

Further GIS solution for the better definition of geographical/landscape boundaries

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Abstract: The precise delineation of geographical landscapes at the relevant limits of error is a key procedure from the perspective of landscape planning, development and management. Besides, the term landscape is one of the fundamental spatial categories of geography, thus the definition of its boundaries is of key importance. Delineation of landscapes, being highly integrated units, is not straightforward at all. For example botanical, pedological or geomorphological patterns can be highly different, and patches usually cannot be fully overlain, moreover the mentioned landscape forming elements do not exhibit distinct boundaries within themselves either. Consequent spatial errors and errors of content related to integration are superimposed by temporal and technical errors. When determining the type of boundaries the ecotone approach has been accepted, namely landscape boundaries have to be perceived as transitional zones with a varying width. As a consequence the evaluation of boundaries with fuzzy methods seems logical. Our study covers four environmental factors, and fuzzy boundaries are determined for these. In the Carpathian Basin the characteristic length of boundaries varies between a few 100 m and a few kilometres.

Key words: accuracy of the landscape borders, fuzzy method, ecotone, geostatistical method

Introduction

It has been an issue of geography to establish, how “accurately” it is possible or necessary to draw the boundaries of (natural) landscapes. The debate-provoking statements of Csorba (2008) inspired us to present some of our results regarding the boundaries of landscapes. We share his debate-provoking claims to a great extent, for which Baranyi (2009) has stated an answer from a professional aspect. In our study a newer, fundamentally quantitative interpretation formed in connection with landscape boundaries has been used. Geoinformatical, fuzzy methods and neutral data were used in the mentioned examples. The surveys were carried out in micro-region scale, concerning the territory of Hungary.

The concept of landscape and its interpretations

Several disciplines applying the concept use the landscape from their own point of view. The concept is used in everyday life as well, thus it is not surprising that a confusing system of notions has evolved around it. Thus, for instance according to the landscape-architects and garden designers the landscape has developed on *natural basis* due to social activities, it constantly changes, although it is a unit that can be treated as constant in its basic framework (Csima 2009). Others regard the landscape as basically an *aesthetically* homogenous *category* (European Landscape Convention 2005), and there are some, who primarily regard it

as a *functional unit* (e.g. in the fields of agriculture, forestry, regional analysis and planning). The list could be continued with several other approaches of natural and social sciences (e.g. ethnography), and as a result, the debate concerning the interpretation of the content of landscape can hardly be concluded. The geographical approach to landscape is mostly based on natural geography (a category of “natural history” – Marosi 1981), and according to this interpretation a section of the surface constitutes a unique, complex unit based on the structure and effect of the processes influencing it (Pécsi – Somogyi – Jakucs 1971, Mezősi 2003). In the present days, the scientific explanations mostly use this approach as well.

Thus today in geography we regard the landscapes as entities whose frameworks are defined by natural factors. More accurately, distinct units with characteristic values are formed by all the (natural) landscape shaping factors, complemented by the characteristic entities of social activity, and in interaction with the artificial elements. The primacy of the natural landscape shaping factors and the role of the other landscape shaping factors in modifying this system of connections are expressed in this approach, and it is understandable that as a result, the use of the ethnographic, historical categories, which are difficult to delimit on the basis of natural factors, was often dismissed. As a result, the notion of the geographical landscapes which also connect to everyday life (“liveable landscapes”) only evolved in the case of the Őrség, Hetés or Vendvidék, and the local characteristics also present in the meso-regions of the Sopron-Vasi Plain or Alsó-Zagyva Valley are not associated with these regions. For this reason e.g. the Jászság is not present in the inventory of micro-regions (Marosi – Somogyi ed. 1990). The activity of the society is closely connected to the landscape, as several landscapes, cultural landscapes are the results of it (e.g. Hortobágy).

Several approaches have evolved based on the interpretation of the role and importance of the natural and social factors present in the landscape, but especially on the judgement of the role played by the anthropogenic influences in the shaping of the landscape. The natural landscapes

are considered to be the integrated unit of (natural) factors, and they literally do not exist today due to significant anthropogenic influences. Their analysis can (could) be carried out with typically scientific methods due to the fact that the parameter-constructors are of similar character. A well-definable hierarchy can be formed in this field with the more uniform methods. However, the landscapes can be regarded as having been formed mainly by the anthropogenic activities, which is the basis of the *cultural landscape* concept, that characteristically means landscapes formed by the influences of society, and its processes are mainly regulated by anthropogenic factors.

The different conceptions make several people wonder whether landscapes exist as objects at all. Some consider it an obvious choice to treat landscape as an epistemological category, according to which – in the primary approach – plains, floodplains and volcanic mountains are indeed clearly distinct landscapes (Hajdú-Moharos et. al. 2000). The extent of the anthropogenic influence can, however, override these categories, that is, occasionally this is not a stable areal unit denotation. The scientific explanation of the notion dates back to Humboldt, who had no doubt about their existence and characterised them in a complex way in the course of his journeys. The uncertainty among the numerous interpretations is reflected in the opinion stating that the landscape is actually a mere fiction, it does not exist as a separate object and it can be considered an aesthetic category instead. However, the landscapes were defined as loose units of natural and social factors even before the geographical approach used today emerged, thus for instance the landscape descriptions of Kogutowitz (1930, 1936) were based on ethnographic and natural factors and the historical land use of the given landscape. That is, their existence was not doubted, but their contents and extent was, when, for instance he defines the landscape by the ethnographic boundaries (e.g. the name of the Ormánság refers to the relief), or when he matches the landscapes to orographic data (e.g. Mecsek).

If a task of landscape planning, development, arrangement or protection needs to be solved, then – as well as the margins of error to be given – the accurate delimitation of landscapes is also an essential task. The more accurate areal limitation is similarly required when ensuring the safe functioning of the environment (Csorba 2008). Units established through different concepts can hardly provide a basis for the above tasks, moreover, even the existence of a “landscape” born this way is doubtful (e.g. the Alvidék named after the native population, or Drávaszél – Kogutowitz 1936, or the part of Kemeneshát marked as Cser). A good example of application within the framework of regional planning and development is one of the most successful products of geography,

the inventory of micro-regions prepared in 1990 (and updated in 2010) (Marosi – Somogyi ed. 1990), which we can be proud of, however, it is known that it is the integrated system of geography that would suit such tasks, which could not be realised in the unclear conditions.

Interpretation of the landscape boundaries

Prinz (1936) already addressed the question concerning the boundaries of the landscapes, and according to him it does not “seek natural boundaries” but rather corresponds to the administrative boundaries formed as a result of several natural and social influences. As it has been mentioned above, the content of the landscape has changed to a great extent in the last 60-80 years, and the professional environment, (e.g. ethnographic – Kogutowitz, or morphological – Bulla) in which it was interpreted, has changed significantly. The older concepts of landscape categorizations (landscape structures) and those prepared in the last 20 years, only show agreement on the levels of macro-regions and meso-regions.

Accurate knowledge of the units regarding the different source- and derivative data is required, as they can be important not only for the answers demanded by the discipline, but also from the point of view of application. From the point of view of science the demand for a scientific definition of the different territorial unit arises, i.e. the requirement that, through the knowledge and proper use of the technique of defining the landscape units (types), the different evaluators should recognise identical units. The fact that these units are also the functioning elements of the geographical systems can also require the feasibly accurate landscape (areal) delineation. From the aspect of the examination concerning the boundary, it is immaterial if it refers to the content category of the geographical landscape or that of the landscape type (recently the expression “landscape character” of similar meaning has been used instead). In the present study the writers do not aim at separating these notions.

The boundaries of the landscapes and landscape shaping factors do not correspond to one single line, which cannot indeed be expected, as in most cases the factors themselves cannot be delimited by clear lines. Generally, the lithological, topographical, soil, or vegetation boundaries do not correspond strictly even on the level of macro-regions (figure 1) although the inevitability of their interconnectedness is known (e.g. the connection of lithology and the soil). From the aspect of the boundaries, the accurate exploration of the connections between

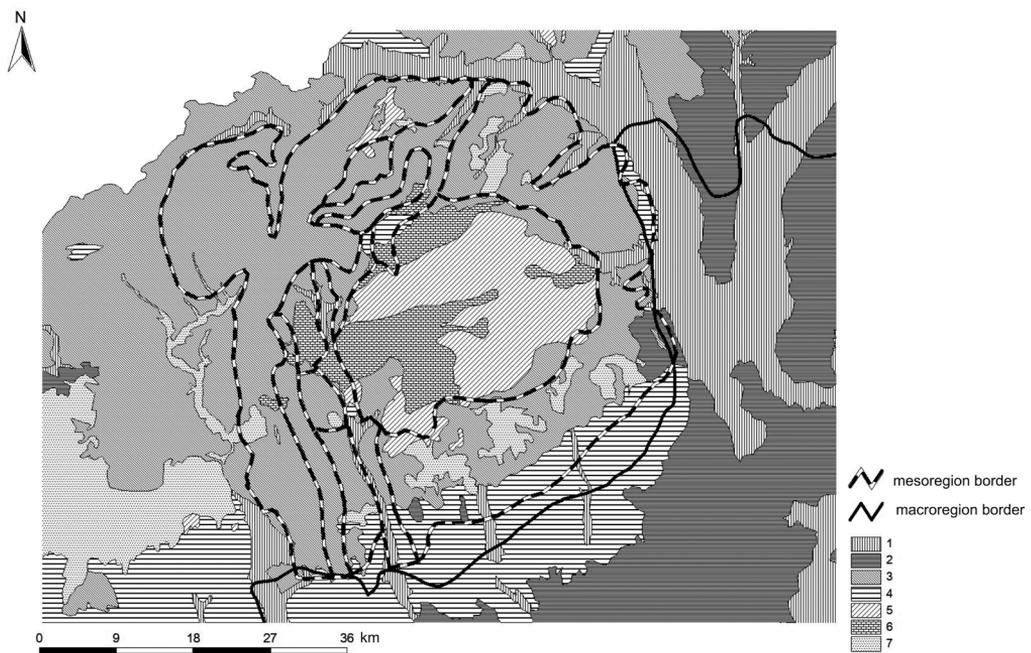


Fig. 1. A major landscape unit, a macro-landscape type and its lithological boundaries (based on the Hungarian National Atlas 1989): 1-alluvial sediments, 2-loessy sediments, 3-Tertiary and older loose sediments, 4-black loam, erubase, 5-limestone, dolomite, 6-clay shale, phyllite, 7-volcanic rocks

the landscape shaping factors, or that of the landscape shaping factors and the ecological units of the landscape are still to be carried out. Due to the scarcity of the suitable data, empirical methods can be used here instead of statistical ones. An important professional task can be, for instance, to clarify to what extent the relief predicts the mosaic-like pattern of the landscape (Lóczy 2002).

The landscapes mostly show areal consistency on the lower levels of the hierarchy, and a good example of this is that in a micro-region, for instance, even the vegetation (the factor which is the most capable of fast changes apart from the anthropogenic factors) only shows a few kilometre margin along the central “core” of the landscape. The boundaries of the landscape are regarded as strips (the ecotones) and the interpretation of the boundaries as wider zones is also suggested (Bastian 1997, Csorba 2008).

In practice, the areal scope of landscapes is determined by the boundaries of the ecotopes, which, in turn, are described through the landscape shaping factors. Several factors of the accurate determination of the regional units are known, from the scale to the extent of integration of the landscape shaping factors. The local delimitation of the natural units defined with the notion of landscape is a significant professional issue due to the above mentioned factors. Thus the debate is not about whether it is worth, but whether it is possible to carry out the delimitation accurately. Out of the numerous influential factors, the following are highlighted:

a. One of these is the establishment of boundaries of the landscape shaping factors, which can be carried out with limited accuracy even in theory, as in this case the boundaries cannot be drawn clearly. Thus it is problematic even professionally to decide where to draw the boundary of two soil types (e.g. the transition between meadow soil and bog soil can cover a zone of tens or hundreds of meters), but the same can be said about the geomorphologic forms, or the vegetation types which are even more interlaced. In case of the top of the vegetation, not only the *spatial*, but the *temporal* accuracy is limited as well, as the development of the types, the transition from one to the other takes 10-100 years even in this case, with the swiftest natural change (Csorba 2008). We can experiment with refining the accuracy of the boundaries of the landscape shaping factors, for which different geostatistical procedures or in-field sampling can be used, but these can be only be truly regarded as the boundaries of the integrated landscapes in a limited way (Hegedüs 2006, Deák 2008, Molnár et al. 2010). These mostly refer to one or a few, possibly weighted natural factors, but in their interpretation this is the landscape. Integration is better served by the vegetation map of MÉTA survey, in which a number of other natural factors (soil, topography, climate) are taken into consideration besides the vegetation data, however, not in an integrated way. (This, on the other hand, limits usage because of its redundancy.)

b. The other is the inaccuracy in the content of the definition of landscapes, which is related to defining the integrated base units of the landscape. In this case it must be clarified which factors are taken into consideration and to what extent when defining the units (ecotopes or micro-regions): for instance whether the parameters determining orography or lithology are considered equally important, significant on a plain or in a mountain or not, and what factors are reasonable to take into consideration when defining landscapes. In this case the inaccuracy results from the fact that there is essentially no statistical, system analytical background for the definition of the factors necessary for the integrated landscape units, and, moreover we know from experience that these have different significance and weight in different areas (Bastian – Schreiber 1999). The integration is even more complex in the case of the cultural landscapes formed through anthropogenic activity.

c. The third obstacle regarding the accurate definition of landscape can be called *technical* and is in connection with scale. In the daily practice of landscape planning the landscape units have to be delimited in very different scales, as, for instance the planners of urban areas need a large scale, and e.g. the regional area planners require a smaller scale. The same percentage of error concerning the drawing of the boundaries is usually not accurate enough for planning in case of larger scales (for the planning of a strip of forest or water quality buffer zone), whereas on the higher levels of the hierarchy (e.g. micro-region cluster, meso-region) the occurring km-size mistakes are only suitable for overall surveys (Csima et al. 2004, Csorba 2008). An additional problem is that in the case of different scales, different relationship network of the factors can be encountered (Mezősi 2009).

In addition to the manifold interpretation of their content, the uncertainty of the landscape boundaries is also caused by the ratio of the natural/social influences. Today natural landscapes hardly exist in Europe, as they have all developed as a result of anthropogenic influences to greater or lesser extent. Besides, the changes of

the “naturally defined” landscapes usually result in considerably lesser transformation than the anthropogenic influences which can entirely override the pattern and content of a landscape.

On the whole however, fundamentally it is the natural factors that mark the boundaries of the landscape, but they constitute a complex system incorporating social elements as well. This is the most vulnerable point of examinations concerning the landscapes.

The analysis presented here uses the solution that is also used by several landscape analysts: they attempt to draw the boundaries by analysing the landscape shaping factors one by one. The solution however avoids several traps of the individual evaluation of the factors (pl. weighting, determination of the number of parameters), but does not examine integrated units. The solution is based on the examination of the ecotones that constitute the boundary with a fuzzy logic, which approaches the question of the boundary from a different direction. The use of the fuzzy method is not alien to landscape ecology, but those rather concern land use units and their sources are remotely sensed data (Ji 2002, Arnot– Fisher 2007, Chong et al. 2010).

The applied method

The idea of the fuzzy “soft sets” was introduced by Zadech in 1965 (Kóczy -Tikk 2000). According to the fuzzy logic the border of a set is not a clear line but two neighbouring sets gradually transform into one another. A geographical example is the interpretation of the soils on the basis of depth, as shown in figure 2.

In accordance with this logic, the landscapes can also be considered “soft” sets as the boundaries of the landscape shaping factors are not constant either, they continually change in space and time. This means that the elements of neighbouring sets usually are not completely independent of each other, but each element of one set also represents the other set to a certain extent. For instance, the soil boundaries are not usually clear lines, and in the Chernozem soil dominating one set, elements of other sets (e.g. meadow soils) can also play a role to a certain extent. Arnot and Fisher (2007) deal with the analysis of ecotones based on fuzzy logic (in a Bolivian example, on the scale of macro-regions), although in their case the task was not the definition of boundaries but the determination of the size of ecotones (however, the principle is not so different from our chosen method).

In the course of the analysis, we interpreted the landscape boundaries as “fuzzy boundaries”. The aim was to find out where the boundaries of the landscape can be drawn with this method. These can be understood as narrow or wider, possibly several km wide ecotones, as the limit can often be fitted to clear boundaries. Natural data were used in the analysis (and the results will have such bounds as well). Corresponding to the scale of microregions and mesoregions, we used the soil, relief, vegetation and lithological data of scale 1:100000 and 1:200000 maps. The homogeneity of the landscape shaping factors for each micro-region was calculated and these figures provided the basis for further calculation. The level of homogeneity was determined by the percentage of the soil types, vegetation types, etc. within a micro-region as compared to the area of the given micro-region.

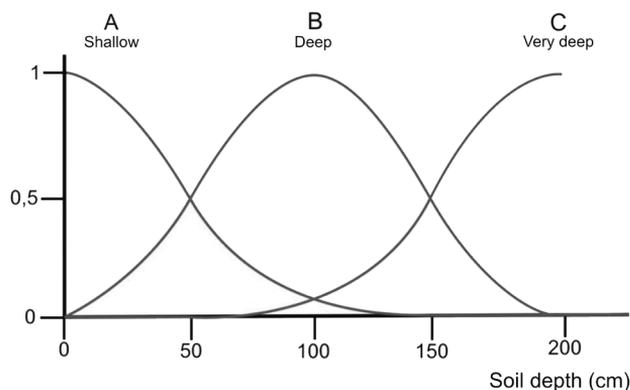


Fig. 2. Classification of soils based on their depth applying fuzzy logic (after McBratney– Odeh 1997)

The reason why these homogeneity maps were used is that, on the one hand, the fuzzy analysis requires uniform numerical input data, and, on the other hand, we do not face the problems of priority and weighting of the landscape shaping factors in the course of the examination. Originally, the factors from which we construed the homogeneity data were the following:

- soil – 9 soil types (textual data) e.g. BET (referring to brown forest soils),
- rock – 9 rock types (textual data) e.g. basalt,
- relief – slope angles (numerical data),
- vegetation – 10 natural flora types (textual data) e.g. beech-groves.

The analysis concerning these homogeneity maps was carried out with the IDRISI Taiga software. The applied fuzzy function is presented in figure 3. The calculations used for fuzzy sets can be described as:

- the areas with a homogeneity value lower than 30% belong to the set of border zones (these appear on the result map with a value of 1),
- the areas with a homogeneity value higher than 70% belong to the set of homogenous landscape cores (these appear on the result map with a value of 0), whereas
- the areas with a homogeneity value different from the above are given a new value that indicates the percentage in which they belong to one or the other of the sets.

For the joint analysis of the fuzzy maps produced individually for each landscape shaping factor we have to use fuzzy set operations. In the IDRISI Taiga software these set operations can be carried out with the OVERLAY tool, using the MIN set operation, which means intersection in the mathematical sense.

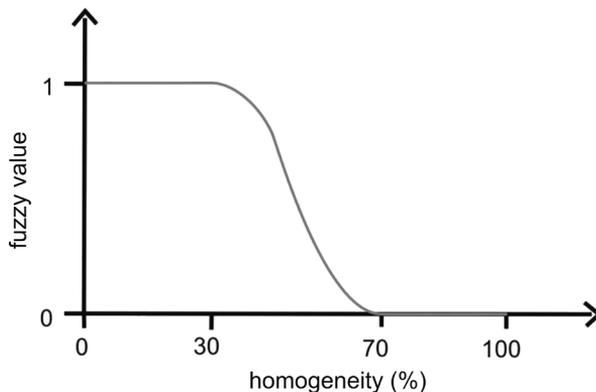


Fig. 3. The general pattern of the fuzzy function applied for landscape forming elements

Results

Taking into consideration the four (natural) landscape shaping factors used for the calculation, we managed to determine those areas where the inhomogeneity is significant. This means that the mentioned zones can be regarded as areas where the definition of the landscape boundary – on the basis of the four factors – is uncertain. Those surfaces can be contrasted with the above areas where the factors are significantly more homogeneous and thus they can be regarded as the cores of the landscapes from the aspect of landscape ecology (fig. 4). This confirms the observation that the width of ecotones between the different types of landscapes – depending on the scale – can vary in an extremely wide interval, and can range from a few dozens of metres to several hundreds of kilometres (Bastian 1997, Forman 1995). In the domestic (Hungarian) areas values between a few hundreds of meters and 3-5 km were recorded with the applied method.

According to the statistical examinations, the average value of the fuzzy in the examination is 0.64. The resulting data were sorted into four categories. The areas with a fuzzy value of 0 (the homogeneity of all landscape shaping factors is over 70%) cover 80% of the surface and these can be regarded as the “cores” of the landscape. On the other hand, the areas with a fuzzy value of 1 (the homogeneity of all landscape shaping

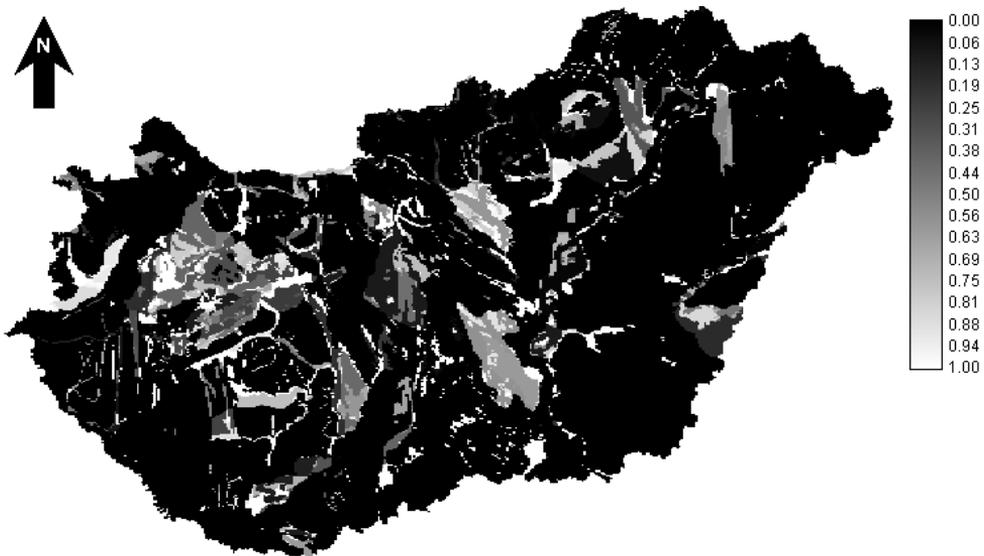


Fig. 4. A fuzzy result map based on four landscape forming elements

factors is below 30%) cover 5% of the surface, and on the basis of the above factors, the boundary can be drawn anywhere within these areas. In addition, the transition between these values is some 15% (figure 5). Here the boundary is – explicable - drawn differently by vegetation or relief research. On the basis of taking the numerous factors into account simultaneously, the solution of the delimitation of landscapes can be provided by a wide inhomogeneous ecotone.

A more detailed analysis of two study areas is presented here. One of them is the loess ridge in Kiskunság, where the drawing of the boundary is especially uncertain in the south-western part. In this area of the micro-region a 3-7 km zone could statistically belong to the core of the landscape in 43.5% (and it could belong to the transition zone in 56.5%). The problem is caused by some larger inhomogeneous patches (they have a fuzzy value of 0.9 with low homogeneity everywhere), thus it is understandable that some suggest the modification of the landscape boundaries on the basis of the vegetation (Deák 2008). This zone could instead represent a wider ecotone (fig. 6).

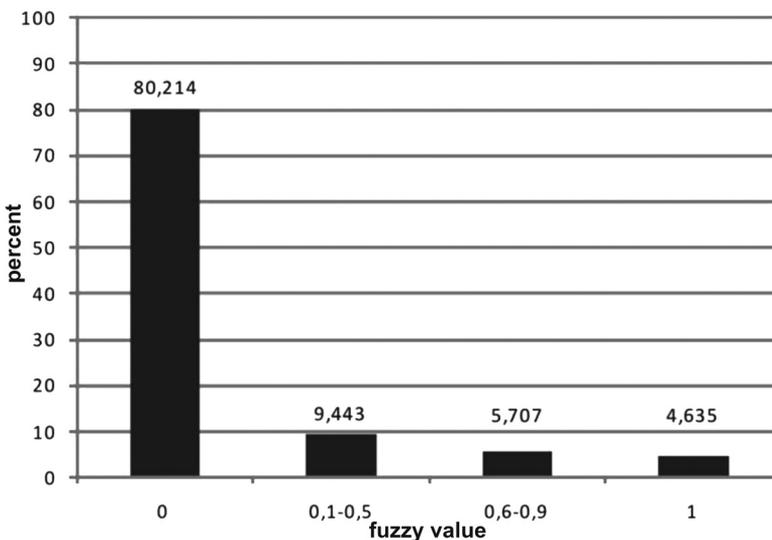


Fig. 5. The proportion of fuzzy categories compared to the total area

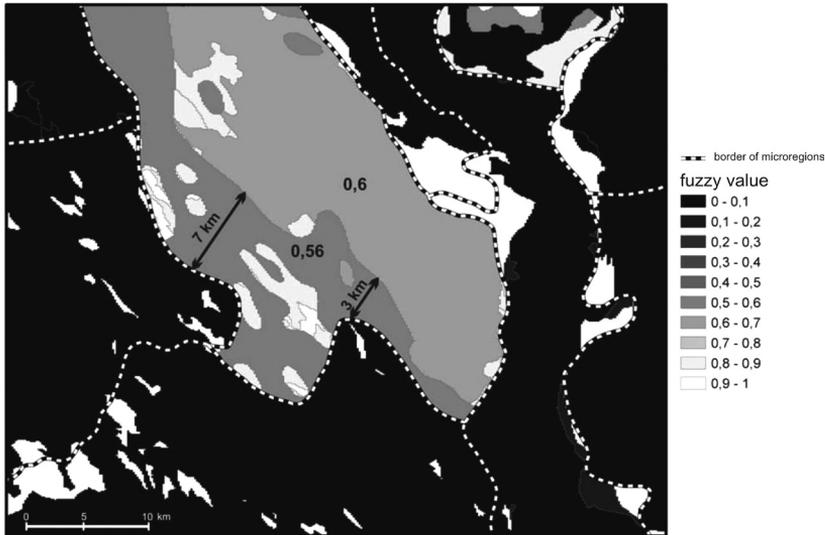


Fig. 6. Fuzzy map on the SW region of the Kiskunság Loessy Ridge

The other example concerns the eastern and southern parts of Outer-Somogy. Here the Koppány valley stands out clearly (with a value of 1) justifying that it is reasonable to treat the rivers as separate units. That is, these valleys cannot be attached to any regions automatically – statistically. To the south of this area the low-homogeneity area (fuzzy value 0.74) is such where the landscape boundary cannot be drawn definitely on the basis of the data. This 6 km-strip can again be treated as ecotone, although the data also suggest that the significant difference from the environment is the result of the inconsistent categorization of the soil (e.g. it is not necessarily reasonable to separate the brown forest soil and brown earth in the basic database, or else all different subcategories should have been used).

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Summary

The landscapes are the characteristic, basic territorial units of geography. Although several methods are known for their interpretation, their reasonably accurate territorial definition is also important from theoretical and practical aspects. This is hindered by the fact that the borders of e.g. the botanical, soil or relief landscape shaping factors differ, and these cannot even be defined clearly themselves. If the problem is solved with the help of integrated units (which itself reflects that these units were formed by individual landscape shaping factors) then it is mainly the pattern depending on the scale that is problematic, and if the partial factors are analysed, their mosaic-like pattern causes problems when drawing the boundary. It is more important to choose a solution where the natural and social factors, and also their influences can be integrated.

The suggested and presented method was based on the analysis of the boundaries of landscape shaping factors (the numbers and types of these can be increased) using fuzzy logic. The landscape boundaries can be recorded – as ecotones – with this process. The solution ensures that the landscape shaping parameters are of the same type in the examination (it frequently happens today that the statistical analyses are carried out with

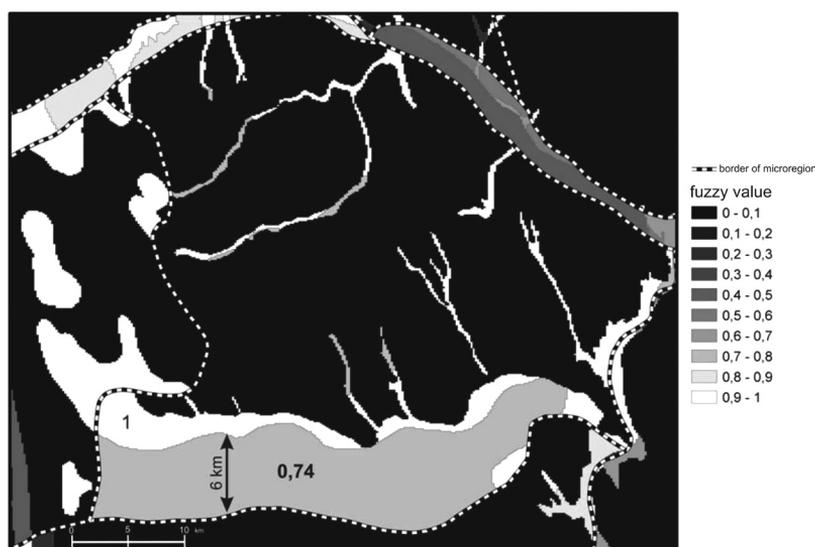


Fig. 7. Fuzzy map of Eastern Outer Somogy

very diverse types, although the nominal or scalar types only provide very different possibilities) but the steps of weighting the factors, which include several errors, are excluded from the evaluation. Even so, the conscious choice of parameters is essential and, if necessary, the preliminary statistical examination of the pattern (e.g. with a featureanalyst software) can be practical.

This analysis does not primarily aim at the modification of landscape boundaries, but it presents their analysis with a different approach, where the often zone-like appearance of the boundaries is emphasised. This is in line with our experience that the boundaries are not static (we have data of this fact in connection with the vegetation – e.g. Méri–Körmöczi 2010), which demonstrates the relative steadiness of the core areas and the pulsation of the ecotones depending on the types that constitute them, that is, they are not rigid categories. Our analyses show that the landscape boundaries usually represent a transition zone of a few hundred meters to a few kilometres in width. This problem concerns the stability of the landscapes and their sensitivity to the changes. It is known that the landscape can be regarded as system where changes of the anthropogenic influence (but generally that of one landscape shaping elements) can cause the instability of the system and induce changes. The sensitivity of the landscape is interpreted as the swift reaction to the disturbing effects, which indicates the conditional instability of the landscape system.

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