Rural or Urban? Delimitation of The Czech Republic Municipalities Using Łukasiewicz T-norm

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Abstract: Due to substantial population movement last two decades in The Czech Republic,it is very difficult to delimitate rural and urban areas. This population movementtogether with new settlement, improvement of municipality infrastructure andother socioeconomic changes are characteristic features of suburbanization. Thisphenomenon has affected many rural-like municipalities, especially thosesurrounding larger cities. Villages with close contact to adjacent cities have become more urban-like since then and vice versa. To maintain sustainability and quality of life in peripheral municipalities development funds has beenestablished. But these funds respect only one strict rule - municipalities with lessthan 2,000 inhabitants can reach the financial support in The Czech Republic. This sharp limit is no moresuitable although being very clear and simple. Fuzzy sets and operationsallow to (1)combine more socioeconomic indicators for complex delimitation, (2) definetransitional municipalities in order to refine their delimitation and (3) respectdynamics of suburbanization. This paper presents the usage of fuzzy logicprinciples for proper delimitation of rural and urban areas which much morerespects aspects of suburbanization and helps consequent fund policy to be moreapplicable.

Key-Words: fuzzy logic, rural and urban areas, Łukasiewicz T-norm, GIS, geocomputation, delimitation.

1 Introduction

The statistical survey has a long and rich tradition in European countries and The Czech Republic is no exception. Nowadays, the Czech Statistical Office (CZSO) has a number of statistical databases available, whose thematic scope is very wide and thus suitable for geocomputation and consequent geovisualization. Many of those analyses are depending on the data available and on its methodological steps. In this matter, different approaches of data processing might lead into different results. This aspect has to be taken into account especially in decision making process. These days, the use of GIS (Geographic Information System) in decision making in spatial issues is becoming matter-of-course. And more, fuzzy logic serves as a robust tool to support decision making itself [2, 7, 10, 11, 12]. Decision making process could not be carried out without experts in particular field of study. And concept of fuzzy logic offers the mathematical apparatus for analytical processing of that expert defined information (in spoken, vague language) [1, 2, 6, 10]. Joining visualization capabilities and fuzzy modeling together is greatly useful and requested in spatial oriented decision making processes.

One from these processes is defining rural and urban municipalities – Local Administrative Unit 2 (LAU 2) according to the Eurostat administrative classification system. Importance of this municipality definition might not be seen at first, but accurate delimitation of these two types of municipalities is very important because of one simple reason – financial support of regional (rural) development, either from EU or The Czech Republic resources, depends on the fact in which type (rural or urban)the municipality falls. One widely accepted methodological guide for delimitation of such municipality areas is provided by Organisation for Economic Co-operation and Development (OECD) and is based on the one single indicator: total population (threshold is 2,000 inhabitants) and its derivative population density with threshold 150 people per km^2. Visualization of

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The Czech Republic municipalities classification into rural and urban area is in Fig.1.

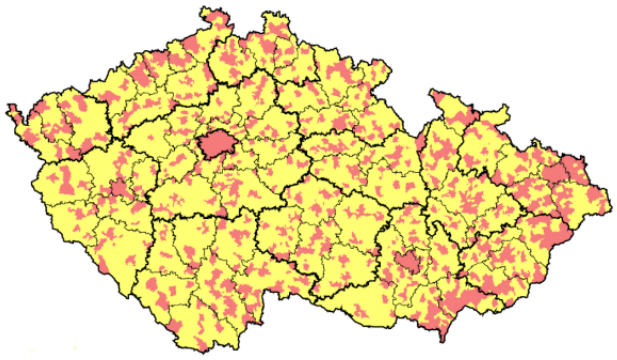

Fig. 1.Classification of The Czech Republic municipalities into rural (yellow) and urban (red) areas according to OECD methodology [3].

Nevertheless it is obvious that character of rural or urban area is not depending only on one indicator. One strict rule determines municipalities into these two types of areas in sense of Boolean logic, which is no longer sufficient due to suburbanization trends. What if the municipality with population close to threshold value increases number of inhabitants to e.g. 2,001? This would exclude the municipality from financial support but the municipality is remaining rural-like. Using the fuzzy modeling it is possible to set the transitional zone between rural and urban area (and still using only one indicator) and smoother the abrupt Boolean delimitation. The transitional zone is in fact the fuzzy membership. If more indicators are added into the fuzzy modeling, to getbetter estimates of municipality type that reflect current suburbanization trends.

2 Methods and Data

General concepts of fuzzy sets are nowadays well-known and described in detail by many authors, e.g. [2, 4, 6, 11]. Generally, with the fuzzy approach, municipality can be evaluated such as the 0.7 belonging to the urban type and 0.3 belonging to the rural type (maximal fuzzy membership for urban area is equal to 1, minimal is equal to 0 and vice versa for rural areas). This will ensure a smoother transition from the urban municipalities through the transitional type to the rural type (and vice versa). It is necessary to note that there is a difference between fuzzy membership/degree of truth and probability of some event. Basically, the concept of fuzzy logic is distinct from probability theory, because of its vaguely defined sets (in other words − fuzzy logic works with some uncertainty or vagueness from the beginning and uses expressions “around”, “almost”, “perhaps”, etc.). Although the same indicators are used, operations using fuzzy numbers bring some uncertainty in the definition of rural areas and smooth the transition between urban and rural areas.

Fuzzy methods take into account some uncertainty and offer a gradual membership to rural or urban area for municipalities instead of classic Boolean logic membership defined by yes/no or 1/0 status (to be entirely rural or urban area). Thus, the abrupt transitions between urban and rural type of municipalities can be eliminated using fuzzy logic and fuzzy sets. Simply said, fuzzy logic makes the transition between rural and urban area significantly smoother and then it could be claimed that municipality belong to urban or rural area with some degree of membership in range <0, 1>.

For transitional zone modelling and consequent municipality delimitation, Łukasiewicz T-norm and its modification is usedin this paper. Firstly, two indicators recommended by OECD and Czech strategic documents were used (Table 1). These indicators were transformed to fuzzy numbers using linear fuzzy membership function described as follows:

$$\mu_{\tilde{A}} = \begin{cases} 1 & x \geq b \\ \dfrac{x-a}{b-a} & a < x < b \\ 0 & x \leq a \end{cases} \qquad (1)$$

whereμ_A is municipality degree of membership, a is lower threshold value, b is upper threshold value and x is indicator value.

This principle of deriving municipality degree of membership is depicted in Fig. 2. The transitional zone is between a and b value.

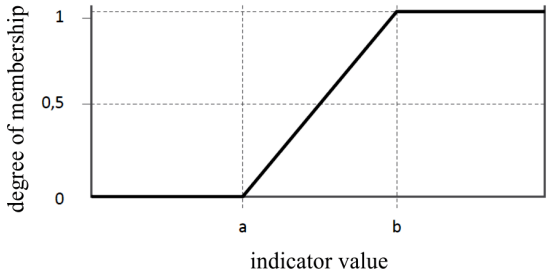

Fig. 2. The principle of deriving municipality degree of membership.

Upper and lower threshold were set according to OECD and Czech strategic documents in two variants. First one strictly follows OECD and Czech recommendations (Variant 1), second one is experimentally modified (Variant 2) to take into

consideration those municipalities close to 2,000 inhabitants.

Table 1. Threshold values for fuzzy membership calculations.

	Total population		**Population density (people per km^2)**
	Variant 1	Variant 2	
Lower threshold	2,000	1,500	100
Upper threshold	5,000	5,000	200

Since fuzzy numbers for all municipalities for both indicators are calculated, it is possible to combine them using Łukasiewicz T-normin order to obtain overall fuzzy degree of membership.

Łukasiewicz T-norm logic is based on intersection of two fuzzy sets. Generally, this intersection is stricter than common intersection or simple average [7]. In fuzzy set theory, the Łukasiewicz intersection is defined as [4]:

$$C = A \otimes B \tag{2}$$

just when

$$C(p) = A(p) \otimes B(p) = 0 \vee (A(p) + B(p) - 1) \tag{3}$$

where C is fuzzy intersection, A and B are fuzzy sets (indicators) of objects p.

Equation (3), sometimes called strong conjunction, implies that sum of both membership grades subtracted by 1 is compared with 0. If both indicators have fuzzy membership lower than 0.5, then overall municipality membership is equal to 0. And vice versa if both memberships are equal to 1, then overall municipality membership is equal to 1. Analogically, if the sum of indicators membership values is greater than 1, the transitional zone is defined. Fuzzy degree of membership was calculated for every single municipality in The Czech Republic and results are displayed via maps in Fig. 3 and Fig.4. Maps are depicting municipalities degree of membership according to rural area (fuzzy membership is equal to 1), but it is very easy to obtain fuzzy membership for urban areas by calculating the complement.

For further analysis, another four indicators were added to model rural and urban area using fuzzy sets. These indicators should represent characteristics of municipality more accurately than "only" total population and population density. One indicator – total population in municipalities**(A)** – is included again into computation together with new ones:

- **(B)**Population on built area
- **(C)**Ratio of flats in family houses and permanently occupied flats (in %)
- **(D)**Population on completed flats in 1993 2006 (in %)
- **(E)**Population change (1993 – 2006; in %)

Threshold settings are shown in Table 2. Total population upper threshold was modified according to preceding simulated calculationsencompassing all indicators.

Łukasiewicz T-norm was experimentally modified in order to take into account new set of indicators:

$$F = A \otimes B \otimes C \otimes D \otimes E \tag{4}$$

just when

$$\begin{aligned} F(p) &= A(p) \otimes B(p) \otimes C(p) \otimes \\ &\otimes D(p) \otimes E(p) = \\ &= 0 \vee (A(p) + B(p) + C(p) + \\ &+ D(p) + E(p) - 2.5) \end{aligned} \tag{5}$$

where$F$ is fuzzy intersection, A,B, C, D and E are fuzzy sets (indicators) of objects p.

Subtracting coefficient *2.5* was chosen as a half of the maximum sum of fuzzy sets A to E (similarly to previous Łukasiewicz T-norm (3)). If the resulting number $F(p) < 0$ then the fuzzy membership is equal to 0 (it is entirely rural area), otherwise was the resulting number normalized into fuzzy scale <0; 1>, with urban area fully membership equal to 1. Result of this modified Łukasiewicz T-norm is shown in Fig. 5.

Table 2. Threshold values for fuzzy membership calculations.

	(A)	**(B)**	**(C)**	**(D)**	**(E)**
Lowerthreshold	1,500	3,500	70	45	-5
Upperthreshold	3,500	6,500	90	55	10

Dataset used for the fuzzy analysis was provided by CZSO and contains 6,249 municipalities with

desired indicators for each one. Some indicators originate from Czech Population and Housing Census held in 2001, others from annual statistical surveys in particular area.These statistical data were joined with geodata in Esri ArcGIS for Desktop software, where final visualizations were made.

3 Results

Fig. 3 shows municipalities delimitation calculated by Łukasiewicz T-norm using 2 indicators in Variant 1.Municipalities with high urban area membership are located in neighborhood of bigger cities (Prague, Brno, Plzeň or Olomouc). These areas are typical for suburbanization processes and therefore the degree of membership of small municipalities is quite high and became more urban-like recent decade. In addition to that there is high urban area membership in southeastern part of The Czech Republic, although missing a main city center that would cause the suburbanization. This part of The Czech Republic is very specific by occurrence of relatively large municipalities that are closely connected to each other and forms middle-sized town cluster. On the contrary, typical rural regions of The Czech Republic are identified on the county and country boundaries, especially in the central part of the country. The most of the rural-like municipalities are located in counties peripheral parts and have at least two aspects in common – the nearest larger city is many kilometre distant and the terrain is hilly. Overall polarity of municipalities in these regions indicates that significant amount of citizens are moving to cities and smaller municipalities are losing their population. This process makes the difference between urban and rural areas deeper. And especially those regions should be supported by rural development funds.

Figure 4 depicts the Łukasiewicz T-norm using 2 indicators Variant 2. The main difference from Variant 1 is that the lower threshold is moved down to 1,500 inhabitants which resulted in increased number of municipalities that have higher urban area membership. In other words, formerly pure rural municipalities became less rural and gained urban area membership. Also municipalities that are in close relationship with large cities increase their urban area membership. This is confirmed in Table 3 where numerical results are mentioned. Nevertheless, basic spatial patterns are similar to those observed when applying Variant 1. Major changes in municipalities membership occurred nearby large and middle-sized cities and vice versa. Peripheral and outskirt areas remain rural-like even after Variant 2 application.

Figure 5 shows municipalities delimitation calculated by modified Łukasiewicz T-norm using 5 indicators. It is important to note that this approach brings more uncertainty because of additional data (indicators) are included [5]. This approach retained full membership to rural areas of those municipalities which are considerably rural-like in previous two analyses and also reduce full urban membership of small cities, which are now classified in transitional zone. Major spatial configuration and pattern of municipalities with the respect of their rural or urban membership corresponds with previous analyses. But the whole transitional area became wider by using five indicators and this approach appears to be less strict than previous ones. It is interesting that Ostrava, the third largest city located in northeast part of The Czech Republic, lost its full urban membership. This is because of the specific character of the city which is not compact and additional indicator affected its final membership value.

Table 3 shows summaryof municipalities delimitation using above mentioned three approaches. According to the Table 3, full membership to urban area varies between approaches with significant difference in the third method where only 160 municipalities are classified as fully urban areas. On the other hand, full rural membership decreased from 5,213 to 4,931 using various approaches. Relatively small differences are between first and second method using two indicator but diverse thresholds. Transitional zone (0,001 – 0,999) defined by modified Łukasiewicz T-norm using 5 indicators covers two times more municipalities than first two approaches and makes the delimitation less strict.

Table 3. Numerical results of the fuzzy analyses. Łukasiewicz T-norm using 2 indicators in Variant 1 **(1)**, Łukasiewicz T-norm using 2 indicators in Variant 2 **(2)** and modified Łukasiewicz T-norm using 5 indicators **(3)**.

Numberofmunicipalities			
Rural area membership	**(1)**	**(2)**	**(3)**
0	554	596	160
0,001 - 0,250	75	99	163
0,251 - 0,5	105	104	172
0,501 - 0,750	119	176	286
0,751 - 0,999	183	229	537
1	5,213	5,045	4,931

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4 Conclusion

Presented fuzzy approach for proper municipality delimitation confirmed the assumption that abrupt Boolean methods for rural and urban areas delimitation is not sufficient enough to take into consideration recent suburbanization trends. Using fuzzy sets and basic arithmetic operations it is possible to smoother the transition between rural and urban areas. This allows rural development policy makers to do better decision in order to support underdeveloped rural areas more precisely and sensitively respecting current demographic trends in east Europe.

Whole calculation of municipalities degree of membership was made using only two indicators in the first parts of the paper − total population and population density. With only these two indicators, it is possible to compute four different delimitations (as is shown above) of municipality type with degree of membership. This was made because of the comparison with current OECD delimitation. When four more indicators were included, new and more accurate results emerged. It could be stated that the more indicators added into calculation, the more accurate and confident the results are.

Presented fuzzy approach could bring a new decision making tool for finance redistribution towards rural or urban area municipalities. Very simple and less real situation respecting current method for municipality type delimitation should be replaced by more comprehensive approach. And fuzzy set and logic are representing such approach.

Rural and urban area delimitation using fuzzy sets and logic was and is still intensively studied by authors at Department of Geoinformatics (Faculty of Science, Palacky University Olomouc) in cooperation with the CZSO (e.g. [8, 9]).

5 Acknowledgement

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Appendix

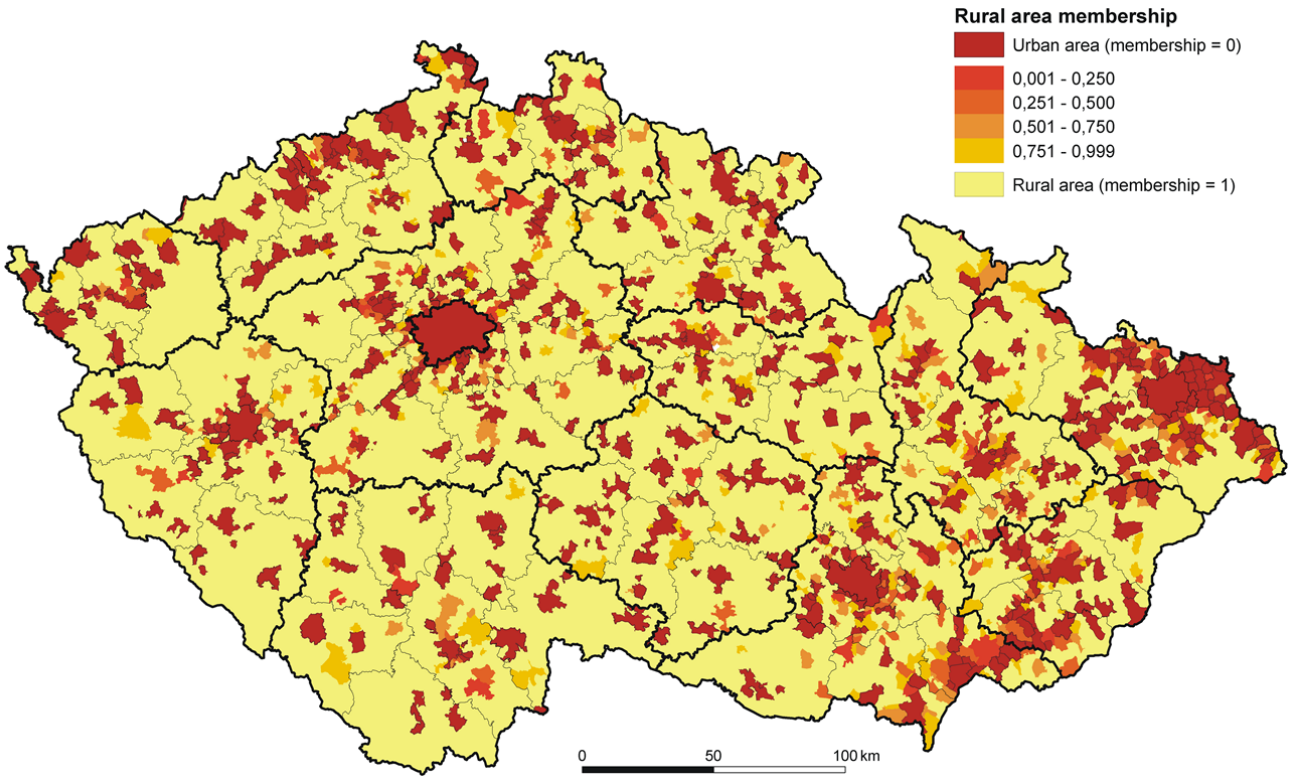

Fig. 3. Rural area membership by Łukasiewicz T-norm using 2 indicators (Variant 1).

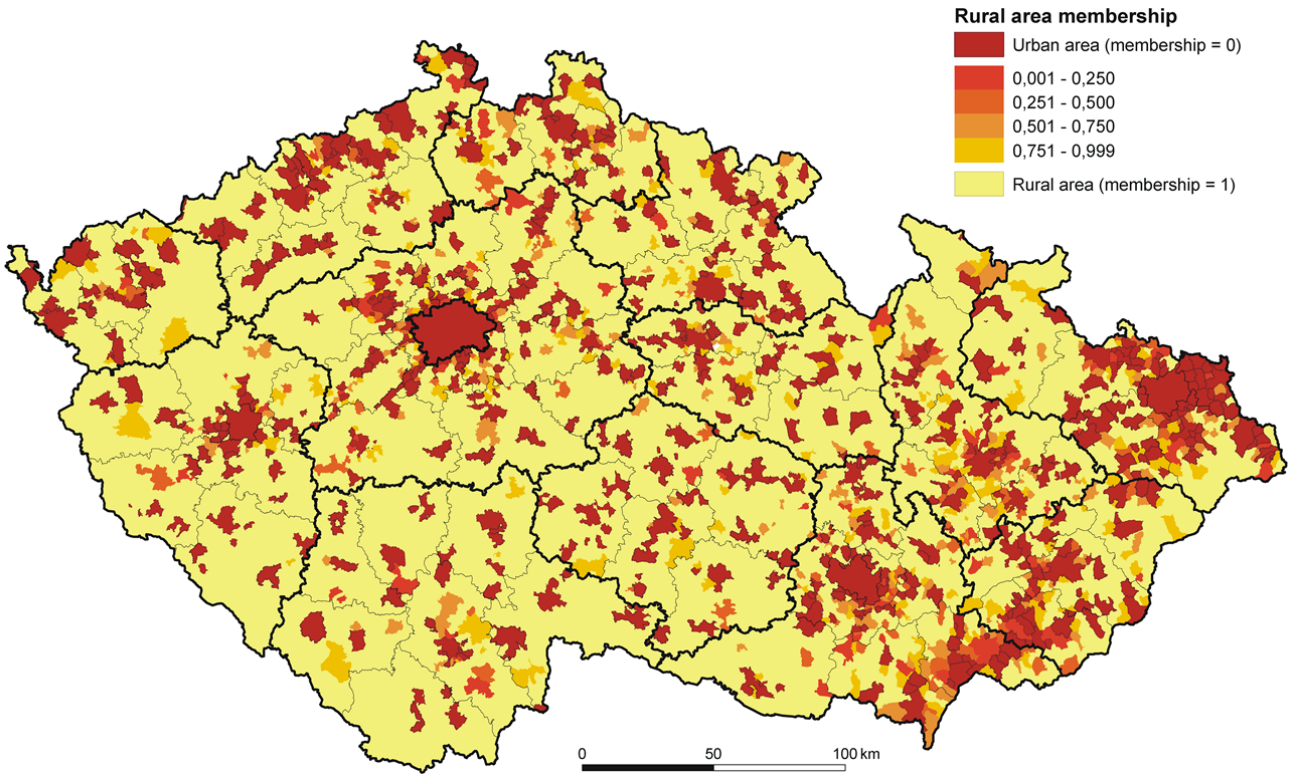

Fig. 4. Rural area membership by Łukasiewicz T-norm using 2 indicators (Variant 2).

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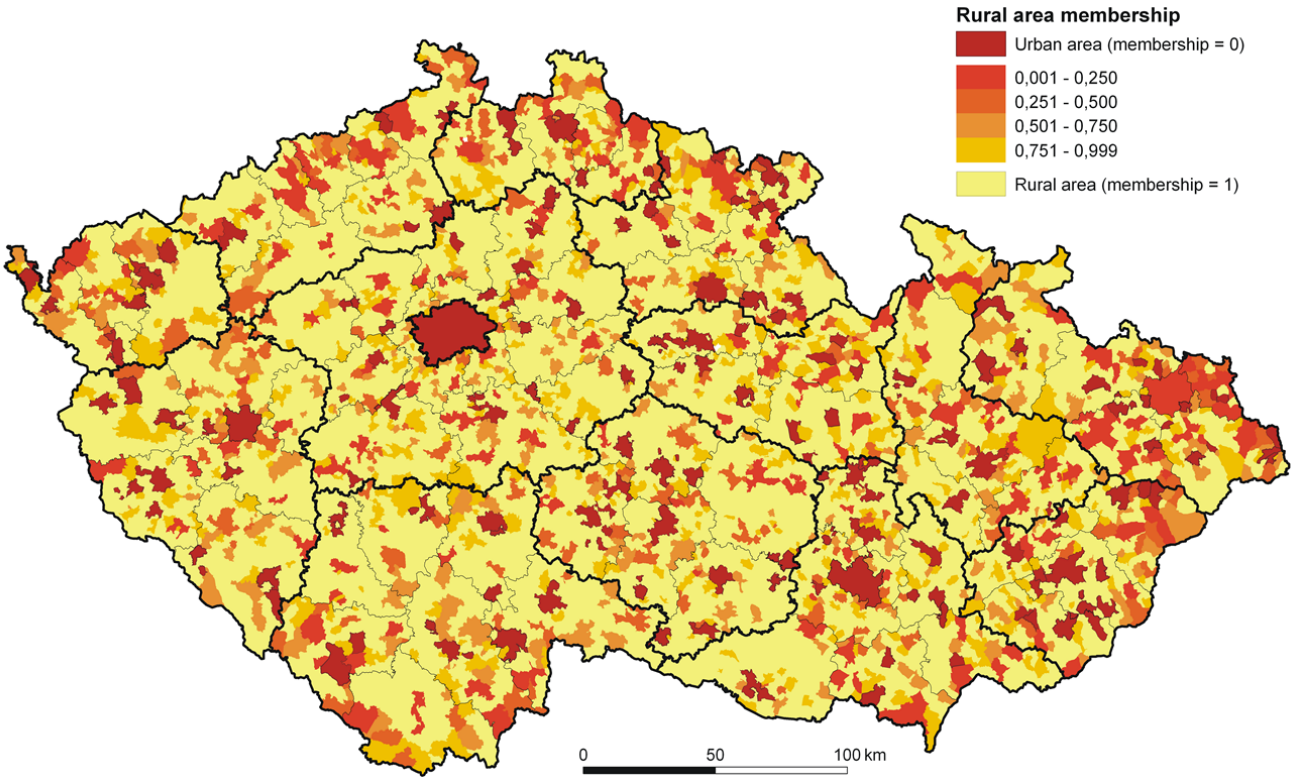

Fig. 5. Rural area membership by modifiedŁukasiewicz T-norm using 5 indicators.

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