Study of Landscape Fragmentation to Characterize of Urban Sprawl

Ms. Mona Lacoul[1], Dr. Lal Samarakoon[1]

[1]Geoinformatic Center
Asian Institute of Technology
Klong Luang, Pathumthani 12120, Thailand

As Kathmandu Valley is experiencing the highest rate of urban expansion than other cities of Nepal, the Valley was selected for urban sprawl study. The study is based on the notion that urban land fragments previously homogeneous rural landscape, results in increased landscape disorganizations. Firstly, general landuse /landcover maps were developed by classifying satellite images of three different years, 1988, 1996 and 2005. Measurement criteria were developed to convert landuse/landcover maps into rural fragmentation maps, consisting of three fragmentation classes; interior, perforated and patch. The next step was to identify sprawl through changes in fragmentation maps and further classify sprawls to infill, expansion and outlying sprawl.

Key Words: land fragmentation, urban, landuse, remote sensing, GIS

Introduction

Sprawl is pattern and pace of development, in which rate of land consumption for urban purposes exceeds the rate of population growth, results inefficient use of land. Burchell (1999) defined of sprawl as low density residential and nonresidential intrusions into rural and undeveloped areas, and with less certainty as leapfrog, segregated, and land consuming in its typical form. Identification Sprawl "hotspots provides a scenario of where the growth is occurring, assists in visualizing environmental and natural resources threatened by sprawl, helps in projecting future direction and pattern of growth, and facilitating landuse planning process. Further, mapping sprawl provides a picture of where the growth is occurring, helps identifying the environmental and natural resources threatened by sprawl, and to suggest likely directions and pattern of growth.

Mapping sprawl requires a consensus on a definition of sprawl and needs to ascertain indicators assessing the phenomenon. Important Sprawl indicators are (i) fragmented landuse pattern (ii) lack of functional space (iii) poor accessibilities. Sprawl can be measure by landscape change analysis performed by use of appropriate remote sensing and GIS techniques. Over the past several decades, remote sensing techniques have been widely explored for delineating growing suburban areas. More recently, remote sensing-based urban analysis is beginning to focus specifically on the delineation of "suburban sprawl".

K. Ritters et. al (2000) developed a fragmentation model based on two indices (i) proportion of forest, P_f in analysis window and (ii) the proportion of all adjacent pixel pair that include at least one pixel of forest, P_{ff} in analysis window to measure forest fragmentation. The indices could identify six classes of fragmentation (interior, patch, transitional, edge, perforated and undetermined) from amount of forest and the occurrence its adjacent forest pixels. D. L. Chivo (2002) modified the forest fragmentation model to a urban fragmentation model to five categories of sprawl (Infill, expansion, isolated growth, linear branching, clustered branching). This urban growth model successfully portrayed informative picture of dynamics of changes occurred. D. L. Chivo (2002) found a 5*5 window size was found be appropriate for representing the proportion of forest in the analysis window and also maintained interior forest at appropriate level considering resolution of the data (Landsat TM, 30m resolution) , the size of the smallest feature of interest and practicality of various window sizes. Further, K.Ritters et al (2004) analyzed the importance of road layer for forest fragmentation by comparing fragmentation as calculated from land cover alone and after superimposing detailed road maps. The use of road layer facilitated to identify fragmentation caused due to road.

Urban growth causes a decrease in amount of forest area, farmland and open space and also leads to break up of originally natural landscape and disrupt ecosystems and fragment habitats. Analysis of landscape fragmentation and urban sprawl assists in visualizing the real consequences of development on the landscape (E. H.Wilson. et al, 2002). This will facilitated in identification sprawl types in the valley and helped to visualize effect of the result of the past decisions and polices in urbanization. This study on urban sprawl would assist implementation better policies in future to regulate haphazard urban expansion.

2. Objectives of Study

As rural and natural landscape in the Kathmandu Valley is changing continuously to urban classes, the concerned organization could not fulfill the demand of basic minimum infrastructure such as water, drainage and road. The planner need visualize the growth in recent years to regulate the future growth. Hence, the study is trying to identify the type of sprawl based on land fragmentation.

- Identify scale of land fragmentation at three time periods 1988, 1996, 2006
- Identify type of sprawl based on landuse fragmentation

3. Methodology

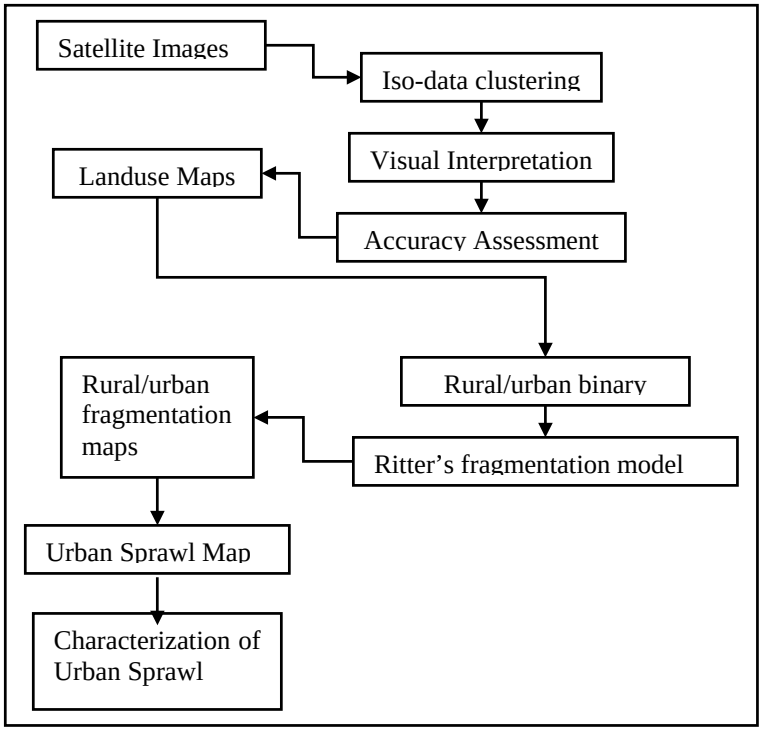


Figure 1. Flowchart showing overall methodology of analysis

3.1. Land Cover Classification

Three dataset LandSAT TM (1988, 30 m resolution), ADEOS (1996, 18 m resolution) and ASTER (2005, 15 m resolution) were used in this study to obtain landuse in eight years difference. TM data was classified into 20 spectrally separable clusters were obtained using ISODATA clustering method. These classes were further grouped into three landuse classes using spectral signature of each of the classes and relative association of clusters on the image. The classes are urban, agriculture land and forest. Similarly, other two datasets ADEOS and ASTER were also classified into 20 spectrally separable clusters to obtain three landuse classes. The factors such as resolution of available data, parcels size in the study area and terrain complexity affected the accuracy of landuse. For example, fallow lands showed similar spectral signature as that of urban area. Visual interpretation was performed on all three landuse maps to eliminate mixed class problems. As landuse map is the primary input for landscape fragmentation study, the landuse maps were compared against topographical maps (1:25000 scale, 1994), IKONOS image (2001, 4m resolution), Aerial Photographs (1992), ground truth data (2004).

It is not possible to identify the entire road network from the images. Road has significant role in urban land fragmentation. Road layer is added on to each of landuse layers before further processing.

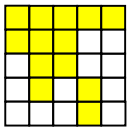
3.2. Identifying landscape fragmentation

The urban growth model is based on forest fragmentation model developed by Ritters et. al (2000). There are two major modifications done in the models by Civco D.L. et al (2002). Instead of forest versus non-forest binary image,

input image is a binary image of non-developed versus developed to derive non-developed fragmentation image. Based on the Index Pf, proportion of non-developed, three fragmentation classes are defined for the model based on the index, whereas six classes are used to quantify forest fragmentation in forest fragmentation model. The classes are interior, perforated and transitional forest. Following are the criteria

- Interior Class: all the pixels surrounding the center pixels are undeveloped class. (Pf =1)
- Perforated Class: Most of the pixels in the surrounding area are undeveloped, but center pixel appears as part of edge of undeveloped class. (pf>0.6)
- Transitional Class: Pixel is part of undeveloped class on a developed background.(pf < 0.6)

Each of the landuse maps are converted in fragmentation map based on the proportion of undeveloped class in 5*5 moving window.



Yellow represent undeveloped pixels and white represents developed urban pixels. Out of 25 pixels, 13 are undeveloped pixels. So, $\mathbf{P_f}$ = 13/25 =0.25

Figure 2. demonstrates calculation method of Pf.

3.3. Urban sprawl

Urban sprawl is characterized by change in landscape fragmentation map over a period of time. The change is classified in three categories,(i) the class that are not changed, (ii) the re-growth class (iii) changes that indicate urban sprawl. The definitions adopted for sprawl types are based on D.L. Civco (2002). Infill growth is defined as the development of small area surrounded by existing developed land. Expansion is defined spreading out of existing developed land. Outlying growth is defined as land that is interior undeveloped and changed to developed land. The change map is categorized into infill, expansion and Outlying (i) transitional fragmentation class to developed (ii) perforated fragmentation class to developed and (ii)interior fragmentation class to developed respectively.

4. Results and Discussions

Analyzing landuse maps of three different periods, urban landuse has increased from barely seven percent in 1988 to twenty percent in 2005. Agriculture land has decreased from sixty five percent to sixty two percent in the same time period. Most affect landuse is forest landuse, which has come down from twenty percent to sixteen percent in the same period. During first eight-year period, urban area increased from twenty four square kilometer to thirty eight square kilometer. It has increased from thirty square kilometer to seventy square kilometer. The study demonstrates that agriculture land and forest are decreasing, but doesn't provide information on land fragmentation and sprawl type.

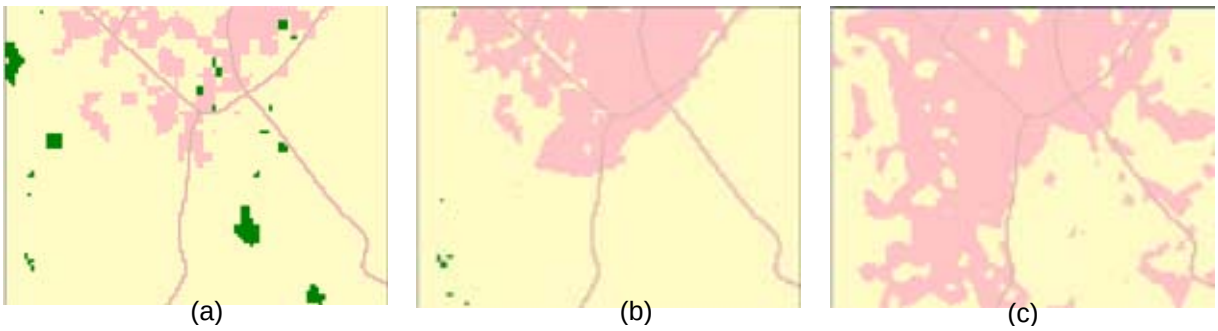


Figure 3: urban growth of along the ring road in Lalitpur area in (a) 1988 (b) 1996 and (c) 2005, vector road layer is overlaid on the classified image.

Looking at statistical information of each of fragmentation map of Kathmandu Valley (figure 4), interior undeveloped class is converted to urban, transitional and perforated classes. The sample pictures (figure 3) show decrease in interior undeveloped class into other categories. At the same time there is increasing trend of urban, perforated and transitional classes in three images. This analysis clearly portrays state of land fragmentation over time. Initially, big interior patches in 1988 image are converted into several smaller patches. The rate of loss is 1.98 square kilometer per year during the period 1988 to 1996. The rate of loss of interior undeveloped class is 5.77 square kilometer per year during the period 1996 to 2005. Urban area increases by rate of 1.79 square kilometer per

year during the period 1988 to 2005. Similarly, increasing trend is seen in case of transitional and perforated classes with the rate of 1.22 square kilometer per year and 0.63 square kilometer per year respectively.

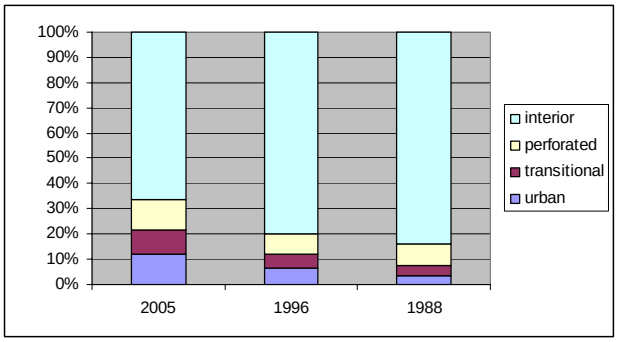


Figure 4: Change in area in fragmentation map

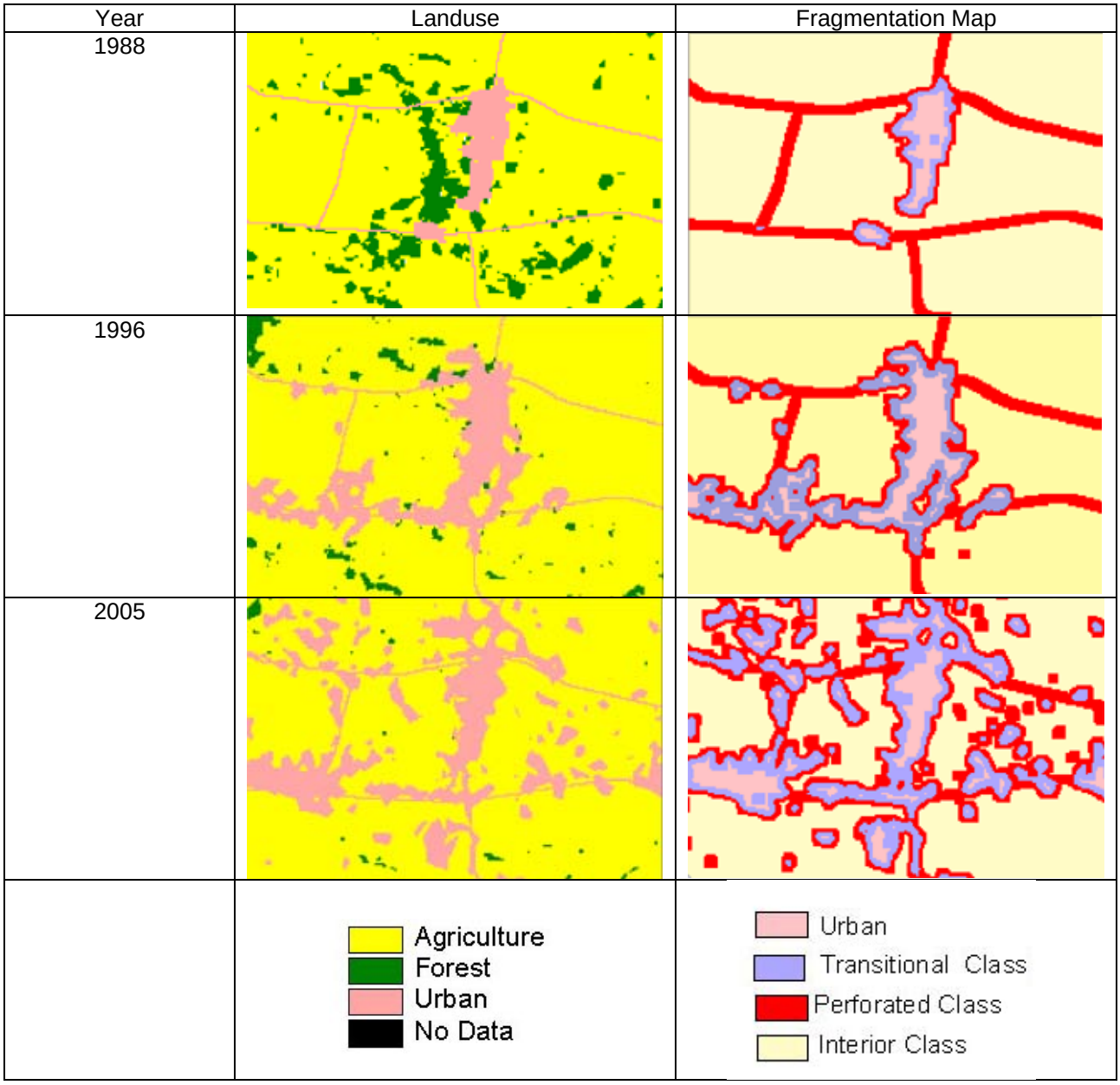


Figure 5: A sample of study area showing landuse and land fragmentation in three different years

Figure 6: Outlying sprawl in purple color in change map in the period 1988-1996 with orthoimage 1992

Studying change map between two time periods, outlying growth is predominant among three types. In the period 1988 to 1996, outlying growth is found to be 13.59 square kilometer. During the period 1996 to 1988, 46.72 square kilometer of outlying growth is seen in the valley. This type of changes occurs which development occurs at some distance away from existing urban area and along major transpiration corridors outward from urban area. Infill growth is seen 6.24 square kilometer during first period and 10.23 Square kilometer during second period. The expansion growth is also known as urban fringe development, is a belt of land that on the outskirts of city which continuously changing from rural to urban. 2.28 square kilometer of expansion growth has occurred during the period 1988 to 1996. During 1996 to 2005, expansion growth has increased to 4.97 square kilometers.

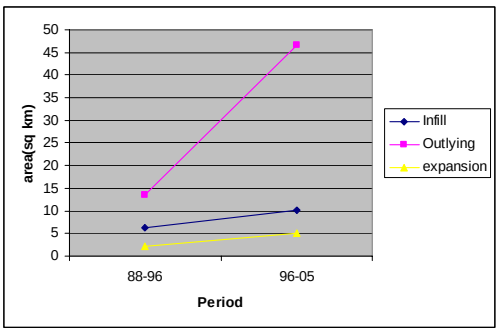


Figure 7: urban sprawls in the valley

The valley is experiencing more of sprawl than infill growth. Consequences of such a growth are significant loss of open space and agricultural lands, greater reliance on vehicles, higher resource consumption (i.e. energy and water), greater infrastructure costs, and higher costs of service (K. Snyder et al,1998). Infill development contributes to a more compact form of development which is less consumptive of land and resources. Infill development is not easy as there are many barriers; however, it should not be ignored as a development direction. (J. T. Farris, 2001). For the valley, appropriate policy and regulation should be formulated for infill development to reduce outlying sprawl to certain extent.

5.Limitations

The whole study relies on landuse fragmentation model, which is output of landuse information. The result highly depends on accuracy of landuse classes obtained from satellite images. Some errors might exist on satellite derived landuse information. As the study requires sets of landuse data, the information might magnify the error. Further, an analysis widow 5* 5 is used to determine fragmentation classes based on earlier research on TM data. As three datasets ASTER, ADEOS and TM having different resolution are being used, the optimum window size to define land fragmentation should be explored.

6.References

Kurt Rutter, James Wickham an John Coulston(2004), Use of Road Maps in National Assessments of Forest Fragmentation in the United States Ecology and Society 9(2):13

Daniel L. Civco, James D. Hurd, Emily Hoffhine Wilson, Chester L.,Arnold, and Michael P. Prisioe, Jr.," Quantifying and Describing Urbanization Landscapes in the Northeast United States, Photogrametric Engineering and Remote Sensing , vol 68, No 1, October 2002

Ken Snyder and Lori Bird(1998), "Paying the Costs of Sprawl: Using Fair-Share Costing to Control Sprawl", http://www.sustainable.doe.gov/articles/sprawl.shtml#_Toc437077599

Kurt Rutter, James Wickham , Reobert O'Neill, Bruce Jones and Elizabeth Smith, "Global Scale Pattern of Forest Fragmentation", Conservation Ecology, Vol 4, No 2: