

VISUALIZATION OF LAND USE CHANGES IN POLAND BASED ON NEIGHBORHOOD ANALYSIS (1990-2006)

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BACKGROUND AND OBJECTIVES

Land use is defined as spatial distribution of forms of land cover patches, utilized or not by man within framework of the spatial and mutual relationships. The term refers to the functional character of given terrain and is identified also with the socio-economic description of the surface (Kozubek, 1992, Ciołkosz & Bielecka, 2005, after Stamp, 1960, Kostrowicki, 1959).

The observed dependency of land use and neighboring land cover patches is pointed out in many publications from geography or spatial economy; i.e. the economic utilization of observed lot (or patch) has the smaller consequence for future than the existing land use in its neighborhood. Either the situation, existing neighborhood or predominant land use types in given, whole region are the factors stimulating of further land use changes of the observed lot (Hagoort, 2006).

The majority of land use models come from geography. They usually concern the modeling the development of urbanization. The generalization of the results of the research investigations are the conclusions concerning the stability of land use. The majority of observations proved the consolidation of the given land use forms, but there were local stability phenomena or geographical and historical inertia processes dominating over the existing forms of urbanization (Hagoort 2006, after Wilder, 1985, Bourne, 1965, Lee, 1974, Batty, 1996). The collision of different types of land use with existing ones in neighborhood can be the modifying factor. Other factors which can be taken into account are spatial and economic externalities. It was observed that the existing patterns of lot's and neighborhood land use consolidate through the succession.

METHODS AND RESEARCH MODELS OF LAND USE CHANGES

The wide set of tools and methods has been used to studies of land use changes. Between others the statistical and econometrics models were used (determined usually by the domain of the scientist). The geographers often used the spatial interactions models. The spatial planners - models of (non)linear programming and the economists either the utility maximization models or often multi-criteria and multipurpose decision support systems. The research field of land use changes is interdisciplinary and forces the application of integrated tools based on simulations; The input - output models (Hagoort, 2006) as well as fuzzy logic (Biłozor, 2003) have been also used. GIS software obviously has become the tool of simulations and geovisualizations of the models' results.

The two categories of factors influencing on land use changes (both within urban and rural areas) were confronted. The core of the studies was the evaluation of spatial changes arising from affecting neighborhood and succession for the following each forms of land use for the given area. The definition of basic spatial unit was the inseparable and indispensable element of the studies. This problem was connected with the scale of spatial research; either the real estates lots, administrative units or even the (ir)regular geometric grids of cells (e.g. squares, Voronoi's polygons) could be used. The spatial units were categorized according to the pre-defined typology of land use classes.

Obviously the number and the types of classes of land use differentiated dependent from aim, the scale and the area of geographical study.

Another aspect of the research of land use changes takes into account the spatial externalities (Hagoort, 2006). They are defined as the unexpected, indirect results of leverage of men causing changes of costs or the values for other ones - without visible operations (Mishan, 1969). Spatial externalities of land use changes disclose themselves usually throughout intensity (rate) and spatial extent. It can be distinguished both negative and positive spatial externalities. The higher spatial externalities related with given spatial land use class (form) implicit the higher probability of change of land use class for the spatial unit (Tobler, 1979). Summarized influence of land cover spatial externalities (net externalities) can be analyzed using multi-variables models, spatial or conditional spatial models of land use changes (according to Tobler - described detailed further).

The main changes of land use has been recognized and the set of models has been distinguished (Hagoort 2006, after Tobler 1979):

- Independent model – of changes: each following land use form is not related with previous one in the same place; this is random variation;
- Dependent model – of changes: each following land use form is strictly related with previous one in the same place; future land use depends on present situation in the same place;
- Historical model – of changes: newly appearing land use forms depend directly on at least two chronological previous ones in the same place;
- Multivariate model – of changes: when the future land use depends on many different features, recognized at present on this area;
- Geographical model – spatial model of changes
- the future land use in the place depends on neighborhood (at present).
- Future geographical model – conditional spatial model - the future land use in the place depends on planned land use forms in the neighborhood.

The regions of urbanization are the most interesting for geographers. The studies of urban land use changes are the larger part of numerous research projects. Their conclusions were different because the studies concerned specific and different geographical locations. However some common findings have been recognized. The different elements of landscape change with different speed (Hagoort 2006, after Whitehand, 1967) but some of them are more susceptible on changes and additionally the different rates of land use changes take place relative to centers of cities (Hagoort 2006, after Wilder, 1985). The different temporary profiles of urban land use changes became longer than the scale of man's life and even longer than the perspective of the spatial planning (Hagoort 2006, after Wegener, 1995). On the other side the courses of main streets are usually the most durable elements (Hagoort 2006, after Whitehand, 1967) and some types of land use forms do not surrender to changes or the successions do not take place (Hagoort 2006, after Wilder, 1985).

The land use changes are the effect of complex conditions. In practice the mixed models of the ones described above are applied. The most often the multivariate and geographical models are linked including transport, employment and population using SDSS like e.g. Metronamica (ITC[®]).

CELLULAR AUTOMATA AND MAP ALGEBRA

The changes of land use can be treated as complex and (at least partly) random process. The complexity of interactions implicates that conventional deductive models are constrained especially in the case of spatio-temporal phenomena (Fulong Wu, 1999). Probabilistic models are also effectively applied. They make use of the concepts of random development of reality, and the notions of statistical events, probability, random variables and empirical distributions of probabilities (Ratajczak, 1999). According to Fotheringham (et al., 2000), one of the purposes of spatial and visual analysis of maps is indirect understanding of the phenomena by analyzing spatial patterns and inferring about spatio-temporal processes. Wolfram (2002:299) stated three possible mechanisms that can be responsible for complexity and randomness: „ (...) there is random input from the environment at every step (...) there is random input only in initial conditions. And in the third case, there is effectively no random input at all (...)” The first mechanism is captured in the so-called stochastic models. The second is suggested by chaos theory. The third mechanism is suggested by the behavior of simple programs (op. cit.). This approach is related to use of cellular automata in research of land use changes (Werner, 2005).

One can observe a more and more frequent application of cellular automata to spatial research. Cellular automata are mathematical models for complex natural systems containing large numbers of simple identical components with local interactions. They consist of a lattice of sites, each with a finite set of possible values. The value of the sites evolves synchronously in discrete time steps according to identical rules. The value of a particular site is determined by the previous values of a neighbourhood of sites around it.

The cellular automata are similar to map algebra models in GISc. There were numerous approaches undertaken of creation of uniform methodology joining both ideas (Takeyma & Couclelis, 1997). Map algebra is the scheme of cartographical modeling. It describes all the possible transformations of raster maps assembling them in four basic classes. They are the following (Takeyma & Couclelis 1997, Longley et al. 2006, after Tomlin, 1983):

- Local operations examine raster maps cell by cell, comparing the value in each cell in one layer with the values in the same cell in other layers;
- Focal operations compare the value in each cell with the values in its neighboring cells – most often eight neighbors;
- Global operations produce results that are true of the entire layer, such as its mean value;

- Zonal operations compute results for blocks of contiguous cells that share the same value, such as the calculation of shape for contiguous areas of the same land use, and attach their results to all of the cells in each contiguous block.

MODIFICATION OF TOBLER'S GEOGRAPHICAL MODEL

The proposed modification of geographical model is based on introduction of additional coefficients into the geographical model.

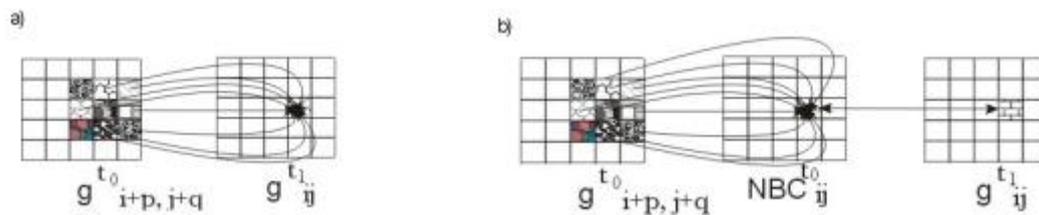


Fig. 1. a) Tobler's geographical model of land use changes; b) Proposed modification of geographical model

The assumption of analysis of land use is that there is one-to-one relation between land cover class description and its unique number. The operationalization of the modified geographical model needs two additional steps in research:

Definition of algorithm of neighborhood coefficient (NBC) based on the land use types of Moore neighborhood (3x3 cells around the central one),

Definition of the reverse algorithm of neighborhood coefficient (NBC) for the reconstruction of the primary land use types based only on the value of NBC.

The proposed modification of geographical model are the following:

Construction and evaluation of neighborhood coefficients (NBCs) for each cell in the map of land use. They values of NBCs describe the Moore neighborhood for each cell (one-to-one relation, each cell is described by value of NBC which is unique characteristic of the configuration of 8 neighboring cells).

statistical comparison and visualization of NBCs for each cell, to determine on this basis, the most statistically significant occurring transitions between the neighborhoods and the final land use in the cells,

Construction of the rules of the transition for simulation and prediction of future land use changes using cellular automata and map algebra.

Classic analysis of land use is based on comparison previous and recent land use. The modified geographical model is based comparison of the values of previous NBCs and recent land use classes.

NEIGHBOURHOOD COEFFICIENTS (NBCs)

The idea of using of the neighborhood coefficients in analysis of land use changes is combination of map algebra and two-dimensional cellular automata. The aims of research were the formulation of the theoretical structure of the neighborhood coefficients (Werner, 2009), their operationalization and checking their usability in practice.

The NBC is calculated according to the mathematical equation (eq.1) involving the number describing land use classes and the consecutive numbers of the cells in Moore neighborhood. The operationalization of research procedure is the construction and application of special (linear) filter for original input map of the numbered land use classes.

The NBC is reversible. It is possible to reconstruct (calculate) the original input land use classes in Moore neighborhood (their nominal numbers) from the value of NBC of the center cell. This procedure let modify and extend geographical model of land use (Hagoort, 2006, after Tobler, 1979) to the purpose of definition the rules of succession of land use classes when comparing maps from two or more different years.

The mathematical foundation of NBC is modular arithmetic. The reconstruction of NBC could be proved using Chinese Remainder Theorem. The computational proof is the spreadsheet application.

NBC EQUATION



$$NBC_c = \sum_{i=0}^8 k_i * n^i, \text{ where } k \in \{0,1, \dots, n\} \text{ Eq.(1)}$$

i – the consecutive number of the cell in Moore neighborhood

k – the consecutive number, describing in ordered, nominal scale the class of land use,

n – the total number of land use classes.

The reverse algorithm of reconstruction of the original Moore neighborhood can be calculated using the following procedure: the modulo division of the NBC value (using the total number of land use classes as divider) gives the original land use class in the NW (North-West) cell. The second operation is modulo division of the quotient of the previous calculation and it gives the value of original land use class in the N (North) cell... and so on and so on.

The only assumption is the same sequence of the cells in NBC and reverse neighborhood cell values calculations.

APPLICATION OF NEIGHBORHOOD COEFFICIENTS FOR PREDICTION OF LAND USE CHANGES



Fig. 2. Steps in analysis of neighborhoods

For the simulation of land use changes in Poland the Corine Land Cover maps were used (1990, 2000 and 2006). The following nine classes of land use have been defined and numbered: (0) urban fabric, (1) industrial, commercial or transport areas, (2) mineral extraction, dump or construction sites, (3) green urban areas, (4) permanent crops or mosaic farmlands, (5) pastures, (6) standing forests, (7) natural & semi natural vegetation and (8) water courses and bodies. The maps of NBCs were calculated for all three studied years. They have been presented on the graph.

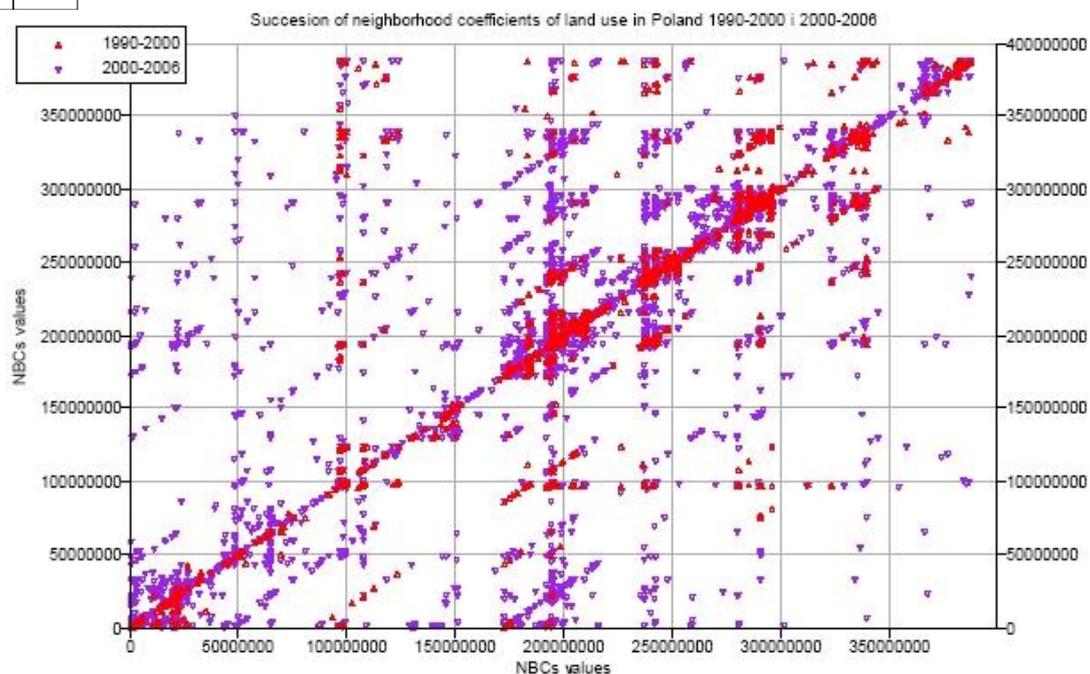


Fig. 3. The neighborhoods coefficients of land use in Poland 1990-2000 and 2000-2006

The values of NBCs are very large (even huge). That is why only the Moore neighborhood has been taken into account (because of the lack of computing power). The shape of the graph of the NBCs succession is similar (at the glance) to Sierpiński triangle fractal.

The descriptive statistics measures analysis allowed to define the set of transition rules of the recognized land use succession and then apply to the original map of land use in Poland in 1990. The form of transition rules were the 'if logical condition' which can be described e.g. if the defined predominant neighborhood exists in 1990 then the central cell of Moore neighborhood will change into the given class in 2000. There have been 45 rules construed.

Next these rules have been applied to map of land use in Poland in 2000. Then the simulated map compared with real map of land use in Poland in 2006 and also calculated Kappa coefficients of similarity (taking into account the spatial and statistical similarity of the simulated and real situation, see table 1). The results are comparable to the analogous simulations using SDSS Metronamica SL model (ITC©) for Warsaw Metropolitan Area (Korcelli, Grochowski, Werner, Kozubek, 2010)



Land use in Poland 2006	Real	Simulation	Kappa coefficients
	km ²		
urban fabric	9984	10981	0.72
industrial, commercial or transport areas	1448	1444	0.87
mineral extraction, dump or construction sites	499	517	0.07
green urban areas	673	512	0.64
permanent crops or mosaic farmlands	169519	167121	0.92
pastures	27357	31508	0.87
standing forests	94985	92920	0.97
natural & semi natural vegetation	4855	4427	0.73
water courses and bodies (including lagoons)	5392	5281	0.98

Tab. 1 Comparison of real and simulated land use in Poland in 2006

The last step in the application of NBCs to prediction of land use was the simulation of future land use in Poland in 2012 using the construed set of rules (see fig 4.).

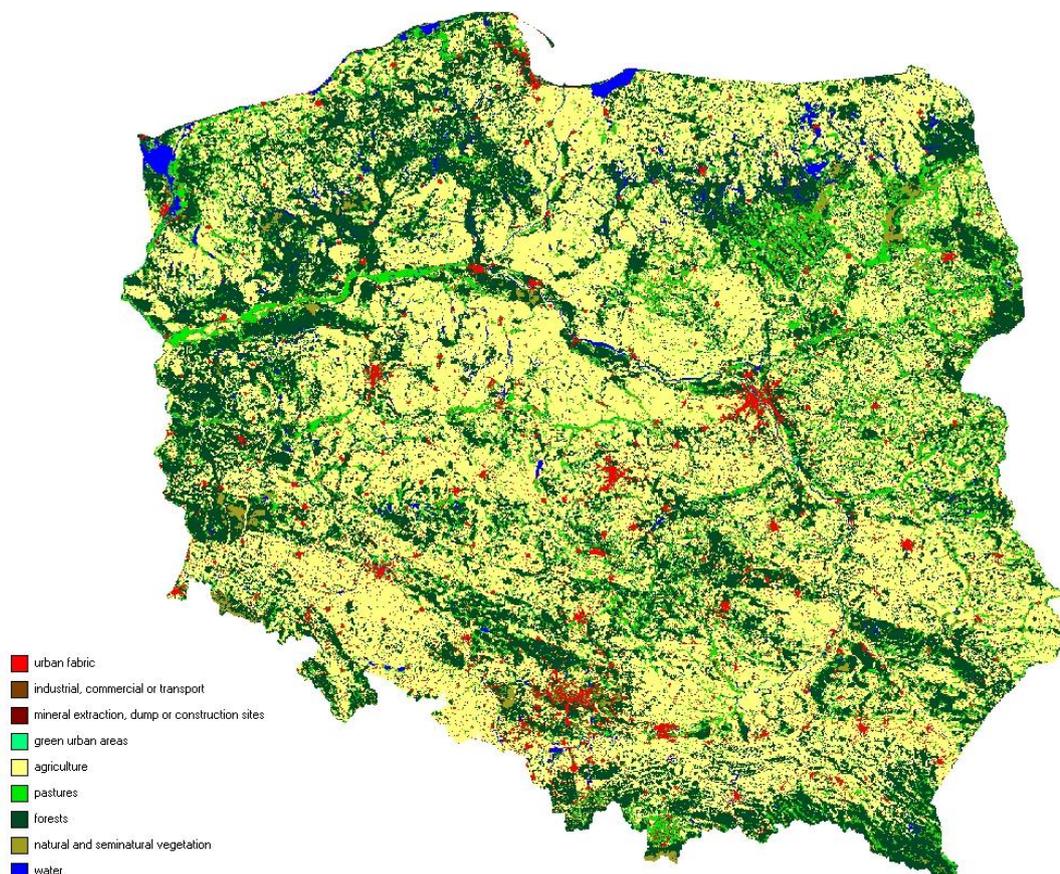


Fig. 4. Simulated land use in Poland in 2012

VISUALIZATION OF NEIGHBORHOODS OF LAND USE

It seems that the neighborhood coefficients can be applied to construction of the new kind of maps i.e. maps of neighborhoods of land use. Map of Neighborhoods of Urban Fabric in 2006 shows two predominant areas: core urban areas of large agglomerations and the agricultural neighborhoods of small cities. There are also others ones but they are marginal. The only phenomena presented on the map are the urban areas and the neighborhoods are distinguished with colors.

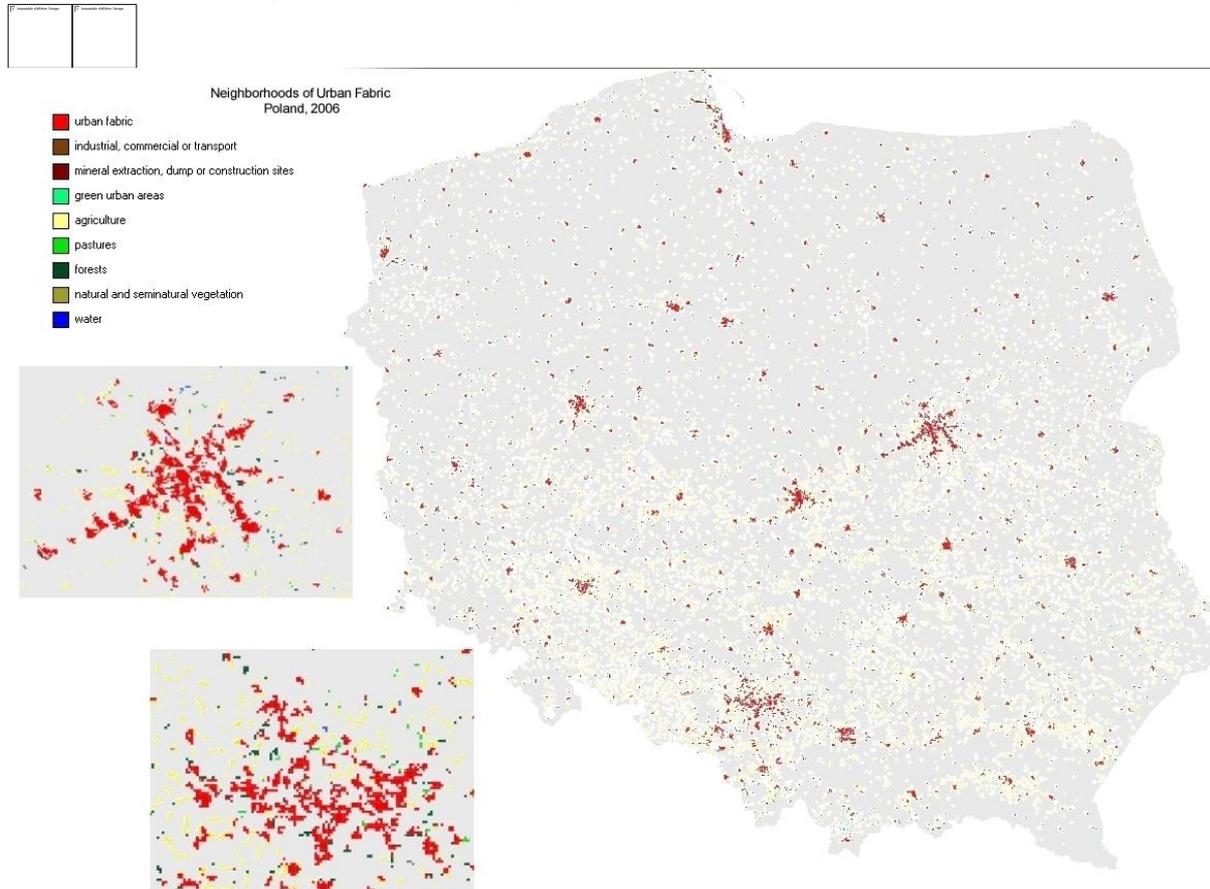


Fig. 5. Neighborhoods of Urban Fabric in Poland (2006)

The industrial areas are commonly concentrated and located within the range of urbanized areas.

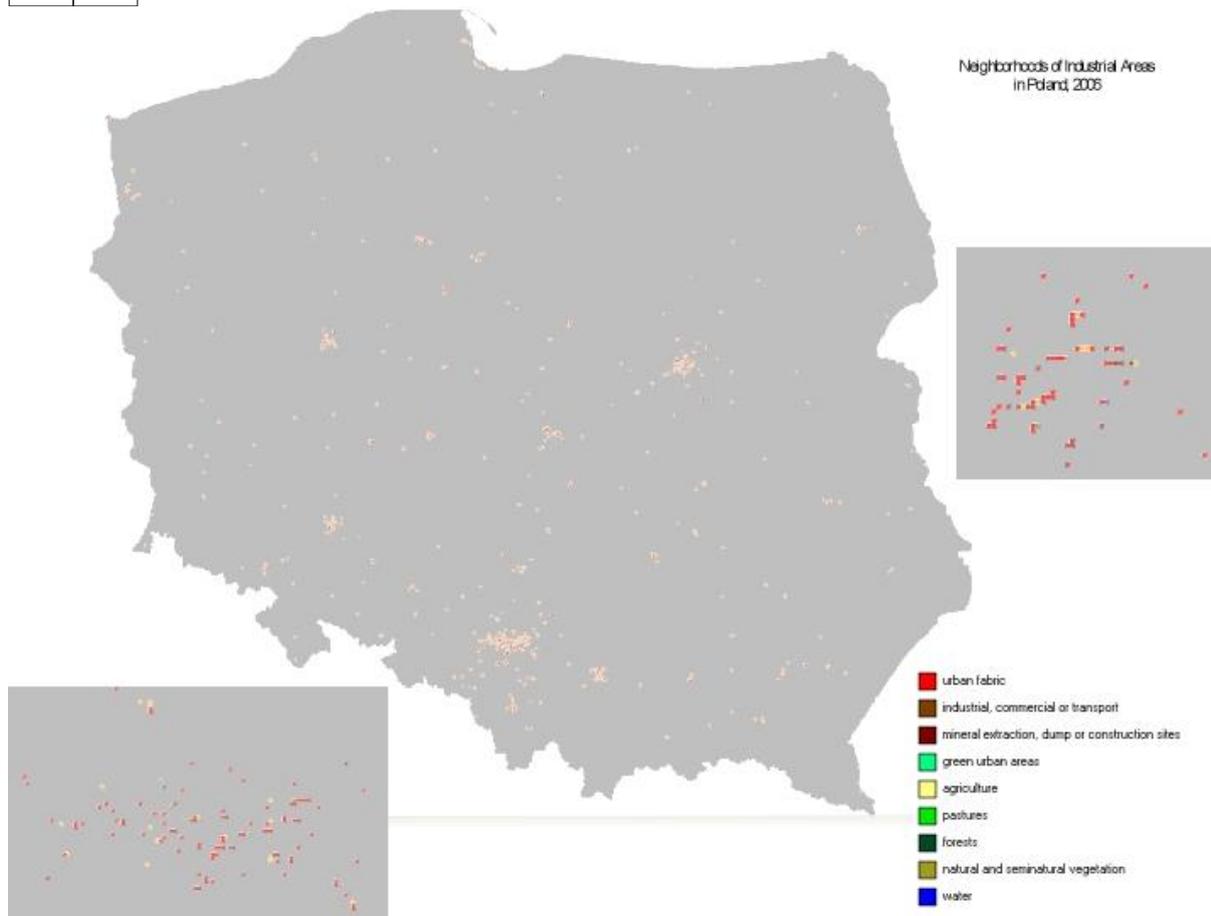


Fig. 6. Neighborhoods of industrial areas in Poland (2006)

The neighborhoods of agricultural areas are most often adjacent to themselves but the significant neighborhoods are also the forests and pastures.

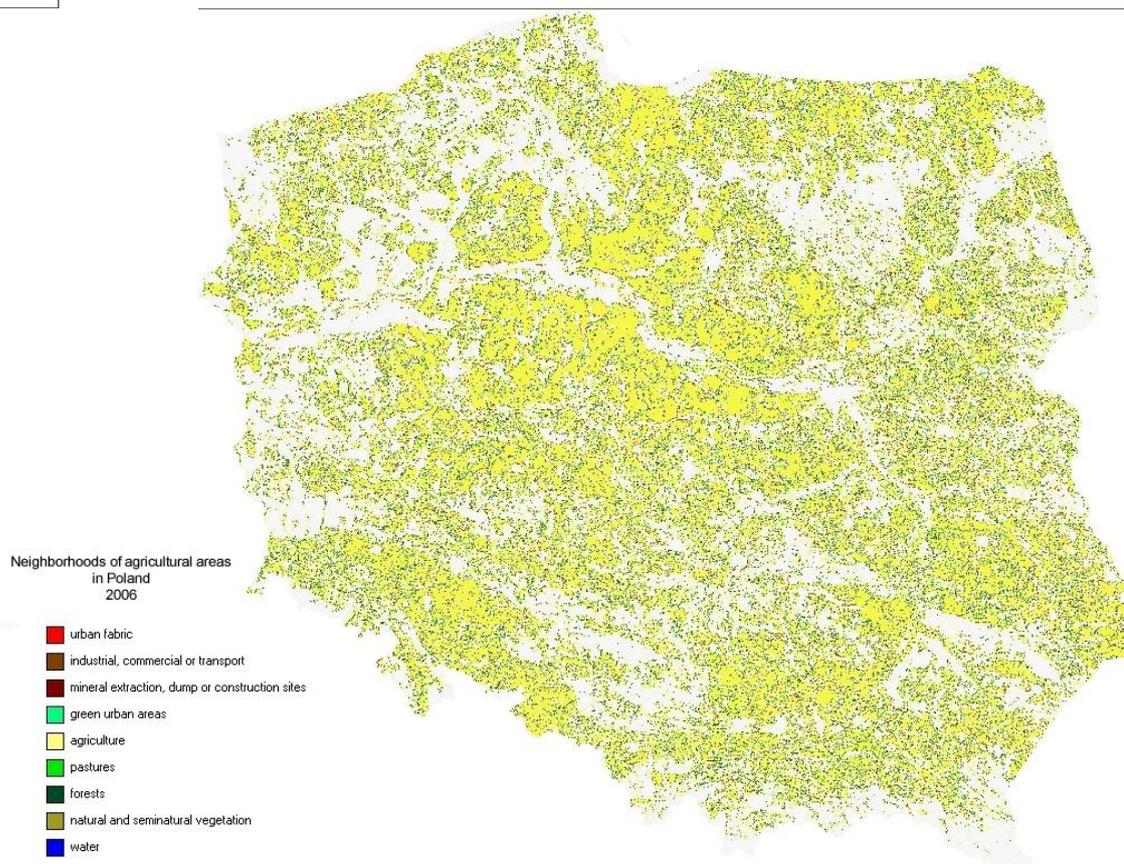


Fig. 7. Neighborhoods of agricultural areas in Poland (2006)

Assembling together the classic approaches to land use changes (overlay maps and crosstabulations) with the maps of neighborhoods coefficients it will be possible to extend the spectrum of statistical analysis and geovisualizations. It seems that the construed procedures make possible a new look on traditional analysis of land use changes.

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