Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

URBAN EXPANSION ASSESSMENT BY USING REMOTELY SENSED DATA AND THE RELATIVE SHANNON ENTROPY MODEL IN GIS: A CASE STUDY OF TRIPOLI, LIBYA

Abubakr A. A. ALSHARIF
University Putra Malaysia, 43400, UPM, Serdang, Malaysia
abubaker1140@yahoo.co.uk

Biswajeet PRADHAN*
University Putra Malaysia, 43400, UPM, Serdang
biswajeet24@gmail.com

Shattri MANSOR
University Putra Malaysia, 43400, UPM, Serdang, Malaysia
shattri@gmail.com

Helmi Zulhaidi Mohd SHAFRI
University Putra Malaysia, 43400, UPM, Serdang, Malaysia
Hzms04@gmail.com

Abstract
Urban growth is a spatial dynamic phenomenon that indicates population growth, economic expansion, city importance level, and so on. The use of current and historical data in urbanization analysis is necessary in urban spatial studies and future urban planning. This research aims to study, examine, and assess the urban expansion of Tripoli spatially and temporally by using remotely sensed data, geographic information systems (GIS), and the statistical relative Shannon entropy model. Remotely sensed data (four satellite images from 1984, 1996, 2002, and 2010) and GIS were used to determine the extent of urban area and urban growth in Tripoli in five different directions. Shannon's entropy model was implemented to analyze and assess urban expansion trends as a process and pattern in the study area. Results show that the Tripoli metropolitan area has a high level of sprawl along its urban expansion history. The hypothesis employed for Shannon's entropy zone division produces good insights on overall urban growth, urban growth direction, and specific urban growth over time. The obtained results provide good guidance for modeling urban sprawl processes, understanding urbanization causative factors, and predicting future urban patterns. Furthermore, the findings of current paper can be used by decision makers and urban planners to identify past and present urban expansions tendencies to prepare for future urban demands.
Keywords: Urban sprawl; Shannon's entropy; remote sensing; GIS; Tripoli.

1. INTRODUCTION

Rapid urbanization has been recorded in developing countries during the last century, thus providing an indication of increasing urban issues and environmental problems in such areas (Angel et al., 2005; Kumar et al., 2007). The rapid economic development of various developing countries has caused noticeable changes in urban landscapes (Yeh, Xia, 2001). Urbanization progression is considered the most prominent driver of land cover change in the history of human civilization (Deka et al., 2010; Weng, 2001). Uncontrolled population growth causes uncontrolled urban sprawl, which leads to serious problems such as food insufficiency, illegal settlements, environmental pollution, environmental deterioration, occupation of fertile farming lands, forest destruction, reduction of surface water bodies, and permanent changes in land cover (Al-sharif et al., 2013a; Benfield et al., 1999; Grimm et al., 2000; Hedblom and Söderström, 2008; Maktav et al., 2005; Pathan et al., 1991; Weng et al., 2007). Information on the amount and process of urban expansion is important for conducting land and water resource management, facility allocation, urban planning, and so on. Urban sprawl assessment, prediction, and monitoring represent the necessary information for urban development plans. Urban planners require handy tools to achieve smart and balanced growth, examine and understand current land-use status, and measure future requirements (Alpopi et al., 2011; Baptista de Silva, et al.,2012; Huang, et al.. 2009; Jat, et al.. 2008; Wang and Mountrakis, 2010). Sandhya and Joshi (2013) reported that studying and analyzing changes and monitoring different time series are difficult by using traditional techniques of surveying. However, remote sensing systems are practical tools for collecting data in a quick and cost effective manner. In urban studies, analyzing and understanding the behavior of spatiotemporal changes in urban expansions and patterns are needed. The urbanization process can be analyzed by using geographic information systems (GIS), remote sensing, and the ground information of the study area (Al-shalabi, et al., 2013a, b; Al-sharif and Pradhan, 2014a, 2014b). Furthermore, detecting and mapping forms of urban sprawl patterns on landscapes can be achieved efficiently by using the aforementioned approaches (Barnes, et al., 2001; Bhatta, 2009; Sui, 1998). However, researchers have reported that urban sprawl lacks a specific definition (Bhatta, et al., 2010b). Nonetheless, urban sprawl can be defined simply as the quantity of urbanized area and the amount of its dispersal in the study area landscape.

Thus, areas with impervious surfaces increase in urban sprawl and the further spreading of impervious surfaces corresponds to higher intensity sprawl (Jaeger, et al., 2010). The definition of urban sprawl can be used to describe and explain both situations, that is, the process (the change of urban sprawl in a landscape) and pattern (the amount of urban sprawl in a landscape) (Sarvestani, et al., 2011). Several

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

measures and factors are used to identify and quantify urban sprawl, although many of these measures exhibit several limitations (Bhatta, et al., 2010b; Ramachandra, et al., 2013). Shannon's entropy was used for several statistical data analyses. Shannon's entropy technique can verify and identify the disparity of urban sprawl and urban areas (Alabi, 2009; Kumar, et al., 2007; Lata et al., 2001; Li and Yeh, 2004; Sudhira, et al., 2004; Yeh and Xia, 2001).

The aforementioned model is commonly used in urban geographic studies. Nevertheless, all former urban research have illustrated Shannon's entropy method in different spatial zones divisions either to analyze the urban patterns (Yeh and Xia, 2001) or to identify the urban sprawl of a specific area for a specific period (Kumar, et al., 2007).However, entropy divisions have not considered sprawl direction, sprawl variation, and distance to central business districts (CBDs).

The objective of this research is to study and examine the urban sprawl of Tripoli spatially and temporally by using remotely sensed data, GIS, and statistical relative Shannon entropy model. In this work, the satellite imageries of four periods (1984, 1996, 2002, and 2010) were used to identify the land-use class of urbanized regions in the study area. This work investigated urban sprawl patterns in Tripoli by using Shannon's entropy method and described the past urban growth conditions of the city. The study area was located in a region that has undiscovered and unstudied urban behavior. The zone divisions employed in this study differ from existing procedures to assess urban growth in different directions, identify urban growth variations, and determine urban sprawl in specific zone.

2. STUDY AREA

Tripoli is the political, financial, and commercial center of Libya. Tripoli is over a thousand years old and is located along the Mediterranean coast in the northwestern part of Libya between latitudes 32o 36' 18" N and 32o 54' 17" N and longitudes 12o 54' 04 " E and13o 26' 38" E (Figure 1). Tripoli covers an area of approximately 1143.73km2 with a population of more than 1.3 million individuals.

The Tripoli metropolitan area has become increasingly active economically, particularly in last decade after the lifting of international sanctions. Despite the presence of governmental urban plans, urban growth and development have been spontaneous, uncontrolled, and haphazard.

The implementation of urban plans is affected by corruption, political situations, and economic conditions; thus, urban expansion mainly depends on social trends regardless of the urban plans of the government.

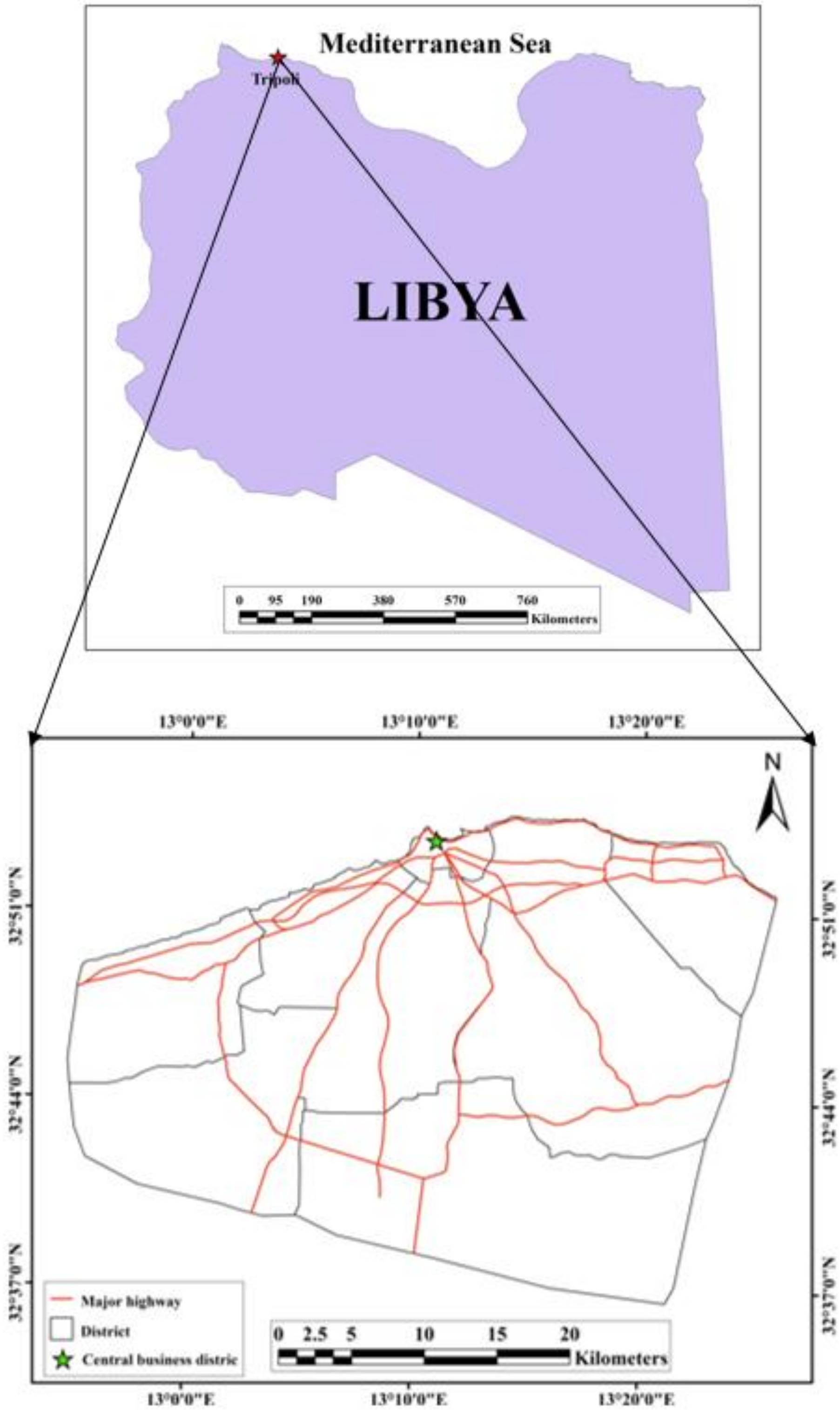


FIGURE 1 - AREA OF STUDY.

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

3. DATA AND METHODOLOGY

Four satellite imageries were used in this study (Table 1). The 2002Landsat satellite images and SPOT 5 image were obtained from Biruni Remote Sensing Centre, Libya. The 2010 SPOT 5 image was obtained from the Libyan Centre for Remote Sensing and Space Science. Unfortunately, the available data in Libya is limited and we did not have any access to imageries for equal periods.

TABLE 1 - LIST OF USED SATELLITE IMAGERIES

Sensor type	Acquisition year	Spatial resolution
LANDSAT– TM	1984	30m
LANDSAT– TM	1996	30m
SPOT 5	2002	2.5m
SPOT 5	2010	5m

Many techniques have been developed to analyze, process, and extract information from remotely sensed data. The specific algorithms or methods to be employed depend on the purposes of the study. ARC/INFO GIS software package was used for image processing, classified land-use map generation, spatial analysis, and map preparation. The imageries were collected as standard products that are radiometrically and geometrically corrected. The image overlay has a low accuracy because the standards used by image supplying agencies are different. To resolve this problem, imageries were rectified and georeferenced during the pre-processing step to achieve high overlay accuracy. In this study, the used images have different spatial resolutions. A simple approach that can be used to fix this difficulty is the resampling of imageries that have high resolutions to match imageries with low resolutions. However, the resampling process will decrease the spatial detail. Thus, the pixel sizes of the imageries were unchanged to avoid probable changes in the precision of the classification process with various radiometric spectral and spatial resolutions. A maximum likelihood supervised classification method was then executed to the imageries at the classification process phase. However, this work focuses only on urban expansion; thus, the classification process was performed by considering two important classes only: non-urban areas and urban areas that are considered sufficient(Bhatta, 2009). Thereafter, the central point of Tripoli that matches the CBD and represents the starting point of the urbanization process in the study area history was determined. Consequently, 51vector map zones of the study area were used to clip classified imageries and to divide the imageries into 51 zones (Figure 2). The urban growth and area for all zones and for every temporal point were calculated with the zone border by multiplying the pixel size with the pixel quantity in every particular zone.

However, different zone divisions were applied to calculate the entropy. Sudhira et al. (2004) used buffer zones about city centers and roads, which are considered important factors in the study and measurement of urban growth. Bhatta, et al., (2010a) used different approaches to analyze the patterns and processes of urban growth by dividing the study area into eight zones (pie sections) to represent eight directions. Fan, et al., (2009) used two designed transects along the urban expansion axes of the study area. The most used zone division is based on administrative divisions and its boundaries (Bhatta, 2009; Punia and Singh, 2012; Yue, et al., 2013) or circular buffer zones about the center of the study area (Araya and Cabral, 2010; Sarvestani, et al., 2011). The model used in this research (relative Shannon's entropy) is unrestricted by the number of divisions used and has high flexibility on how the study area is considered or divided (Bhatta, et al., 2010a).The approach used in this research involves the division of the study area into five pie sections to consider and assess the urban sprawl direction. To consider the effect of distance from the CBD and determine the sprawl in each zone, the five sections need to be further subdivided (Figure 2). This approach will provide further detail on the urban growth process and its patterns in the whole study area and for each particular zone at different times.

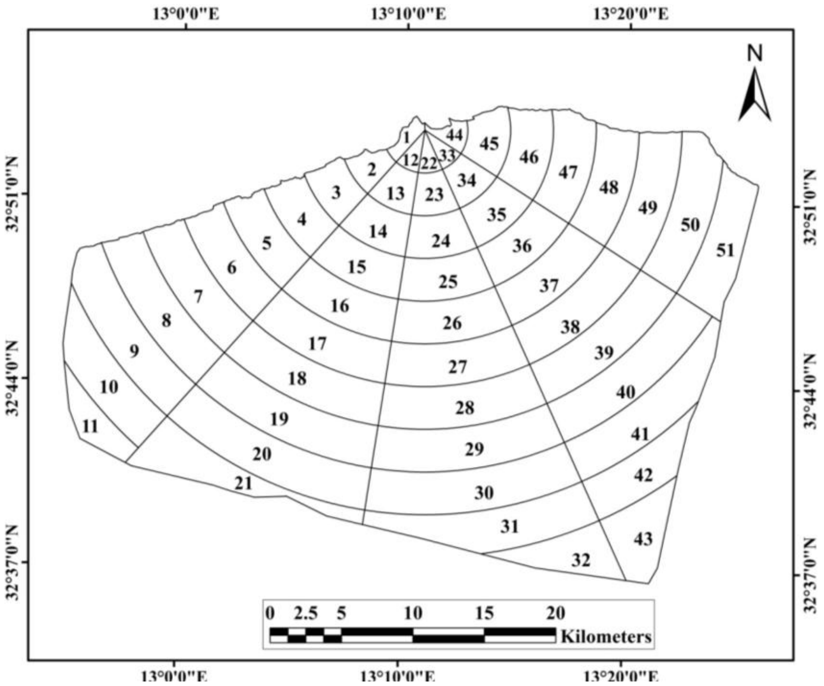


FIGURE 2 -ZONES DIVISIONS OF STUDY AREA.

4. ANALYSIS AND RESULTS

4.1. Urbanized area and urban growth

The satellite images were classified into two classes: non-built up and built-up area for the four temporal dates. Subsequently, the classified imageries were abstracted and simplified for visualizing the urban extents (Figure 3). The classified maps were assessed by using the confusion matrix method. The accuracy assessment of real ground reference polygons were compared with the classified output

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

maps. Overall accuracy values of 91%, 93.2, 95.7%, 94% and kappa coefficients values of 0.89, 0.93, 0.94, and 0.93 were achieved for classified maps in 1984, 1996, 2002, and 2010, respectively. Figure 3 shows that the urban expansion of Tripoli has different signatures. The built-up areas in some zones are dense, whereas other zones have wide-open spaces between urbanized areas. Moreover, the edges between the non-urban and urban areas are clear in some regions, whereas the two classes are close to each other in other areas. Furthermore, the spatial patterns of the urbanization process of every zone changes with the period with various behavioral types. The infill of the non-built-up areas between previously urbanized areas can be seen, thus leading to increased compactness level. The classified imageries show that the study area is growing in dispersed mode. However, quantitative measures that summarize the urban growth properties of study area are required to illustrate the different urban patterns clearly, compare zones, and analyze the transformation of urban patterns over time.

Figure 4 shows the amount of built-up area for the whole study area for each temporal point and directly demonstrates the status of urban areas in the study area. Column graphs of built-up area growth in each zone are illustrated in Figure 5. These graphs are helpful for identifying built-up areas that change in each zone specifically. Figures 3, 4, and 5 provide clear basic information about the built-up areas in Tripoli and the changes of these areas over time in different zones and directions. The expansion rate of urbanized areas increases dramatically along the study area history, particularly in the last decade, wherein Tripoli had a high urban expansion ratio. These findings reflect the overall rapid increment of urban expansion; therefore, the study area needs further analysis.

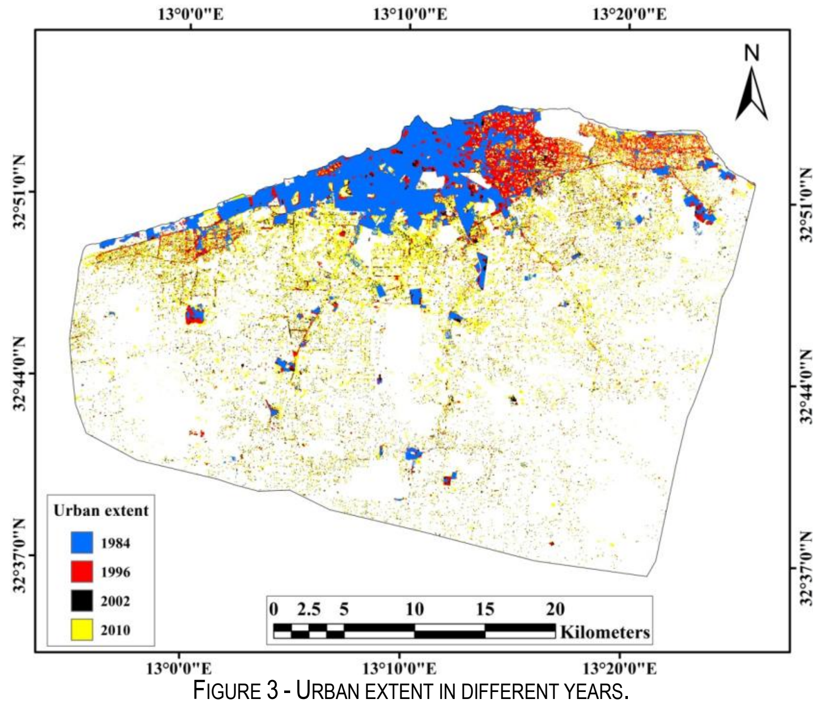


FIGURE 3 - URBAN EXTENT IN DIFFERENT YEARS.

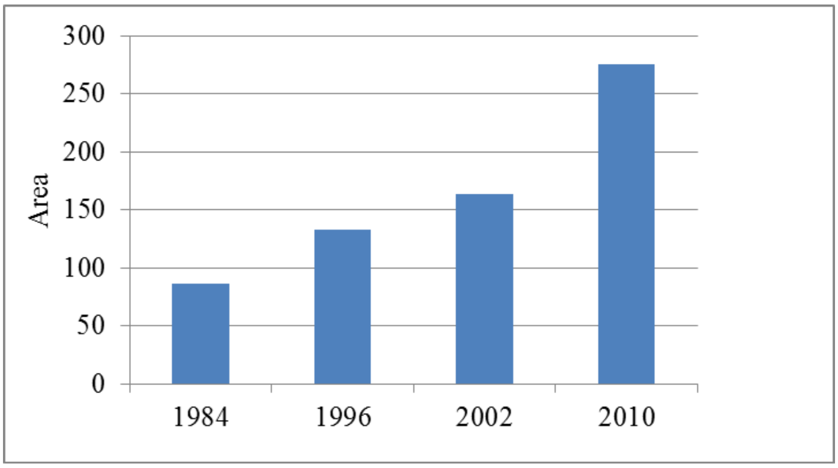
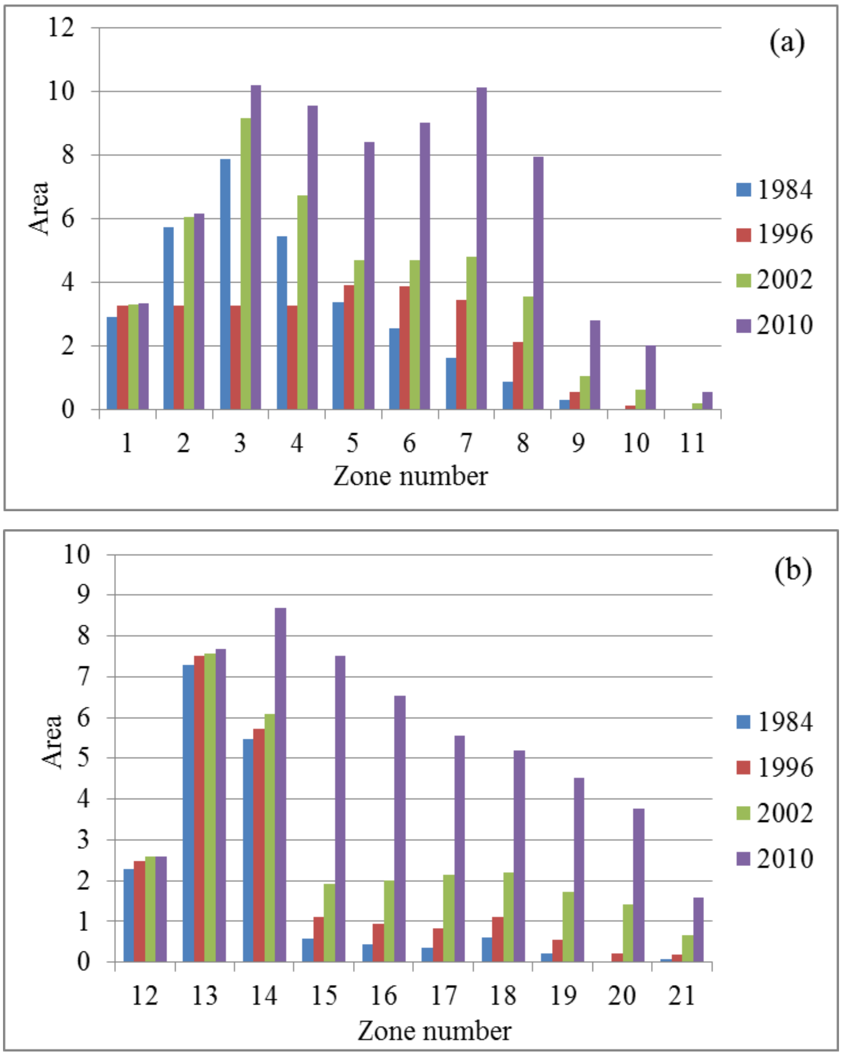


FIGURE 4 - OVERALL BUILT UP AREA IN DIFFERENT YEARS IN (KM2).



Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

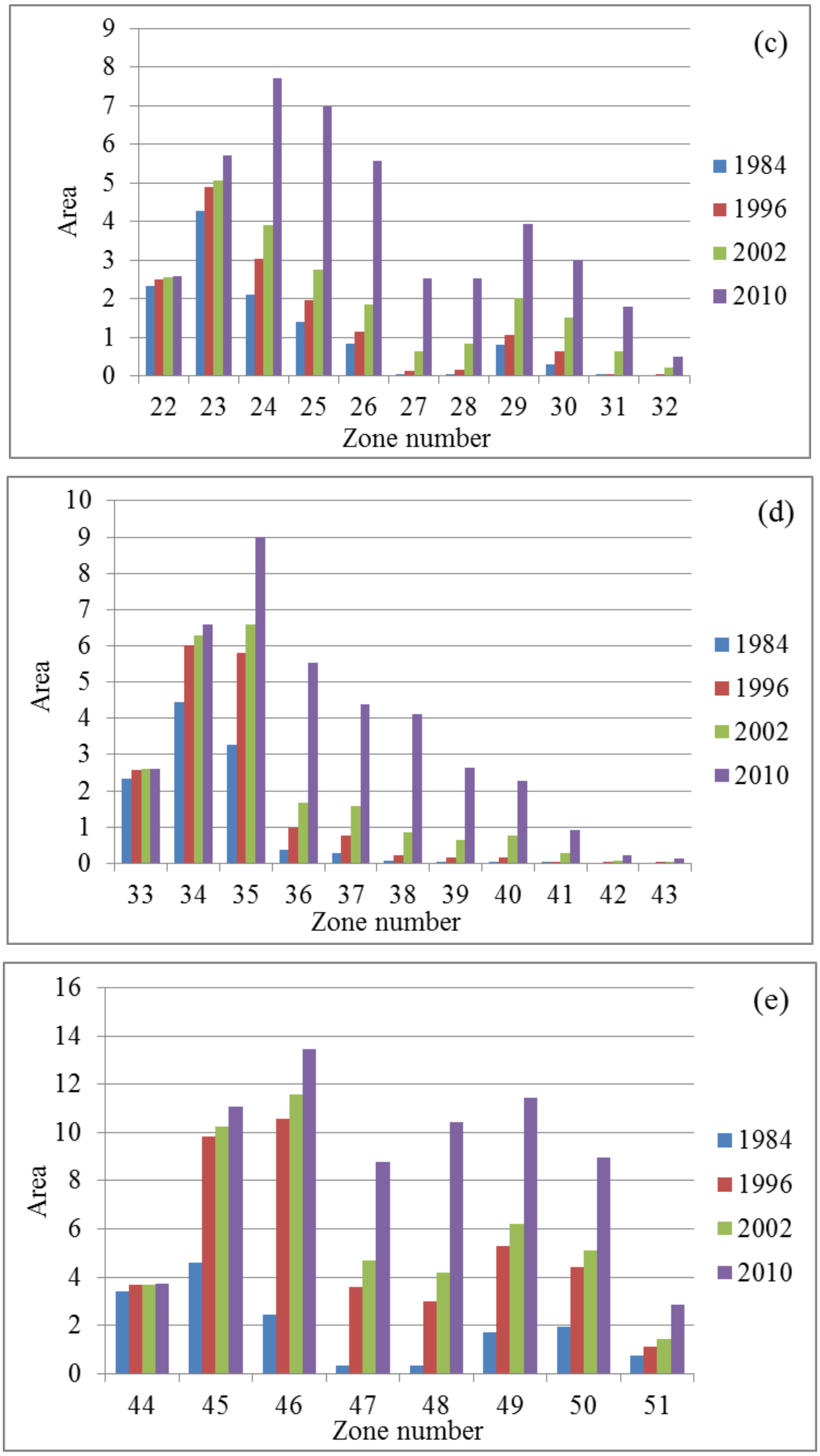


FIGURE 5 - BUILT UP AREA IN EACH ZONE IN DIFFERENT YEARS IN (KM2); (A) ZONES WITHIN 1ST DIRECTION GROWTH; (B) ZONES WITHIN 2ND DIRECTION GROWTH; (C) ZONES WITHIN 3RD DIRECTION GROWTH; (D) ZONES WITHIN 4TH DIRECTION GROWTH; (E) ZONES WITHIN 5TH DIRECTION GROWTH.

4.2. Shannon's entropy of urban expansion

In this step, the relative Shannon entropy technique was used. This technique is widely used to study urban sprawl phenomena. As a good measure of spatial dispersion or concentration, Shannon's entropy model can be used to analyze and assess any geographical variable. This technique is able to reveal the configuration and orientation of spatial patterns and can analyze spatial variables within a GIS (Kumar, et al., 2007; Sudhira, et al., 2004; Yeh and Xia, 2001; Devkota, et al., 2012; Pourghasemi, et al., 2012).

The level of urban sprawl is recognized by the entropy value. The relative entropy value starts from zero to one. A zero value denotes the compact distribution of urban areas, whereas values near one indicate the dispersed distribution of urban areas. Thus, higher entropy values indicate higher sprawl occurrences. In this work, the relative Shannon entropy values were calculated by using following equation:

$$Hn= \sum_{i}^{n} P_i log\left(\frac{1}{P_i}\right) /\log(n) ,$$

Where Pi is the probability or the percentage of the variable occurring within zone i (i.e., percentage of urban area in the ith zone determined by the urban area in the ith zone/zone area), and n = total zones number (i.e., 51).

Table 2 around here

TABLE 2 - OVERALL SHANNON'S ENTROPY OF STUDY AREA IN DIFFERENT YEARS

Year	1984	1996	2002	2010
Entropy (H_n)	0.74	0.79	0.83	0.90

Table 2 demonstrates that the overall values of the relative entropy in different years are larger than the halfway point, that is, 0.5. Thus, we can confidently say that the urban expansion in Tripoli is sprawling. Moreover, the sprawling trend is increasing. These findings are strong and clear evidence that the general urban growth process requires a clear urban planning policy.

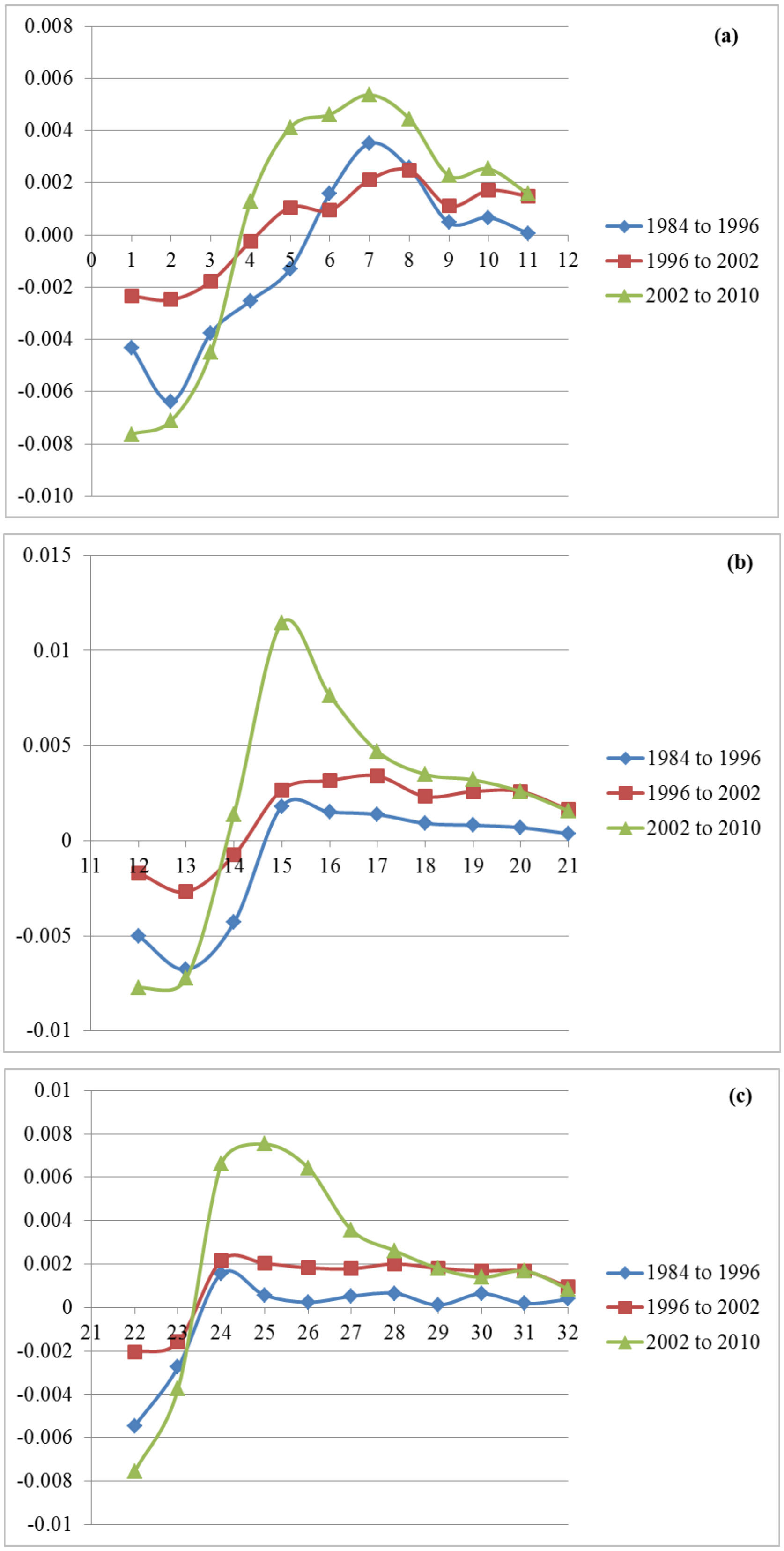
To understand and assess the urban sprawl process in every zone within each direction along the study area history (from 1984 until 2010), the calculated values of relative entropy in older dates are subtracted from relative entropy values in newer dates in each zone. Higher positive values reflect higher urban sprawl rates and more dispersed urban growth. Higher negative values indicate lower urban sprawl rates and higher compactness levels in zones or crowded urban areas.

Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

Theoretical and Empirical Researches in Urban Management

Volume 10 Issue 1 / February 2015

Figure 6 depicts the variation of relative entropy and spatiotemporal urban sprawl behavior in the study area. Figure 6 shows that the change rate values of relative entropy within the 1st direction have negative values in Zones 1, 2, 3, and 4 in all three periods. However, the situation changes in Zone 5 to Zone 11; these zones have a positive change rate of entropy values (i.e., sprawl increase). The highest increase rate of sprawl is clear between 2002 and 2010, particularly from Zone 5 to Zone 8. In the2nd direction, one can note that Zones 12, 13, and 14 become increasingly compact. The rest of the zones within the 2nd direction have increased rate of sprawl in all times. Furthermore, the dramatic increase of sprawl is recorded in Zones 15, 16, and 17. However, for the 3rd direction the findings demonstrate that Zones 22 and 23 will become more compact with increasing time. Other 3rd direction zones have almost similar sprawl increase rates from 1996 to 2002. However, Zones 24, 25, 26, and 27 face significant sprawl increase from 2002 to 2010. The urban sprawl in the fourth direction exhibits almost similar trends that occur in the second and third directions. However, from 1984 to 1996, the largest entropy value occurred in the 34th, 35th,and 36th zones and then decreased gradually by moving away from the CBD. Nonetheless, the sprawl tendency in the 5th direction recorded different behavior history compared with the other four directions. The urban sprawl rate was the greatest from 1984 to 1996 in all zones within the 5th direction, except the 44th zone, which is adjacent to the CBD. Nevertheless, the rate of sprawl decreased obviously and became low in Zone 47 to Zone 51 from 1996 to 2002. Thereafter, the change rate of the entropy value increases again from 2002 but is still lower than the values recorded from 1984 to 1996. The general urban sprawl trend in the whole study area is quite similar. However, the results of analysis illustrate that CBD adjacent zones have the lowest relative entropy change rate; particularly from 2002 to 2010.These findings reflect the high compactness of urban zones. The urban sprawl rate increases with increasing distance from the CBD. The sprawl increase rate becomes extreme in zones that include urban fringes. Thereafter, the sprawl decreases and becomes low in zones that are near the study area border. The effect of the direction of the urban sprawl process in Tripoli differs slightly in the 1st, 2nd, 3rd, and 4thdirections. Only the 5th direction showed different fluctuating sprawl changes; the sprawl was the highest from 1984 to 1996 and decreased to become the lowest from 1996 to 2002.Thereafter, the sprawl jumped again from 2002 to 2010 but still less than the sprawl from 1984 to 1996. The results show that the study area experiences general urban sprawl trends in the majority of directions and zones. However, these recorded urban sprawls are different and influenced by sprawl direction and distance from CBD. This research finding shows that the relative Shannon entropy model can be implemented to investigate the sprawl of urbanization phenomenon in Tripoli. Furthermore, the results demonstrate the relations between urban sprawl and its direction, as well as the distance from CBD in different periods, thus providing clear and specific spatiotemporal sprawl descriptions.


(a)
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
0 1 2 3 4 5 6 7 8 9 10 11 12
1984 to 1996
1996 to 2002
2002 to 2010
(b)
0.015
0.01
0.005
0
-0.005
-0.01
11 12 13 14 15 16 17 18 19 20 21
1984 to 1996
1996 to 2002
2002 to 2010
(c)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
21 22 23 24 25 26 27 28 29 30 31 32
1984 to 1996
1996 to 2002
2002 to 2010

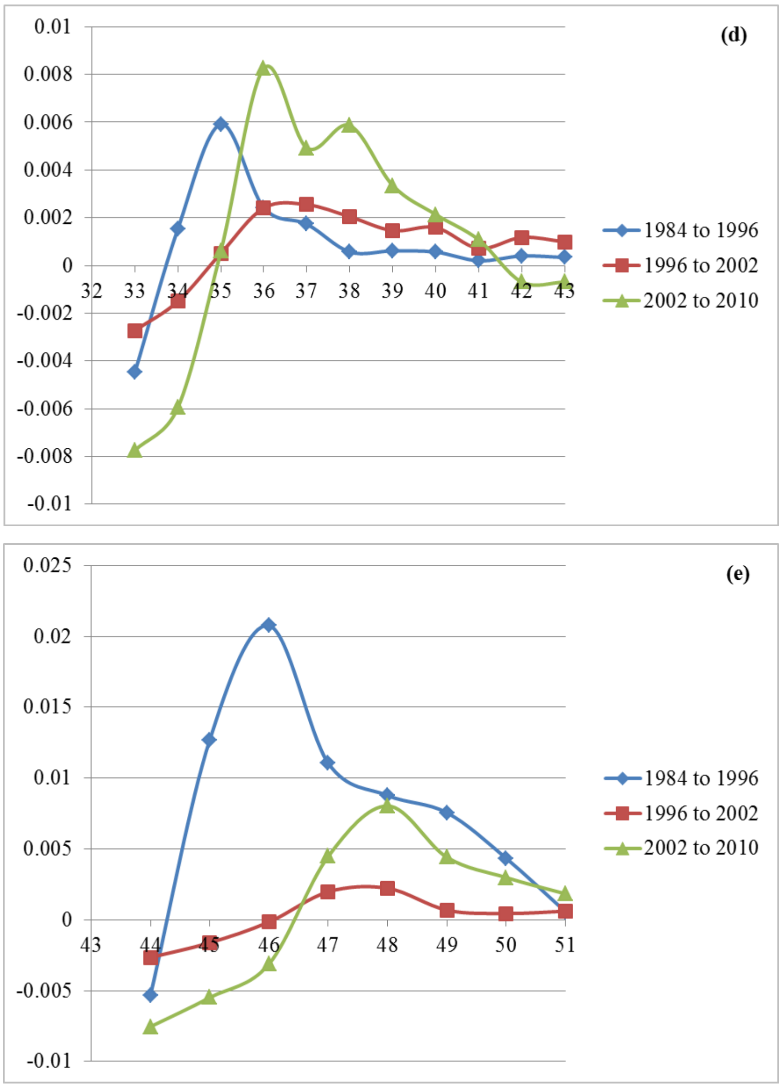


FIGURE 6: VARIATION OF THE SPRAWL IN DIFFERENT GROWTH DIRECTIONS; (A) IN 1ST DIRECTION; (B) IN 2ND DIRECTION; (C) IN 3RD DIRECTION; (D) IN 4TH DIRECTION; (E) IN 5TH DIRECTION.

5. DISCUSSIONS AND CONCLUSIONS

The study area was divided into 51 zones because urban growth had dissimilar patterns in all directions. Furthermore, the study area is bordered by sea in north direction. The study area was divided in both circular (incomplete circles) and pie sections zones. This division approach increases the number of zones and would provide an improved insight into the urban expansion of the study area. The division method considers the effect of the distance to the CBD from each zone and urban growth direction; this approach is preferred by urban planners and decision makers. Moreover, the distance to the CBD is a significant factor because the density of urbanized area changes with this distance. The level of sprawl in each zone is different from other zones. Furthermore, the sprawl varies within each direction, thus leading to different patterns of urban growth. Hence, different policies are needed to address different patterns in each particular area effectively. More zones leads to more details, thus resulting in reliable results. The method applied in this research is based on the built-up area density in every zone. However, the extent of areas existing for urban expansion in each zone is different. Thus, the proportion of urbanized areas in a zone should be used by eliminating restricted and non-developable areas. Nevertheless, the non-developable areas are neglected because these areas are small compared with the overall study area. The results show that the relative Shannon entropy measure is a powerful tool approach for assessing urban growth (as process and as pattern) in different analysis levels (periods, zones, and direction). In this study, the simple approach was used to study the urban sprawl. The simple approach is handy in many instances, particularly in developing countries that have unplanned growth and lack data. Furthermore, planners or decision makers prefer simple diagnostic techniques that necessitate minimum data input. Hence, the simple method will be useful in terms of its simple process of extracting past data from remotely sensed data and in terms of the statistical method applied. In summary, this research used remotely sensed data and GIS to analyze the urban expansion process and its patterns in Tripoli, Libya, by using the relative Shannon entropy statistical model. The results of analysis provide many figures for understanding and assessing the urban sprawl and urban growth in Tripoli. The results also confirm that the use of the model, remotely sensed data, and GIS is practical for identifying urban growth/sprawl patterns and their general trends. The analysis shows that the urban growth of Tripoli is sprawling in the three periods. This finding indicates that the situation will become worse over time. The different hypothesis used for zone division results in good in sights for understanding overall urban growth, urban growth direction, and specific urban growth. Finally, this study presents an exhaustive assessment of urban sprawl status for the studied area. The obtained results can be used by decision makers and planners to recognize the present and past urban expansion to prepare and plan for future urban demands.

ACKNOWLEDGEMENTS

The first author greatly acknowledges the Libyan government for providing data and financial support. Thanks to the anonymous reviewers for their helpful comments.

REFERENCES

Al-shalabi, M., Billa, L., Pradhan, B., Mansor, S., (2013a) Modeling urban growth evolution and land-use changes using GIS based Cellular Automata and SLEUTH models: The case of Sana'a metropolitan city, Yemen. *Environmental Earth Sciences, 70*(1), 425-437.

Al-shalabi, M., Pradhan, B., Billa, L., Mansor, S., (2013b) Manifestation of remote sensing data in modeling urban growth pattern using the Sleuth model and Brute Force calibration: a case study of Sana'a City, Yemen. *Journal of the Indian Society of Remote Sensing, 41*(2), 405–416.

Al-sharif, A. A. A., Pradhan, B., (2014a). Urban sprawl analysis of Tripoli Metropolitan City (Libya) using remote sensing data and multivariate logistic regression model. *Journal of the Indian Society of Remote Sensing*, *42*(1), 149-163.

Al-sharif, A. A. A., Pradhan, B., (2014b). Monitoring and predicting land use change in Tripoli Metropolitan City using an integrated Markov Chain and Cellular Automata models in GIS. *Arabian Journal of Geosciences, 7(10):*4291-4301.

Al-sharif, A. A., Pradhan, B., Shafri, H. Z. M., and Mansor, S. (2013a). Spatio-temporal Analysis of Urban and Population Growths in Tripoli using Remotely Sensed Data and GIS. *Indian Journal of Science & Technology, 6*(8), 5134-5142.

Alabi, M. O. (2009). Urban sprawl, pattern and measurement in Lokoja, Nigeria. *Theoretical and Empirical Researches in Urban Management, 4*(13), 158-164.

Alpopi, C., Manole, C., and Colesca, S. E. (2011). Assessment of the sustainable urban development level through the use of indicators of sustainability. *Theoretical and Empirical Researches in Urban Management, 6*(2), 78-87.

Angel, S., Sheppard, S. C., Civco, D. L., Buckley, R., Chabaeva, A., Gitlin, L., et al. (2005). The dynamics of global urban expansion. *Transport and Urban Development Department, The World Bank, 1*(2), 3.

Araya, Y. H., and Cabral, P. (2010). Analysis and modeling of urban land cover change in Setubal and Sesimbra, Portugal. *Remote Sensing, 2*(6), 1549-1563.

Baptista de Silva, J., Faria de Deus, R., and Tenedório, J. A. (2012). Paying as the urban areas growimplementing and managing urban development charges using a GIS application. *International Journal of Geographical Information Science, 26*(9), 1689-1705.

Barnes, K. B., Morgan III, J. M., Roberge, M. C., and Lowe, S. (2001). Sprawl development: its patterns, consequences, and measurement. *Towson University, Towson*, 1-24.

Benfield, F. K., Raimi, M. D., and Chen, D. D. (1999). *Once there were greenfields: How urban sprawl is undermining America's environment, economy and social fabric.* Washington: The Natural Rrsources Defense council.

Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: a case study of Kolkata, India. *International Journal of Remote Sensing, 30*(18), 4733-4746.

Bhatta, B., Saraswati, S., and Bandyopadhyay, D. (2010a). Quantifying the degree-of-freedom, degree-of-sprawl, and degree-of-goodness of urban growth from remote sensing data. *Applied Geography, 30*(1), 96-111.

Bhatta, B., Saraswati, S., and Bandyopadhyay, D. (2010b). Urban sprawl measurement from remote sensing data. *Applied Geography, 30*(4), 731-740.

Deka, J., Tripathi, O. P., and Khan, M. L. (2010). Urban growth trend analysis using Shannon Entropy approach–A case study in North-East India. *International Journal Of Geomatics And Geosciences 2*(4), 1072-1078.

Devkota, K. C., Regmi, A. D., Pourghasemi, H. R., Yoshida, K., Pradhan, B., Ryu, I. C., Dhital, M. R., Althuwaynee, O. F. (2013). Landslide susceptibility mapping using certainty factor, index of entropy and logistic regression models and their comparison at a landslide prone area in Nepal Himalaya. *Natural Hazards, 65*(1), 135-165.

Fan, F., Wang, Y., Qiu, M., and Wang, Z. (2009). Evaluating the Temporal and Spatial Urban Expansion Patterns of Guangzhou from 1979 to 2003 by Remote Sensing and GIS Methods. *International Journal of Geographical Information Science, 23*(11), 1371-1388.

Grimm, N. B., Morgan Grove, J., Pickett, S. T., and Redman, C. L. (2000). Integrated Approaches to Long-TermStudies of Urban Ecological Systems. *BioScience, 50*(7), 571-584.

Hedblom, M., and Söderström, B. (2008). Woodlands across Swedish urban gradients: Status, structure and management implications. *Landscape and Urban planning, 84*(1), 62-73.

Huang, B., Zhang, L., and Wu, B. (2009). Spatiotemporal analysis of rural–urban land conversion. *International Journal of Geographical Information Science, 23*(3), 379-398.

Jaeger, J. A. G., Bertiller, R., Schwick, C., and Kienast, F. (2010). Suitability criteria for measures of urban sprawl. *Ecological Indicators, 10*(2), 397-406.

Jat, M. K., Garg, P., and Khare, D. (2008). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation, 10*(1), 26-43.

Kumar, J. A. V., Pathan, S. K., and Bhanderi, R. J. (2007). Spatio-temporal analysis for monitoring urban growth–a case study of Indore city. *Journal of the Indian Society of Remote Sensing* Retrieved 1, 35

Lata, K. M., Prasad, V. K., Badarinath, K., Raghavaswamy, V., and Rao, C. H. S. (2001). Measuring urban sprawl: a case study of Hyderabad. *GIS development, 12*(5).

Li, X., and Yeh, A. G. O. (2004). Analyzing spatial restructuring of land use patterns in a fast growing region using remote sensing and GIS. *Landscape and Urban planning, 69*(4), 335-354.

Maktav, D., Erbek, F., and Jürgens, C. (2005). Remote sensing of urban areas. *International Journal of Remote Sensing, 26*(4), 655-659.

Pathan, S., Shukla, V., Patel, R., Patel, B., and Mehta, K. (1991). Urban land use mapping: A case study of ahmedabad city and its environs. *Journal of the Indian Society of Remote Sensing, 19*(2), 95-112.

Pourghasemi, H.R., Mohammadi, M., Pradhan, B. (2012). Landslide susceptibility mapping using index of entropy and conditional probability models at Safarood Basin, Iran. *Catena, 97*, 71-84. http://dx.doi.org/10.1016/j.catena.2012.05.005

Punia, M., and Singh, L. (2012). Entropy Approach for Assessment of Urban Growth: A Case Study of Jaipur, INDIA. *Journal of the Indian Society of Remote Sensing, 40*(2), 231-244.

Ramachandra, T., Bharath, H., and Sowmyashree, M. (2013). Analysis of Spatial Patterns of Urbanisation Using Geoinformatics and Spatial Metrics. *Theoretical & Empirical Researches in Urban Management, 8*(4).

Sandhya, K. G., and Joshi, U. B. (2013). Estimation of variables explaining urbanization concomitant with land-use change: a spatial approach. *International Journal of Remote Sensing, 34*(3), 824-847.

Sarvestani, M. S., Ibrahim, A. L., and Kanaroglou, P. (2011). Three decades of urban growth in the city of Shiraz, Iran: A remote sensing and geographic information systems application. *Cities, 28*(4), 320-329.

Sudhira, H., Ramachandra, T., and Jagadish, K. (2004). Urban sprawl: metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation, 5*(1), 29-39.

Sui, D. Z. (1998). GIS-based urban modelling: practices, problems, and prospects. *International Journal of Geographical Information Science, 12*(7), 651-671.

Wang, J., and Mountrakis, G. (2010). Developing a multi-network urbanization model: A case study of urban growth in Denver, Colorado. *International Journal of Geographical Information Science, 25*(2), 229-253.

Weng, Q. (2001). A remote sensing? GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *International Journal of Remote Sensing, 22*(10), 1999-2014.

Weng, Q., Liu, H., and Lu, D. (2007). Assessing the effects of land use and land cover patterns on thermal conditions using landscape metrics in city of Indianapolis, United States. *Urban Ecosystems, 10*(2), 203-219.

Yeh, A. G. O., and Xia, L. (2001). Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. *Photogrammetric engineering and remote sensing, 67*(1), 83-90.

Yue, W., Liu, Y., and Fan, P. (2013). Measuring urban sprawl and its drivers in large Chinese cities: The case of Hangzhou. *Land Use Policy, 31*(0), 358-370.