Spatio-temporal dynamics of the urban fringe landscapes

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Abstract

Study of the land-use/land cover (LULC) changes close to the boundary of the buildup area (urban fringe) provides deeper understanding of a land-use dynamics at different spatial and temporal scales. Few thoughts have given to the analysis of complicated spatial landscape at a fringe area. The aim of this paper is to resolve this bias by focusing on these interfaces. Results of this paper show that majority of new urban development appear inside the fringe area. Moreover, two different processes of urban dynamics - addition of small and emergence of large buildup patches - have been revealed.

Keywords: Land-Use/Land Cover Change; Urban Fringe; Spatial Analysis; Urban modeling

1 Introduction

Typically, the buildup area is very stable. New constructions appear within this area, close or far away from its boundary. Studies of the Land Use/Land Cover (LULC) changes ignore the distance between the new and existing buildup areas [1-4]. My research demonstrates that the land-use (LU) dynamics within and outside urban fringe are essentially different.

In this research I assume that land-use pattern can be an outcome of *several* parallel dynamics, each characterized by its own rules. Specifically, I demonstrate that the LULC change processes at the urban fringe are essentially faster than further away from the urban boundary and Cellular Automata (CA) and Multi-Agent (MA) models [5-11] should account for that.

To analyze LULC dynamics I compare high resolution aerial photos taken during each 5-10 years, during the long period of 43-years, along the urban – rural – nature gradient. The transect starts at the city center of Netanya, Israel and goes East.

2 The research area and aerial photos

2.1. Research Area

The study transect is of 15 km length and 6 km width (i.e. about 90 km^2). It starts in the center of the city of Netanya (32°20′0″N - 34°51′0″E), located on coastal plain and goes west to the Samarian hills (Fig.1).

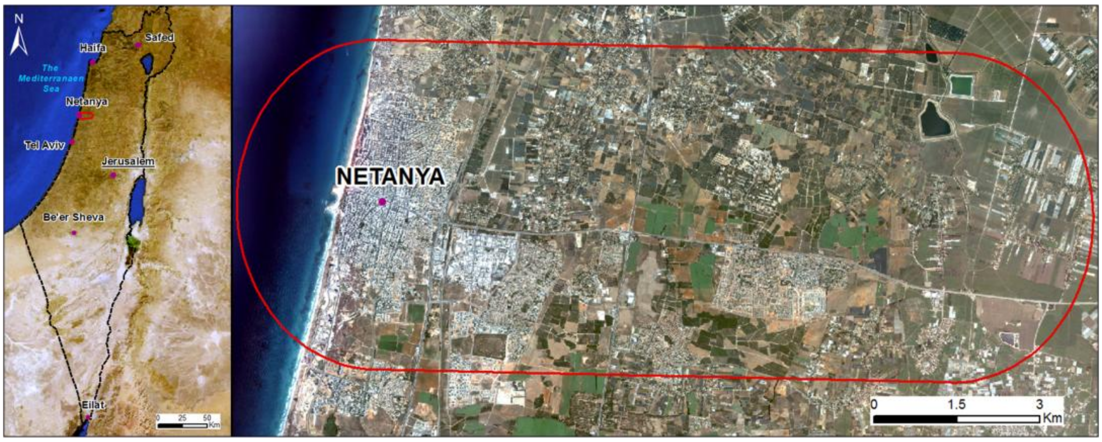

Figure 1: Research transect in Netanya, Israel

The climate of the region is Mediterranean, characterized by long, dry and hot summer, and short, cool and rainy winter, with an average annual rainfall of 570-600 during October-April [12]. The vegetation is mostly represented by semi-natural Mediterranean open savanna grasslands, 6 shrubs and forests. Agriculture in this area is highly industrialized and, mostly, irrigated.

2.2 Aerial photos interpretation

The aerial imagery covering the entire research area was obtained from the Survey of Israel (Table1). To reduce geometric distortions caused by relief, tilt and lens-effects, aerial photos were carefully geometrically rectified. Overall accuracy error is less than 3 m, which corresponds to the research requirements.

Table 1. Aerial photos imagery

Year	Scale
1965	1:35,000
1972	1:30,000
1983	1:40,000
1993	1:40,000
1999	1:40,000
2008	1:12,000

My research is based on the manual classification of aerial photos. Following six land-use/land cover types were recognized in the imagery: buildup, agricultural and vegetated areas, open space, water and roads. Below I consider LULC patterns for 3 land-uses: built-up, roads and open space; where all LULC types that are not built - up or roads, were consider in one class as open space. For the goal of analysis, the vector maps obtained during the manual classification were transformed, applying majority rule, into a regular 30x30 grid with 30x30m resolution (Fig.2).

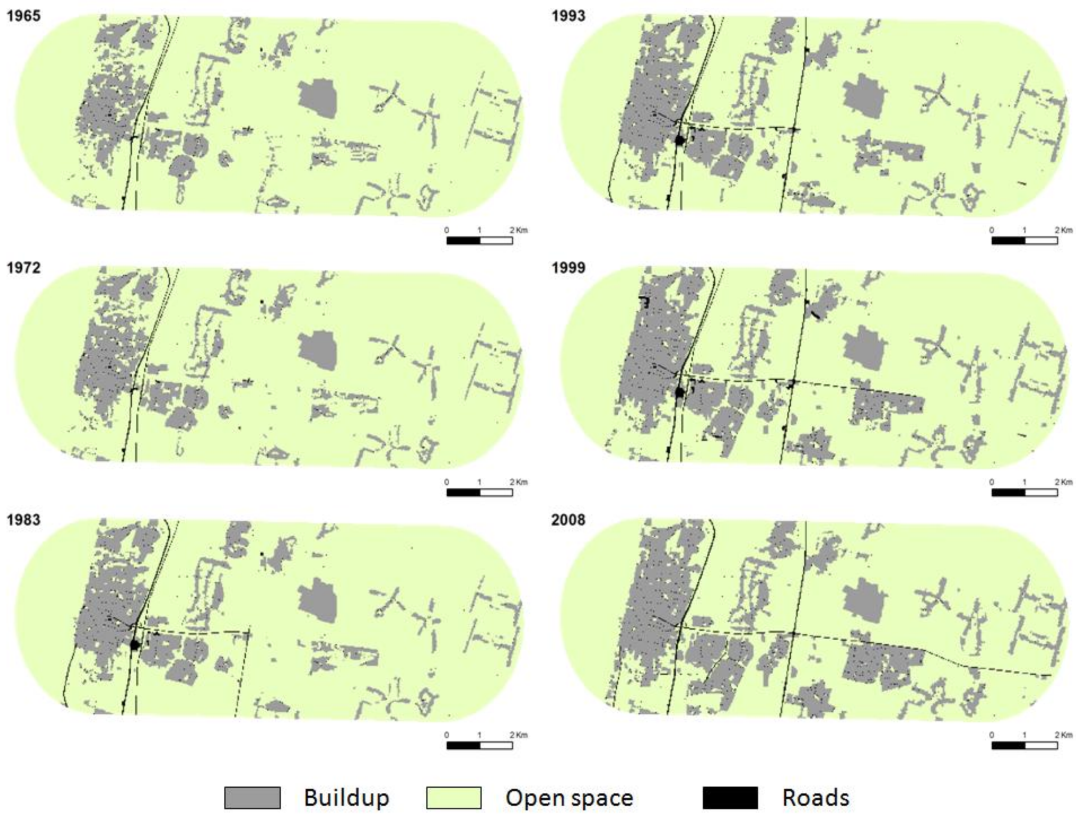

Figure 2: Buildup-road-open space patterns along the Netanya transect, by years

3 Fringe detection and Land-Use/Cover Changes over the fringe

3.1 Fringe Detection

Various definitions of the area close to the buildup area - "peri-urban", "semi-urban" areas, "urban-rural fringe", "urban outskirt" can be found in the literature [13, 14]. The definition as *"the landscape located just outside established cities and towns, where the countryside begins"* [15] or "*a zone along the edges of the built-up area, which consists of a scattered pattern of lower density settlement areas, urban concentrations at transport hubs and large green open space*" [16] provide clear qualitative understanding but are yet insufficient to quantify and operationally detect a fringe area.

To define urban fringe quantitatively, let us consider every cell C of a type L(C) and a circular neighborhood $U_r(C)$ of the radius r of C. Let us start with the definition of *Homogeneous* area: A cell C of a type L(C) belongs to homogeneous area of a type L if a fraction f of the L-type cells within the $U_r(C)$ is higher or equal than a threshold value F, $f \geq F$. Evidently, only high values of F, say, $F \geq 50\%$, are worth considering (Figure 3).

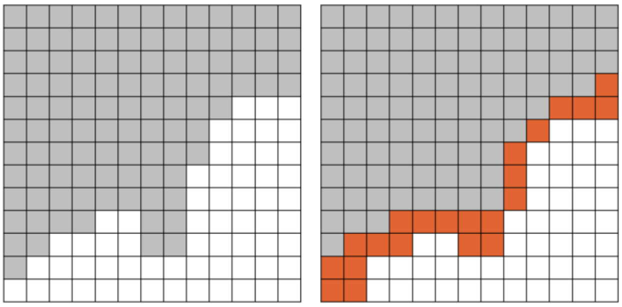

Figure 3: Mixed pattern two homogeneous types (white and grey) and heterogeneous area (red), where radius r is 60m and cell size is 30x30m

Let us denote homogeneous areas of a type L as H_L. Fringe is an inhomogeneous (i.e., heterogeneous) area:

Fringe area: Land cells that do not belong to H_L for any L, belong to a fringe.

Note, that fringe is defines by two parameters – a size of the neighborhood n and a maximal fraction F of the land-use cells of each of the types L.

Based on the above definition, I have estimated the fringe area in the Netanya transect as dependent on F and r (Figure 4). Evidently, the higher are the threshold F or the neighborhood size the larger is a fringe area.

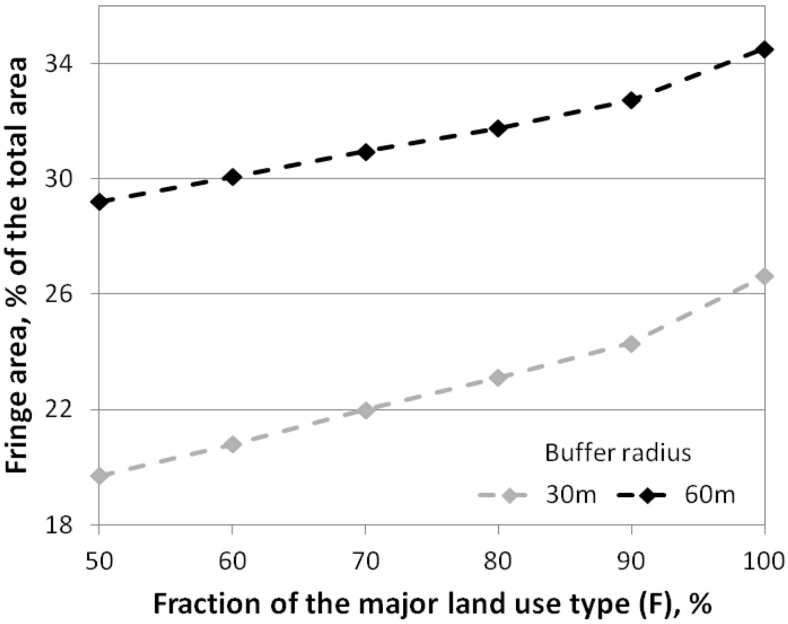

Figure 4: Fringe area as dependent on the fraction of similar land-uses within a neighborhood F and neighborhood's radius r

I detected fringe areas over the Netanya transect by applying the values of F = 80% and r = 60m (Figure 5).

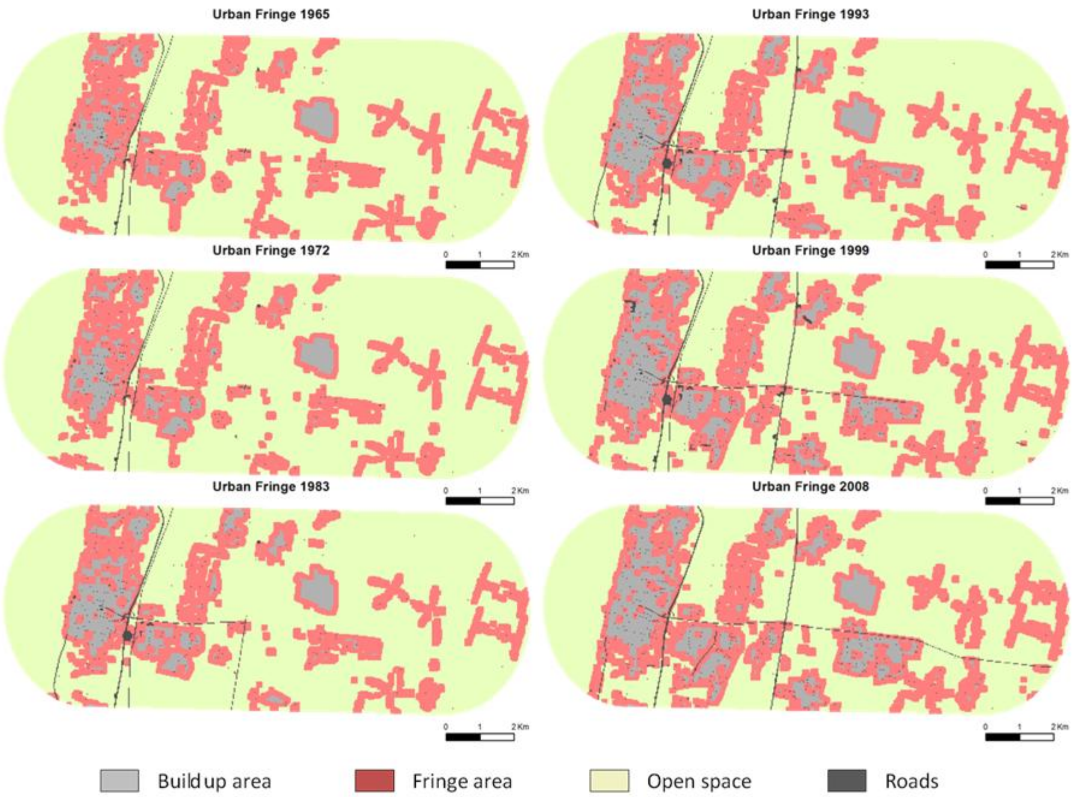

Figure 5: Dynamics of urban fringe along the Netanya transect during the period of 1965 - 2008

3.2 Land-use change detection

The land-use changes between 1965 and 2008, in the Netanya transect, are presented in Table 2. In 1965, the buildup area was 3.4%, while the fringe area was 26.5%. From then on, a buildup area increased linearly, while the area of fringe slightly declined until 1983 and then increased. According to the aerial photos, the decline can be related to the aggregation of buildup patches, while the fringe growth to the rapid urban development within transect, during 1993 and 2008.

Table 2. Land-use area between 1965 and 2008, % of the total area

Land-Use	1965	1972	1983	1993	1999	2008
Buildup area	3.39	4.32	6.13	7.59	8.97	9.97
Fringe	26.54	26.60	25.35	27.11	29.68	31.75
Roads	0.64	0.68	1.12	1.40	1.66	1.42
Open Space	69.42	68.40	67.40	63.90	59.69	56.86

For broader understanding of an urban expansion, I distinguish two different types of buildup area change that occurs inside and outside the fringe area (Figure 6). Figure 7 represents the fraction of the buildup changes inside and outside the fringe area, as a percentage of the total annual LU change area. Annual fraction of LU changes over the entire transect area does not differ significant and remains in the same level ~2.6% comparing to the average fringe size ~27.5% of the entire area. Note that the majority of LU change emerges inside the fringe area. Up to 1983, buildup change remains in the same level, 95% and 5% inside and outside the fringe area respectively. From 1983 to 2008, amount of buildup change outside the fringe greatly increases from 6% to 38%.

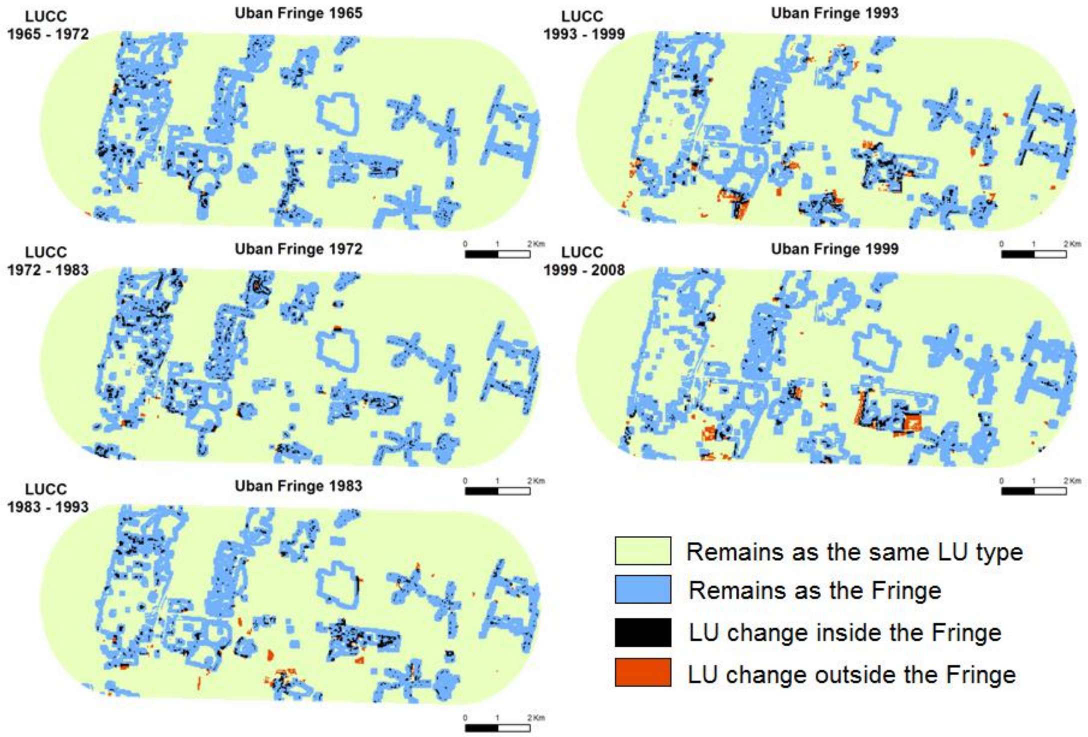

Figure 6: Buildup change inside and outside the Fringe

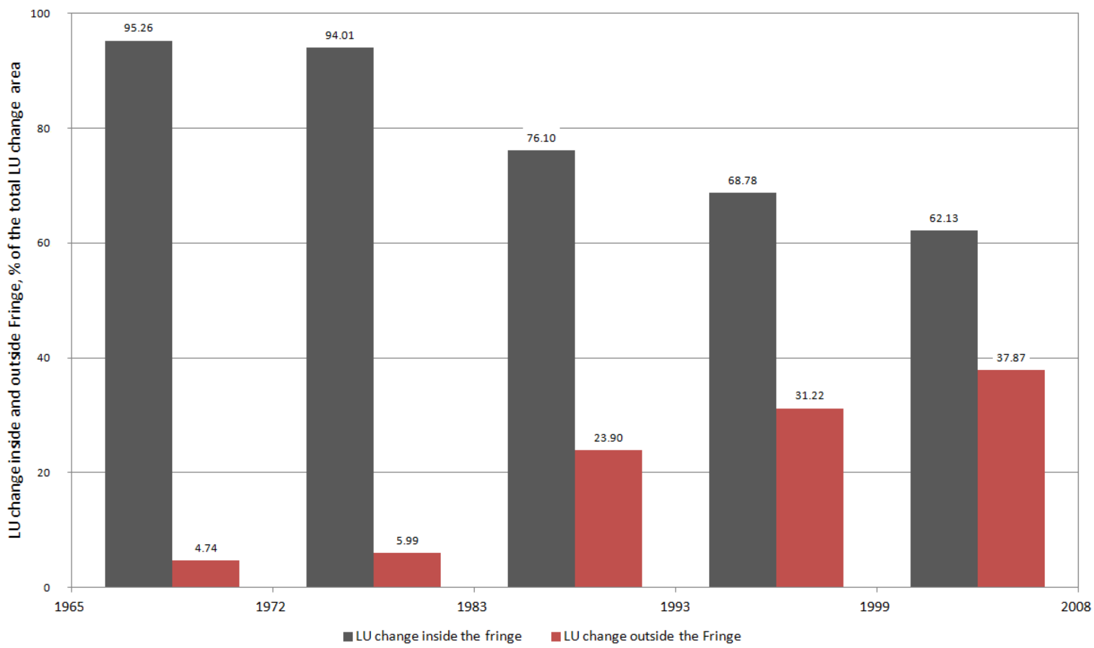

Figure 7: Buildup change inside and outside the fringe

Further analysis applies spatial configurations of LU changes. Patch size density summarizes the number of patches per discrete intervals of 5 cells. Figure 8 represents histogram of buildup patches size, in 30x30 cells, inside and outside the fringe. As it can be seen, the majority of buildup change emerges in small patches that are less than 5 cells and comprise 77% and 69% of all buildup changes inside and outside the fringe respectively. Patches larger than 5 cells emerge less frequent no matter where it occurs. However, large patches more than 30 cells cover essential area and comprise about 4.3% and 1.7%, outside or inside the fringe area respectively.

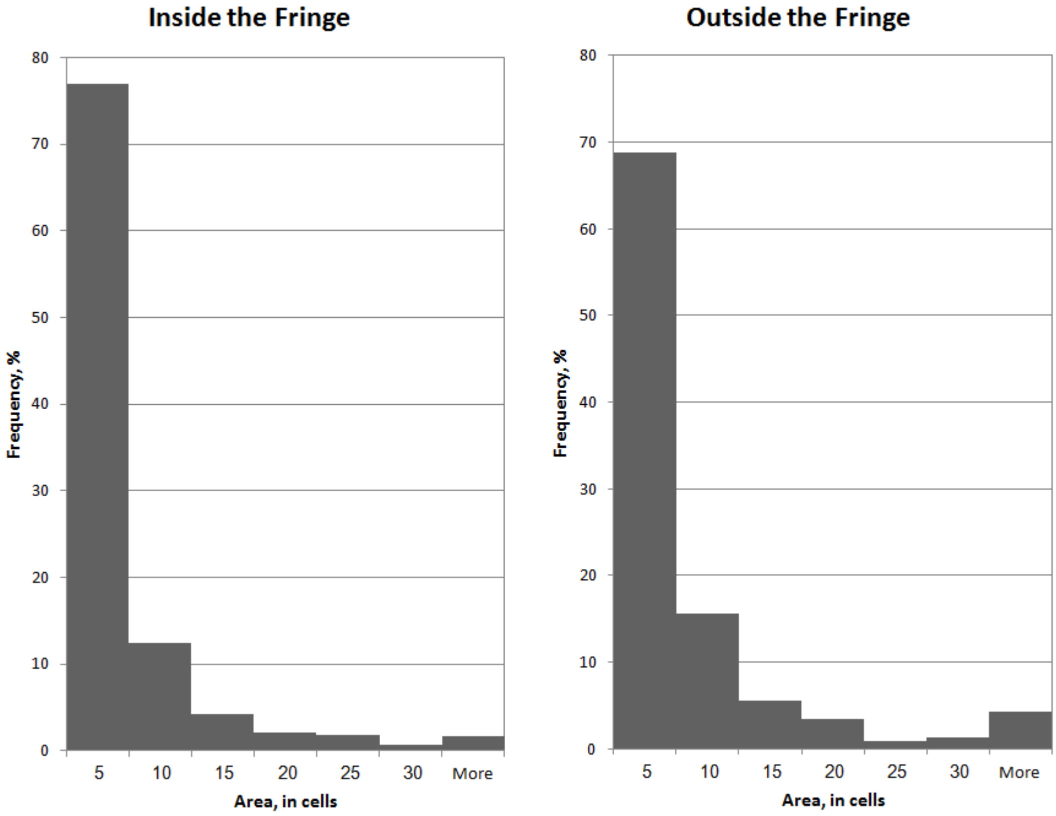

Figure 8: Histogram of LU change patches inside and outside the fringe area

Analysis of large patches is performed separately (Figure 9). Large patches of buildup changes outside the fringe occur since 1983 and increases rapidly. Towards 2008, 58.5% of all changes outside the fringe area emerge in large patches. In contrast, inside the fringe this number is ~20% in 2008.

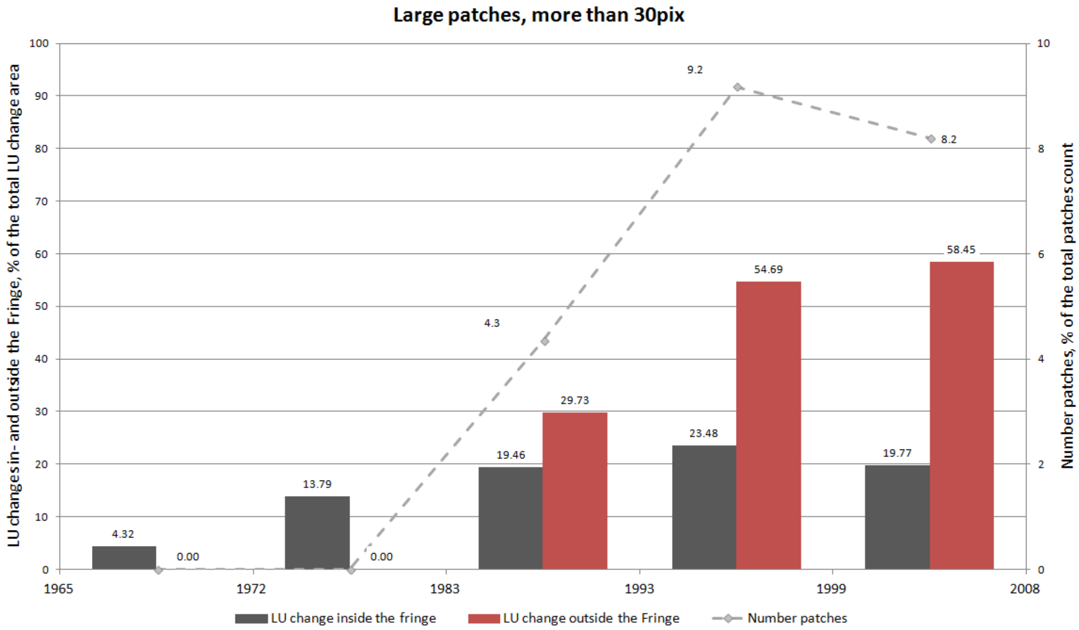

Figure 9: Dynamics of the number of large patches inside and outside the fringe area.

4 Discussion and Conclusions

In this research I propose approach to fringe detection which aims at quantitative characterization of the land-use dynamic processes. Based on this detection, two different processes of the land-use change – addition of small and emergence of large buildup patches - have been revealed. The frequency of LUC changes within a fringe area is much higher than outside, ~80% of changes within a fringe comprising ~20% of the total area. Majority of the buildup patches are small less than 0.45ha, in contrast large patches emerge less frequent. However, large patches compose half of all LU change area. Consequently a new hypothesis implies that land-use changes should be describes by two models – one representing dynamics of the small patches and one describing the emergence of the large patches.

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