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SIMULATION OF CHANGES OF THE WARSAW URBAN AREA 1969-2023 (APPLICATION OF CELLULAR AUTOMATA)

Abstract: It is possible to make analyses within the field of GIS applying cellular automata. One of the purposes of socio-economic geography is indirect understanding of the phenomenon by analyzing spatial patterns and inferring spatio-temporal processes looking rather for local hot-spots. The cellular automata are the tool both for spatio-temporal inferring based on local conditions and data visualization. The evidence is the case study of spatial simulation of Warsaw Urban Area (Poland).
The author verifies the hypothesis that the present layout and extent of the Warsaw agglomeration determines further directions of the city's spatial development. To this end, he employs a method based on cellular automata theory.

Key words: cellular automata, GIS, spatio-temporal processes, urbanization.

The aim of the research is to verify the hypothesis stating that existing spatial pattern and the range of the Warsaw urban area show tendencies for further spatial development of the city. The theory results from adopting a realistic assumption that the neigbourhood of urban and non-urban areas, which constitute the actual city border, is a potential front of urban spatial expansion.

During the process of simulation, socio-economic and physico-geographic factors are not taken into consideration. According to Foteringham et al., (2000), one of the purposes of socio-economic geography is indirect understanding of the phenomena by analyzing spatial patterns and inferring spatio-temporal processes. On the other hand, conventional deductive models are constrained especially in the case of complex 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).

One can observe a more and more frequent application of cellular automata to geographical research (Takeyama, Couclelis, 1997). “Cellular automata may be considered as (parallel-processing) computers, in which the initial configuration encodes the program and input data, and time evolution yields the final output” (Wolfram, 1982). “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 same method was applied to simulate the changes of the Warsaw urban range. The lattice is a homogenous lattice of cells (raster). Next, the range of Warsaw urban and suburbs areas in 1969 were drawn on the lattice. Thus the cells were characterized by two states: urban and nonurban.

The range of Warsaw urban and suburban areas was based on F. Uhorczak’s Poland Landuse Map (Uhorczak, 1969). It was a research polygon, scanned from a paper map, with the following geographical coordinates: longitude between 20^{0}22’45” E and 21^{0}51’18” E and latitude between 51^{0}58’00” N and 52^{0}30’38” N. The research area covers a part of Masovian Lowland: Warsaw Cirque and the surrounding upland plains. The Warsaw agglomeration is in the centre with small towns situated around it. The area covers 6445,25 sq. km. The map is in conical projection and the scale is 1:1000000. The map shows generalized situation of settlement from the maps of scale 1:100000, simultaneously preserving its geographical differentiation. One can precisely identify both agglomerations and small towns (*op. cit.*).

The CORINE land cover database – Version 12/2000 with extended coverage was used as the verification of the simulation results (source of map: The European Topic Centre on Terrestrial Environment, EEA – European Environment Agency). The Corine Land Cover inventory was performed in a 10 year period from 1986 to 1996. So the simulation covers the period from 1969 to 1996. The same research polygon was extracted (using geographical coordinates). According to the metadata file, all features on the map were digitized from an interpretation of satellite image printouts in the scale 1:100000. The positional accuracy (according to CLC specifications) was 150 m and 25 ha minimum mapping unit. The longitude that defines the center of a projection was 09°00’00” and the latitude that defines the center of a projection:. 48°00’00”. The Reference system was Lambert Azimuthal.

There where two raster maps used in the simulation (Fig. 1 and Fig. 2): starting (from 1969) and verification (1996) ones. Uhorczak’s map (1969) was also generalized for urban areas to be deleted which were not present in the Corine coverage in 1996. The maps present a spatial pattern using two states: 1 (black) for the urban and suburban areas, 0 (white) for the rest of cells.

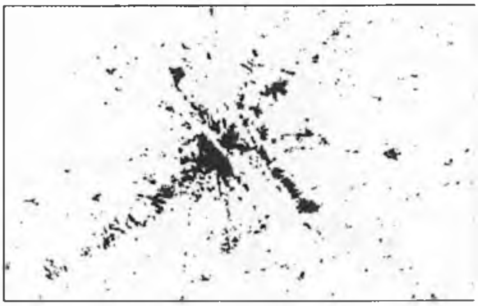

Fig. 1. Warsaw agglomeration and suburban areas on Poland Land use Map in 1969 (generalized)

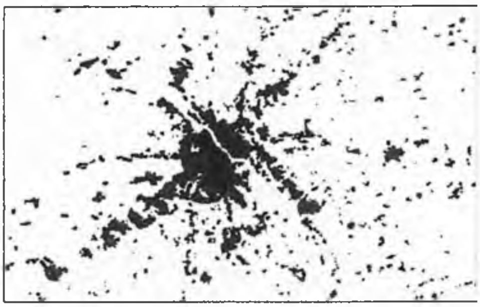

Fig. 2. Warsaw agglomeration and suburban areas in Corine Coverage in 1996

The following rule for cellular automaton was constructed {N1, NE6, E4, SE7, S2, SW8, W3, NW5, C9}.

5	1	6
3	9	4
8	2	7

It is an outer totalistic rule. The state of the central cell is evaluated by applying the state of surrounding ones and multiplied by appriopriate weights taken from the cellular automaton rule. The cellular automaton is also normalized so that they add up to 1.

Before the simulation Uhorczak's map (1969) was transformed, so that each cell showed the count of cell values in Moore neighbourhood (3 by 3 cells). Each cell has one value (from 1 to 9). There were 27 steps of simulation corresponding to 27 years from 1969 to 1996). The results of the simulation are presented in Fig. 3.

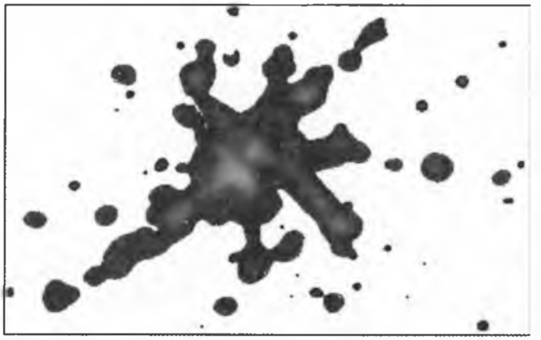

Fig. 3. Simulation of Warsaw urban and suburban area from 1969 to 1996

The simulation was performed in macro command in Idrisi32 GIS software (filtering the map using the cellular automaton as kernel). Next, a statistical summary (in Table 1) and cartographical comparison were made (Fig. 2, 3).

Table 1.

Percentage of simulation and real range of Warsaw urban and suburban area in 1996

Percentage	Area of real range (%)	Area out of real range (%)	Total
Area of simulated range (%)	9,07%	11,56%	20,63%
Area out of simulated range (%)	2,39%	76,98%	79,37%
Total	11,46%	88,54%	100%

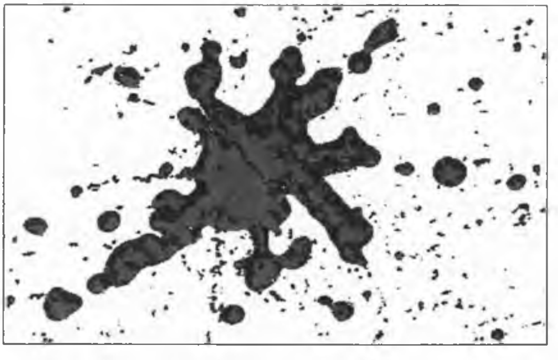

Fig. 4. Comparison of simulated and real range of Warsaw urban and suburban area in 1996 (dark shadow – simulated range)

As Wolfram stated (2002:299) „Three possible mechanisms that can be responsible for 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 stochastics models. The second is suggested by chaos theory. The third mechanism is suggested by the behavior of simple programs (*op. cit.)*.

Looking for a more precise rule for cellular automaton the following was constructed and employed to simulation: {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}:

1	1	1
1	92	1
1	1	1

Exploration of rules proved that other rules with more weight in the center are not applicable because they are normalized (see table 2).

The simulated area is 1.3 larger than the real one. It covers 77% of cells with real range. Taking into account both: regions where real and simulated range are identical and regions where there is neither simulated nor real area – they covered 91,26% of the map (see the NW-SE diagonal in table 2).

Table 2.

Percentage of simulated and real range of the Warsaw urban and suburban area in 1996. Rule: {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}

Percentage	Area of real range (%)	Area out of real range (%)	Total
Area of simulated range (%)	8,84%	6,11%	14,95%
Area out of simulated range (%)	2,63%	82,42%	85,05%
Total	11,47%	88,53%	100%

The maps present the results of simulation. Fig.5. for simulation during the period from 1969 to 1996 and fig. 6. for forecast in 2023 for the rule {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}.

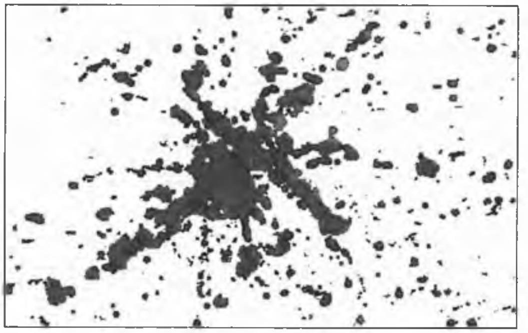

Fig. 5. Comparison of simulated and real range of the Warsaw urban and suburban area in 1996 (light grey depicts the regions where both are identical, white depicts regions where there are neither simulated nor real ranges). Rule: {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}

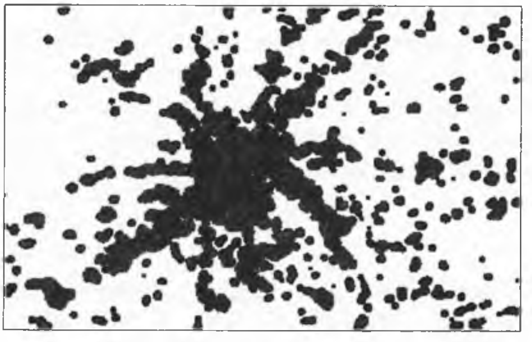

Fig. 6. Simulation of the Warsaw urban and suburban area in 2023. Rule: {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}

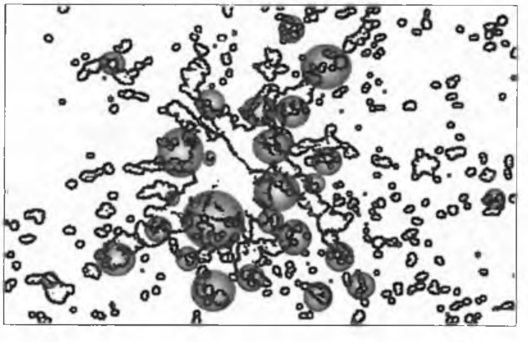

Fig.7. Simulated areas of spatial development of the Warsaw urban and suburban area in 2023. Rule: {N1, NE1, E1, SE1, S1, SW1, W1, NW1, C92}

A visual analysis of maps of the Warsaw urban and suburban area proves that these are the frontier regions of spatial development. The Warsaw urban and suburban area will grow more than twice up to the year 2023 (276 sq. km. in 1969, 740 sq. km. in 1996, to 1927 sq.km. in 2023 r.).

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Translated by the author