Figure 2, depicting the preparations of maps (land cover, city centre and road network) and analysis of urban growth.

1.4. Preparations of Land Cover Maps

False color composite (FCC) of the study area generated from red, green and near-infrared bands of the image. Different tones of red color denote natural and semi natural vegetation. Cyan color with rough texture signifies built-up area. Dark blue to a cyan tone with a smooth texture represents dry river beds. The fallow land has a greenish grey tone with a smooth texture. Bright white tone with no vegetation denote bare soil. The land cover maps have been produced from classification of Landsat images of year 2000, 2010 and 2019 using Maximum likelihood classifier (MLC). It is a parametric supervised classification algorithm. The land cover is classified into six classes i.e., built-up outside municipal limits, built-up within municipal limits, cultivated and managed areas, natural and semi natural vegetation and river course (Figures 3–5).

1.5. Analysis of Urban Growth

In this study the main focus is on the built-up classes (both built-up within municipal limits and built-up outside municipal limits). Urban growth has been quantified in terms of increase in the built-up area over a period of time. Therefore, land cover maps representing the different classes for years 2000, 2010 and 2019 have been prepared for monitoring urban growth. The growth analysis for two time periods 2000–2010 and 2010–2019 has been carried out in GIS environment using overlay operation.

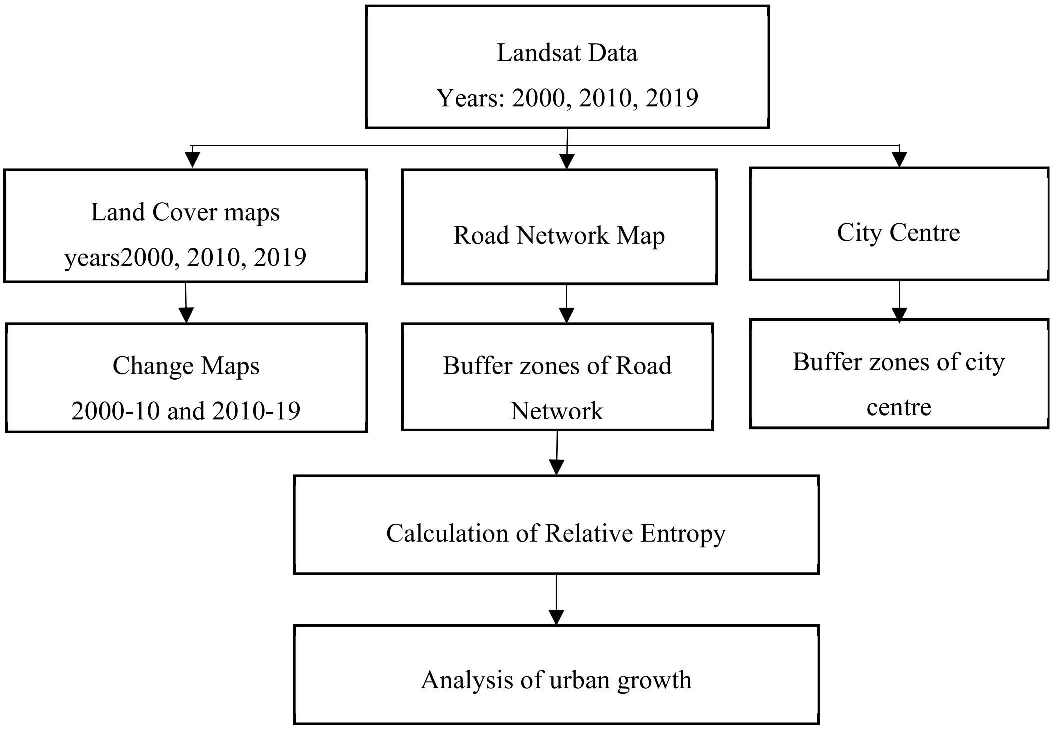

Figure 2. Methodological flowchart of the study.

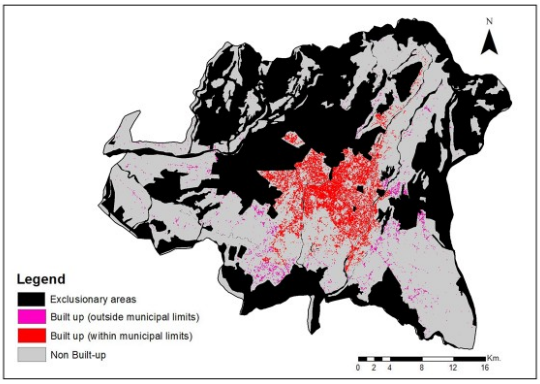

Figure 3. Land cover (2000) of the study area.

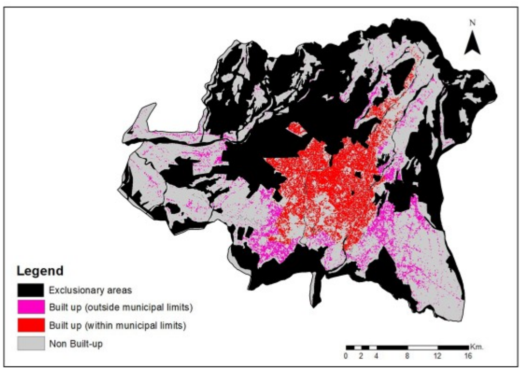

Figure 4. Land cover (2010) of the study area.

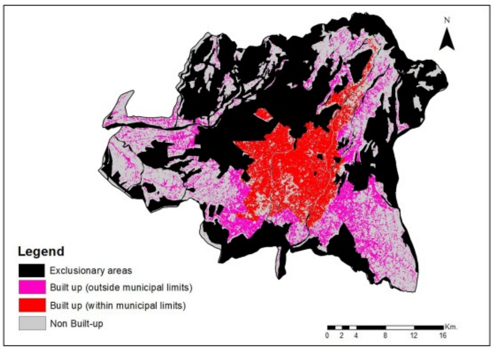

Figure 5. Land cover (2019) of the study area**.**

1.6. Generation of Road Network Map

The road network has been derived from Landsat image of year 2019, google earth and guide map. The road network map, depicts that the network is radial in nature, with the roads radiating outwards from the city center. The radiating roads are interconnected to each other by a network of roads.

1.7. Delineation of City Center

The city center has been defined as that part of the city where most of the business activities are located. In the study area the city core has been identified after consultation with the local planning authorities. The city center consists mainly the area near clock tower and General Post Office (GPO), which have formed the nucleus around which the city has grown.

1.8. Calculation of Relative Entropy:

Shannon's entropy (SE) is defined as measure of degree of randomness or spatial concentration or dispersion of a geographical variable (urban growth) (x_i) among n zones [1]. It is calculated using Equation (1).

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

where p_i is the probability of a phenomenon (variable) occurring in the ith zone. The range of entropy value is from zero to a maximum of log (n). However for comparing the entropy values, the SE is normalized between 0 to1 and is called as Relative Entropy (Equation (2)).

$$RE = SE/\log(n) \quad (2)$$

1.9. Relative Entropy with Respect to Road

Firstly, buffer zones of 200 m, 400 m, 800 m, 1600 m and 3200 m with respect to the major roads are taken in Dehradun planning area. Relative entropy with respect to road was calculated for the built-up area growth for 2000–2010 and 2010–2019 for Dehradun municipal area and outside municipal area (Figure 6).

1.10. Relative Entropy with Respect to City Centre

Buffer zones of 1000 m, 2000 m, 3000 m, 4000 m, 5000 m, 6000 m, 7000 m, 8000 m, 9000 m and 10,000 m with respect to the city centre are taken in the Dehradun planning area. Relative entropy was calculated for the built-up area growth for 2000–2010 and 2010–2019 for Dehradun municipal area and outside municipal area (Figure 7).

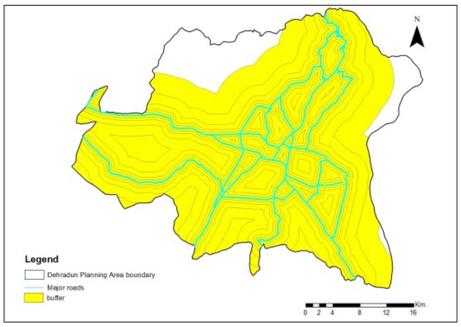

Figure 6. depicts buffer zones along roads.

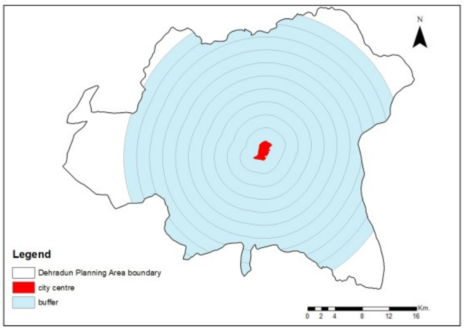

Figure 7. depicts buffer zones along city centre.

2. Results and Discussion

Maps depicting the land cover for year 2000 (Figure 3), 2010 (Figure 4), and 2019 (Figure 5) were generated. Buffer zones are also developed for analysis around the roads (Figure 6), and city centre (Figure 7). The Relative entropy (RE) calculated with respect to road network and city centre is shown in Tables 1 and 2. A set of calculations for SE and RE is shown with Equations (3) and (4).

Table 1. Calculation of RE w.r.t road network within municipal limits during 2000–2010.

Buffer Zones	Growth Area (m²)	*p*	log1/*p*	*p**log1/*p*
Zone 1 (200 m)	4,001,223.677	0.353	0.452	0.160
Zone 2 (400 m)	3,173,374.576	0.280	0.553	0.155
Zone 3 (800 m)	2,928,995.251	0.258	0.588	0.152
Zone 4 (1600 m)	1,212,356.831	0.107	0.971	0.104
Zone 5 (3200 m)	16,849.65951	0.001	2.828	0.004

$$\text{SE} = \sum_{i=1}^{5} p_i * log\frac{1}{p_i} = (0.160 + 0.155 + 0.152 + 0.104 + 0.004) = 0.574 \quad (3)$$

$$\text{RE} = \sum_{i=1}^{5} p_i * log\frac{1}{p_i}/\log_{10}(5) = 0.822 \quad (4)$$

Similarly, SE and RE were calculated for the datasets (Table 2).

Table 2. SE value for different time period w.r.t road and city core**.**

Period	Entropy w.r.t Roads	Entropy w.r.t City Core
2000–2010 within municipal limits	0.822	0.761
2010–2019 within municipal limits	0.812	0.804
2000–2010 outside municipal limits	0.945	0.831
2010–2019 outside municipal limits	0.966	0.837

In the municipal area of Dehradun during 2000–2010 and 2010–2019 period, RE w.r.t roads was 0.822 and 0.812 respectively. Outside municipal area of Dehradun during 2000–2010 and 2010–2019 RE w.r.t roads was 0.945 and 0.966 respectively. The inverse relation between developments inside the municipal rea and outside the municipal are is clearly depicted from Figures 8 and 9. It can be observed that RE w.r.t roads over a period of time in the municipal area remained constant, but outside municipal area it increased. It can also be inferred that along the roads, outside municipal area there was more uniform distribution of built-up areas. In the municipal area of Dehradun during 2000–2010 and 2010–2019 period RE w.r.t city centre was 0.761 and 0.804 respectively. Outside municipal area of Dehradun during 2000–2010 and 2010–2019 period RE w.r.t city centre were 0.831 and 0.837 respectively. It can be observed that RE w.r.t city centre in the municipal area over a period of time increased which lead to a more dispersed distribution of the built-up areas w.r.t. to city centre. The distribution of built-up areas is more compact w.r.t the city centre as compared to the distribution w.r.t to road network.

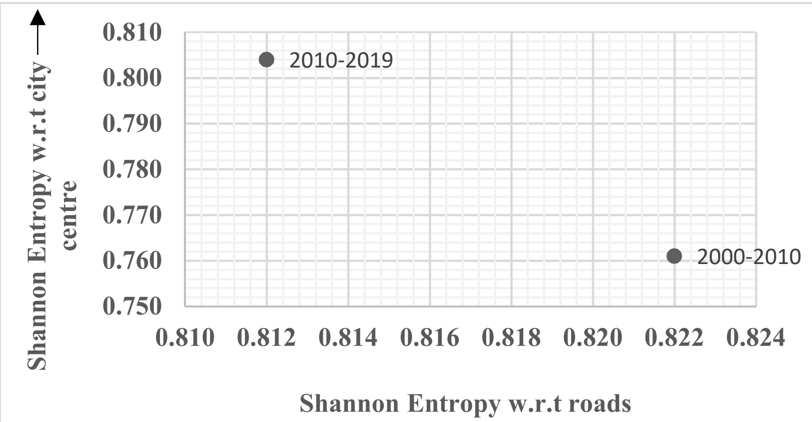

Figure 8. SE w.r.t roads and city core during 2000–2010 and 2010–2019 within municipal limits.

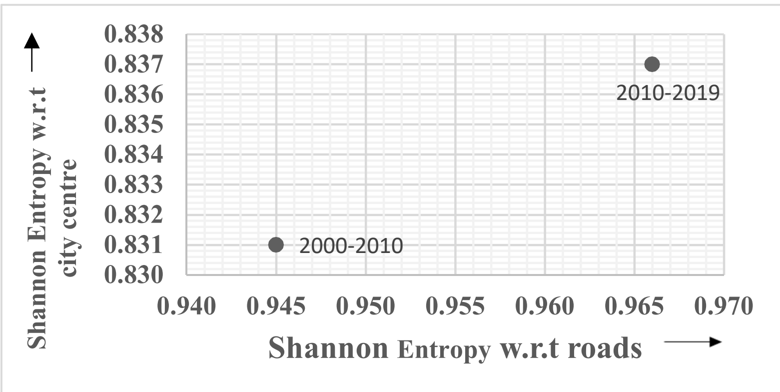

Figure 9. SE w.r.t roads and city core during 2000–2010 and 2010–2019 outside municipal limits.

3. Conclusions

The study reveals that RE can help in quantifying and analyzing the urban growth pattern w.r.t. to road network, city centre and other factors which influence the urban growth process. Higher values of RE indicate higher levels of urban sprawl whereas lower values indicate compactness. The RE can also help in validating the urban growth simulation results, by comparing the simulated growth with the actual growth patterns.

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Conflicts of Interest: The authors declare no conflict of interest.

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