Urban Spatial Growth and Land Use Change in Riyadh: Comparing Spectral Angle Mapping and Band Ratioing Techniques

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Abstract

The analysis of land use and land cover change is one of the steps in assessing spatial and environmental impacts of urban growth to foster urban sustainability. It is important to use accurate techniques and also to relate the result with theories of urban growth for effective urban growth management. This paper explores the use of a band ratio technique for land use change analysis and the linkage of the result with urban growth theory. The study uses multi-date and multisource satellite images to analyse the changing pattern of urban growth and land use change in Riyadh from 1972 to 2005. Two different techniques; - spectral angle mapping (SAM) and band ratioing - are applied for land use classification, also to compare the discrimination efficiency of these techniques in this arid environment. The classified images of different years are compared to analyse the changes in land use and spatial pattern of urban growth. Accuracies of classification results from SAM and ratioing methods are compared to ascertain the most suitable method for the land cover classification in this arid environment. The result indicates that the band ratioing method can be used to discriminate land features especially if a suitable threshold is used. However, the performance is not as promising as the SAM method in discriminating between vegetation and agricultural land. The land use analysis results indicate that urban growth management strategies in Riyadh have not been totally successful and the growth pattern corroborates the urban theory of diffusion and coalescence.

Keywords: urban growth, urban sustainability, urban spatial pattern, urban theory, Riyadh

1. Introduction

Riyadh is one of the fastest growing cities in the Middle East. The population of the city, which is presently over 4 million, is expected to reach about 11 million (from 2.8 million in 1992) in 2020 (Alkhedheiri 2002). The annual population growth rate of Riyadh, although already declining, currently stands at 3.5%. However, the size of growth is a major influencing factor that threatens the sustainability of the city. The resultant spatial footprint pattern has been extensive and the city's population density is declining in a typical sprawl format. The spatial extent of Riyadh is currently over 1000 km^2 and the population density has decreased from 38000 people per square km in 1950 to 6825 in 1999 (Al-Sahhaf 2000). The sustainability of the city is threatened by the increasing demand for water and infrastructure, traffic pollution and encroachment on natural vegetal cover.

Urban growth management strategies have been adopted by the Riyadh Development Authority to curb spatial growth and promote sustainable urban development (HCDR 2004). However, there are indications that the strategies have not been totally successful. The prevailing urban growth needs to be monitored to ensure sustainable urban development. Thus, it is very relevant to analyse the spatial growth, pattern and land use change of the city to foster urban sustainability.

In analysing land use and land cover change; it is important to use accurate techniques and also to relate the result with theories of urban growth for effective urban growth management. The post-classification comparison technique has been widely used for land use change detection and analysis (Jensen 2005). The method requires accurate classification of the satellite images prior to change analysis. Different methods have been developed for image classification and research focus is still on the improvement of the accuracy of classified images. Band ratioing is one of the existing techniques for change detection and land use mapping (Lu et al 2004). It is a simple method but the image bands and thresholds must be identified. Al-Saud (2005) uses a set of band ratios to discriminate land feature in an arid environment. The set of band ratios, which have not been vigourously tested, could be applied in a similar environment (Al-Saud 2005).

The spectral angle mapping (SAM) technique is one of the recent classification methods that are developed to improve classification accuracy. The SAM algorithm computes the similarity between a known spectrum and an unknown spectrum and a group of similar spectra is classified as a class/feature (Jensen 2005). The technique and other recent methods are more complex than the band ratio method. The band ratio method could be a handy classification algorithm because of its simplicity and ease of implementation if discrimination of features is improved.

Researchers have indicated that urban growth and land use change analysis need to be linked with urban form and processes for it to lead to effective urban intervention (Longley and Mesev 2001; Hasse 2004; Dietzel et al 2005). Dietzel et al (2005) have shown that the spatial evolution of urban areas oscillates between two phases – diffusion and coalescence. Empirical observations in some North American cities follow this pattern (Dietzel et al 2005). The question still remains if other cities especially in the developing countries will follow the same pattern. This paper explores the use of a band ratio technique for land use change analysis and the linkage of the result with urban growth theory.

2. Data and methods

2.1 Study area

The study focuses on Riyadh, the capital city of Saudi Arabia. The city is located in a desert at about 400km from the east coast (Gulf) and 1000km from the west coast (Red Sea) of Saudi Arabia. Riyadh has experienced rapid urbanization especially during the oil boom period in the 1970s and 1980s. Rapid spatial expansion of the city has been driven by the oil economy and automobile dependency. In order to manage the rapid urban growth, two phases of urban growth boundary have been implemented. The urban growth boundary for Phase I is delineated for 1995 while the boundary for Phase II is delineated for 2005 (see Figure 1). The boundary is being expanded to cater for future growth. The expansion might become Phase III of the UGB series.

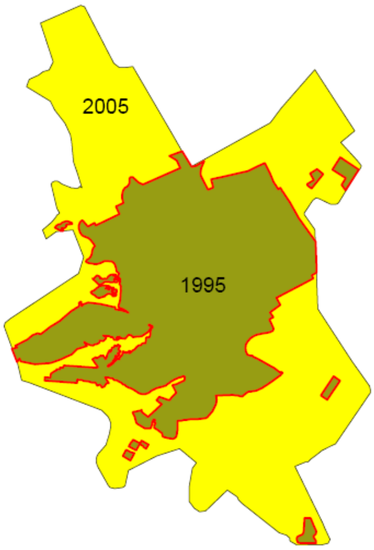

Figure 1. Urban Growth Boundaries for Riyadh City

2.2 Data

The data sources for the analysis include multi-date and multisource satellite images from 1972 to 2005. Vector data (shapefile format) for the two phases of UGB and land use were also acquired for the study from Riyadh Development Authority. The land use shapefile contains the land use data of Riyadh and it is used for the classification accuracy assessment. The satellite images include Landsat MSS (1972), Landsat TM (1985 and 1995) and ASTER (2005) images. They are all geo-referenced and projected to UTM (Universal Transverse Mercator) Zone 38 North. The satellite images for 1985 and 1995 are two scenes. The study area is not fully covered by single scenes (Table 1).

Table 1. Description of satellite images

Image	Date	Path/Row	Resolution
Landsat MSS	1 August 1972	178/43	60m
Landsat TM	31 July 1985/27 November 1987	166/43 165/43	30m
Landsat TM	4 July 1995/13 September 1995	165/43 166/43	30m
ASTER	24 August 2005	Not Available	15m

2.3 Image processing and analysis

The post-classification method for land use change detection and analysis is used in this study. Two different classification techniques, spectral angle mapping and band ratioing, are applied for the classification. Ilwis, a remote sensing and GIS software package that have recently become open source, is used in the analysis. Ilwis has a built-in spectral angle classification algorithm. The SAM algorithm is used to classify the images into four different land use types: urban, natural vegetation, cultivated agricultural land and barren open land. For the band ratio technique, the ratios highlighted by Al-Saud (2005) are used to extract four classes of features from the image. The ratios are based on Landsat TM imagery but they can be used to classify images with similar bands. The ratios are 2/3, 4/5, 5/6, and 5/7. The ratio 2/3 is very good for discriminating natural vegetation while ratio 4/5 is good for extracting barren land. Band ratios 5/6 and 5/7 are good for discriminating urban area and natural vegetation respectively. After the ratios had been computed, different thresholds were applied to the results to get the most suitable threshold for each feature.

The classified images of different years were compared to analyse the changes in land use and spatial pattern of urban growth. Accuracies of classifications from the different techniques were also computed to ascertain the most suitable method for land cover classification in the arid environment. The urban limits shapefiles were used to assess, in spatial context, the effectiveness of the urban growth boundary policy. In order to examine the linkage between urban growth and spatial processes, a metric (PLAND) (Dietzel et al 2005) was computed for urban extent in each classified image. PLAN is the percentage of landscape, or the sum of areas of a land cover type divided by the total area. PLAND could indicate if the process of urban growth is diffusing or not. If the growth is diffusing, it is expected that there will be scattered “seeds” of centers of growth over the landscape and PLAND value will be low. On the other hand, if the process is in a state of coalescence, urban extent will be more compact and PLAND value will be high.

3. Results and discussion

The result indicates that the band ratioing method can be used to discriminate land features especially if a suitable threshold is used. But the performance is not as promising as the SAM method in discriminating between vegetation and agricultural land. The overall accuracy for band ratioing is 69% while the overall accuracy for SAM is 75%. It should be noted that urban extent tends to be overestimated by the SAM algorithm while the band ratio method underestimates the urban extent (Figure 2). The band ratio method has better performance than SAM in depicting the gaps (undeveloped lands) within urban area. It is also more suitable for extracting the road network if the appropriate threshold is applied. In essence the method chosen for a particular study should depend on the purpose of the study and the type of feature that will be classified.

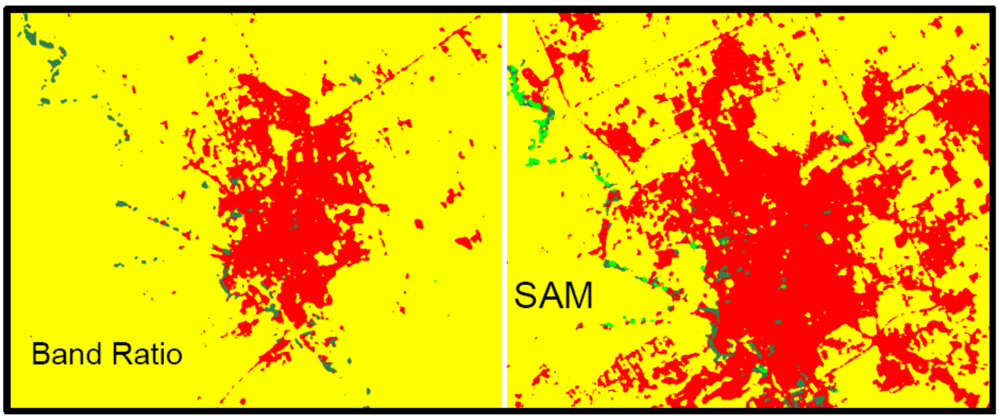

Figure 2. Land Use Classification – SAM and Band Ration Methods

The analysis shows that urban extent in Riyadh increased from about 24 km^2 in 1970 to about 700 km^2 in 2005. The spatial extent computed using satellite images is actually less than the 1000 km^2 that is reported in literature (HCDR 2004) (Figure 3). This is due to leap-frog development in the city. Some land areas of the city are just subdivided and they remain vacant for many years. The vegetal cover has also increased over time due to the fact that increase in urban population leads to increase in vegetal cover in the desert environment. This expansion might have an impact on underground water as water is drawn from the aquifer for irrigation. There is indication that the urban growth boundary implemented by the Riyadh Authority is not totally successful as urban development occurs outside the boundary (Figure 4). Despite the shortcomings, the policy has helped to curb marginal development at the edge of the city.

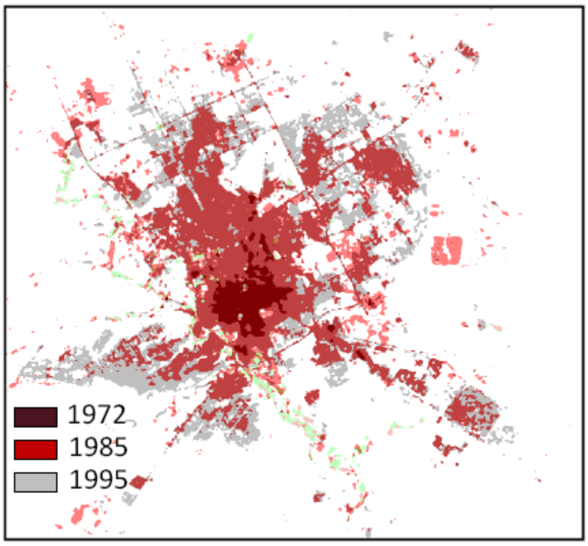

Figure 3. Urban Spatial Growth in Riyadh (1972 – 1995)

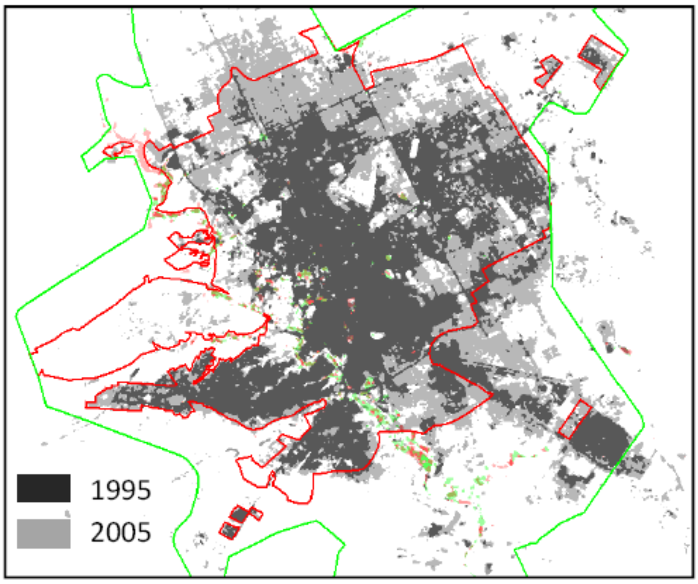

Figure 4. Urban Expansion and Growth Boundary in Riyadh

There is indication that the urban growth process in Riyadh follows the urban theory of diffusion and coalescence (Dietzel et al 2005). The growth of the city started in the 1950s within the city walls. Thereafter, the city expanded outward in a gradual manner. In the 1970s, the spate of development increased, which led to the leap-frog growth witnessed later. The spatial expansion of the city has started tapering as new development is due to 'in-filling" rather than marginal growth at the edge of the city. A look at the results of percentage of built-up landscape (PLAND) will highlight the case better (Figure 5). The highest PLAND figure is 65% for 1972 which indicates coalescence. Thereafter, the figure reduces to 15% in 1985 and picked up again in 1995 and 2005.

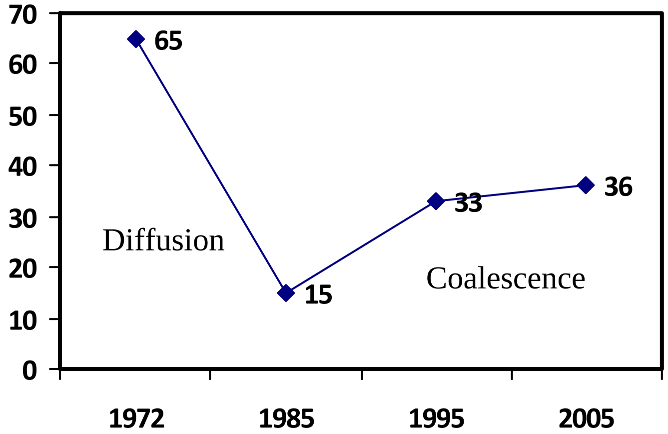

Figure 5. Percentage of Landscape (PLAND) for Riyadh City

4. Concluding remarks

Urban growth management and sustainability have become the common phrase for promoting sociable, livable and environment-friendly cities. The laudable goals of these concepts cannot be achieved without fine-tuning existing methodologies and developing new ones. This paper examines issues and techniques related to urban growth management and applies them in the fast-growing city of Riyadh. The analysis has shown that despite a few failures, the urban growth boundary strategy in Riyadh is working. The hitherto rapid spatial expansion has slowed down and the 'gaps' and brownfields within the city are being developed. There is a caveat. How can it be confirmed that the changes are due to planning intervention and not the normal processes of urbanization, suburbanization and re-urbanization or the oscillatory diffusion and coalescence? Having used these techniques to understand spatial processes of the city, how do planners know when and where to intervene? It is a big step in the right direction to make efforts at improving our understanding of the city. This work could still be extended further by looking into other spatial metrics (such as patch density, edge density and fractal dimension) that were used in testing the hypothesis of diffusion and coalescence. Such a study will help in confirming the universality of the theory.

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