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CARTOGRAPHIC VISUALIZATION OF OUTPUTS FOR SPATIAL DECISION-MAKING IN REGIONAL DEVELOPMENT

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Abstract. Regional development is full of planning and decision making. Having precise results for spatial decision making (SDM) is more than necessary. On one site, there are many approaches how to process input data, on the other hand thematic cartography also operates with many visualizing methods and techniques. Loss of accuracy of the results is more than expected because there are two phases (data processing during SDM and cartographic visualization) where the accuracy might be distorted. In both phases processing recommendations must be obeyed. Selection of spatial decision making method must follow considered aims as well as visualization techniques and setting their parameters (especially during reclassification, interpolation or generalization). Paper deals with the proposal of elementary scheme of SDM and related visualization during two case studies (CS). First CS represents composite indicators proposal followed by weighted sum method using heuristics approaches with the aim to identify the tourism influence on the landscape. Combined visualization techniques for quantitative and qualitative data are presented. Second CS uses ordered weighted average method for finding the best place for building of a new public logistics centre. Constraints and factors represent key indicators and following factor and order weights enable to propose the best accepted risk model. In this case grid maps describe derived values and chosen reclassification documents conversion into linguistic variables.

Keywords: choropleth map, grid map, generalization, reclassification, conversion, GIS.

Introduction

The issue of spatial decision-making is based on both the evaluation and selection of suitable alternatives (the so-called Pareto optimal set identification) and on the effective graphical representation of results (partial or final). At the time when there is a large amount of data of different quality and computing day after day exceeds its limits it is more than necessary the decision-making branch would be based on teamwork possessing at least the roles of analysts and decision-makers. Visualization can be defined as a visual representation of numbers, nouns and verbs representing mechanisms, movements, processes, dynamics, causes and effects (Tufte 1997). Visualization can also serve as a means of reporting, detection or as an inherent part of the process of thinking (Gahegan *et al.* 2001). Yusoff and Salim (2015) in their work dealing with shared visualizations also define five strategies of shared visualizations representing a way for shared data transformation and knowledge leading to required level of understanding. The above-mentioned strategies include shared visualization strategies, shared coordination strategies, multiple representations strategies, shared view mirror strategies and shared object boundaries strategies. The first strategy uses the visualization content, activities and artefacts for multiple users. Shared coordination strategy is a visualization type of strategy carried out by researcher for coordination of two or more elements in a shared way of visualization for a wide range of users. The third strategy, a strategy of multiple representation, is backed by a researcher performing two or more coordinated representation in the form of visualization. In the shared view mirror strategy display a third person is additionally incorporated for the purpose of undistorted results and enables real insight into visual information.

The last strategy allows the integration of knowledge through the border. Analyst (understand the role of the analyst can be divided into many specializations right according to the following schedule of activities) should be responsible for the selection of appropriate method of spatial decision-making, software selection and tools for following processing and appropriate method for visualization. It is more than clear that we can perform a variety of analyses and use sophisticated methods, but if we fail to present outcomes properly and interpret them correctly to decision-makers, the whole previous work is useless. Cleveland (1994) states that by encoding information into a graphical result (graph, chart or map) the work does not end, success will come only if the decision-maker correctly decodes and use the information. Taking into account a number of factors and variables respecting possible suitable alternatives, the aim of visualization is not to provide a detailed presentation of all results and relations but to offer a general overview with the option of more detailed view (Miettinen 2014). The form of presentation of results is also important. Presenting results without considering intuitive approaches will result into decision-maker´s rejection of such unpleasant data presentation. In this context Hamming (1973) underlines that the purpose must prevail over form, namely that the aim of data processing is to facilitate an insight into studying issue not visualizing only numeric values. However, the form of visualization should not be neglected. In the field of cognitive psychology it was repeatedly confirmed that the amount of information provided to decision-makers plays an important role. Studies also proves that the greater amount of information is given to decision-makers the smaller amount of them will be used (Kok 1986). Therefore, visualizing less information and adding details on request seems to be more effective. In the middle of 20^{th} century Miller (1956) emphasized that human perception of visual expression in the case of spatial decision-making (choice of offered solutions) is limited by the number of offered alternatives. He recommends as optimum the limit of seven alternatives plus or minus two alternatives, although he is confirms that such a restriction can not be taken as a strict limit. Firstly, the visualization was associated with computer graphics and the form of scientific visualization was conceived as the way how to use imaging techniques for data sets viewing. Its actual appearance goes far beyond spatial data visualization and is also widely used in medicine, molecular biology, etc.

1. Spatial decision-making

Decision-making process is based on processing of number of criteria (factors and constraints). Spatial decision-making incorporates a spatial dimension of assessed factors and constraints. In fact, it is recommended to use appropriate multi-criteria evaluation (MCE) approaches resulting in assessment offering suitable alternatives (Malczewski 1999). There are many opportunities for MCE method classification. Effat and Hegazy (2009) states that Multi-Criteria Decision Making (MCDM) includes both Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). In case of MCDM applications, the general term Multi-Criteria Analysis (MCA) or Multi-Criteria Evaluation (MCE) is often used (Ruda 2014). The principle of data overlaying representing more criteria for evaluation of given problem in order to resolve it already appeared in works of McHarg (1995), who used a variety of criteria to study the socio-economic dimension.

In contrast to conventional approaches of MCDM, spatially oriented MCDM includes individual criteria as well as their location in space. In essence, the spatial multi-criteria decision making takes into account both the geographic data (data with spatial localization) with decision-making preferences and their final summarization according to specified decision rules (Malczewski 1999, Malczewski 2006a, Malczewski 2006b, Voogd 1983). In general, MCDM process can be divided into four basic steps (Yager, Kelman 1999):

a) criteria and alternatives selection,
b) data normalization and weights setting,
c) specific decision making method implementation,
d) result aggregation and interpretation.

The preferred benefit of MCDM methods is the opportunity to work with many alternatives, which can be judged by the pros and cons of each option alternative properties. In this case, the pros and cons can be scored and then it is possible to eliminate the alternative with the lowest ratio of pros to cons. The combination of the worst and the best properties allows maximizing the most important criterion, even if it is not enough considering positive ratings of less important properties it may be selected as a significant one. The difference between the most positive and most negative properties is used to exclude those alternatives whose differences are largest and therefore difficult to achieve in practice. A number of multi-criteria evaluation methods both for raster and vector data have been implemented in GIS software.

With regard to the desired data processing in GIS, various methods of spatial decision-making can be applied. Boolean method represents this type of standardization for raster data resulting in simplification of all criteria into Boolean images. Their importance is reduced to a form of suitable or unsuitable reference units (RU). This is achieved by reclassification of values into two required classes (0 – inappropriate RU, one – suitable RU) using binary logic. This method strictly determine constrains in raster format and eliminates all RU failing at least in one criterion. It should be noted that using only this method wipes out any intermediate steps in the decision-making process and strictly excludes or permits alternatives under specified conditions. Weighted linear combination (WLC) is a well-known method developed by Keeney and Raiffa (Ozturk, Batuk 2011), also titled Simple additive weighting (SAW). WLC works with continuous criteria (factors) that are standardized in normal numerical range (0–1 or 0–255) and then combined using weights. The weak value of one criterion may be trade off by a number of high-quality criteria. The possibility of factors trade-off, or their replacement by other factors determine the factor weights. The decision rule for each alternative is defined as follows (1):

$$A_{WLC} = \sum_{j=1}^{n} a_{ij} w_j,$$

where a_{ij} is the value of alternative i respecting criterion j and w_{ij} is the normalized weight of j criterion (Triantaphyllou 2000).

According to Žídek (2001) WLC shifts the analysis from extreme risk rejection expressed by AND operation (see Boolean method) exactly between the operations AND and OR, where the extreme risk is not nor rejected neither accepted. Thus WLC allows full trade-off of factors and brings an average level of risk. In connection with Yager´s fuzzy sets theory (1988) a method of Ordered-Weighted Average (OWA) has been developed. Naturally, OWA is similar to WLC. Although criteria are standardized and weighted the same way order weights are set and applied for factors. They are not directly linked to a specific criterion, but assigned to different criteria values from minimum to maximum, which reduce the risk of trade-off. The factor with the lowest suitability is assigned to the first order weight, the next factor is assigned to another increasing order. Using OWA allows to control the level of risk and the level of trade-off. The decision rule is given by (2, 3):

$$A_{OWA} = \sum_{j=1}^{n} \left(\frac{w_j \, ow_{ij}}{\sum_{j=1}^{n} w_{j\, ow_{ij}}} \right) a_{ij},$$

$$ow_{ij} = \left(\frac{k}{n} \right)^{\delta} - \left(\frac{k-1}{n} \right)^{\delta},$$

where ow_{ij} is the order of criteria i weights with regard to criterion j and δ represents the degree of the polynomial function (Tesfamariam, Sadiq 2008).

The opportunity to control the level of risk of decision-making process and the level of trade-off, OWA provides results similar to Boolean operations AND, OR and WLC. Other available methods used for MCDM such an Ideal point method, SMART (Simple Multi-Attribute Rating Technique) based on techniques of Multi-Attribute Utility Theory (MAUT), ELECTRE, PROMETHE (Lootsma 1993) and many other derivations can be found in Malczewski (2006a, 2006c, 2006d), Jankowski (1995), Voogd (1983), etc. Defining the problem is similar to AHP and creates a hierarchical structure. SMART offers the user to evaluate alternatives in terms of the lowest criterion on the basis of the measurement and subsequent standardization of the evaluation. This is a relatively simple solution, focusing on the structure of multi-criteria respectively multi-attribute alternatives.

2. Cartographic visualization (geovisualization) for SDM results

Cartographic visualization is a specific form of visual expression. In connection with the visualization of spatial data geographic visualization (geovisualization) is used. Its position inside geography which works with geospatial data has been addressed later, although cartography itself discussed the issue already in the 50s of the 20th century. The aim of geovisualization is to facilitate the process of information transfer with the help of techniques and technologies for visual interaction with data supporting visual cognitive learning (Cybulski 2014). Nowadays, it is possible to observe a substantial development of geovisualization methodology. Medyńska-Gulij (2012) defines geovisualisation as a visual representation of spatial information facilitating the idea of bringing a better understanding together with the building of knowledge dealing with aspects of human and physical environment. Geovisualisation highlights both cognition and also geographical location. Faby and Koch (2010) points at the difficulty of defining the current expression of spatial dimension in maps in general sense. Thanks to use of programming language and advanced graphics software geovisualization goes through considerable development (Dickmann 2002). G. Andrienko and

N. Andrienko (2006) and Friedmannová *et al.* (2006) define smart geovisualisation describing a visualization based on selection of relevant information, appropriate scale and methods of visual representation according to topic, users profile and form of presentation. MacEachren (1994) discusses two concepts of geographic visualization. On one hand, it is understood as a particular visual representation of spatial data trying to capture their spatial context and highlight solved topic using a visual capability of human brain to identify mapped objects in analogue or digital form. On the other hand, MacEachren *et al.* (1992) discusses it with the ability of map to interact with user through map language. The difference has been seen in capabilities of geographic visualization to reveal specific spatial diversity by well-chosen methods.

With regard to different phases of decision-making process each phase can produce specific map outputs indicating the current form and usability of data although in general thematic maps prevail. In fact, we can distinguish criterion maps, suitability maps and other thematic maps.

Criterion maps represents the spatial distribution of attributes describing a set of criteria being established in the first phase. Based on attributes role within decision-making process we can divide criterion maps into factor maps and constraint maps (Eastman *et al.* 1993). Factor maps present evaluation criteria and according to chosen decision method must be specifically standardized. The form of standardization is also crucial for partial visualization. Mostly, linear scale transformation is applied and so continuous data are visualized using especially choropleth maps with unipolar or bipolar colour scheme. Constraints representing necessary restrictions are used for elimination of alternatives based on certain attributes. Each criterion map can be classified based on attributes measurement. Firstly, we distinguish qualitative (soil types) or quantitative (distance from road) scales of measurement. Following the classification Keeney and Raifa (1993) describe natural-scale criterion maps (eg. distance in metres) and constructed-scale (eg. subjective assessment of aesthetic impact) criterion maps. Both scales can be subdivided into two categories: direct and proxy scales where direct scales measure needed degree of achievement directly but in case of proxy scales the measurement reflects the degree to which an associated objective is met. Keeney (1980) and Kirkwood (1997) found out that the difference between these two scales is not always clear. On the basis of data types further classification of criterion maps can be as follows: deterministic, probabilistic and fuzzy maps (Malczewski 1999). Deterministic maps determine for each criterion a specific information using data transformation. Probabilistic maps demonstrate the probability approach using probability theory. In general, probabilistic maps can be perceived based on objective or subjective probability. Objective probability should have had same results independently on the person performing the proceedings. In fact, it reflects the relative frequency with which a specific result has been examined. Opposite objective probability, subjective probability reveals a perception of likelihood of an event occurring. In case of having additional information we can get more accurate results than we speak about revised probability maps. Using some predict algorithm (weighted linear regression) we can construct predict maps as well as using fuzzy concept to create fuzzy maps considering wanted uncertainty in data and related information.

Suitability maps present the degree of suitability of assessed alternatives. In many cases, results coming from allocation analyses belong to this maps category. Mostly areal method is used in many variations documenting sum of all event values by aggregated maps. Suitability maps can be seen especially in raster format (Meng *et al.* 2011; Feizizadech *et al.* 2013). Vector format is used for analysis with artificially created regions (eg. administrative units). Divergent continuous colour scheme is often used for data visualization because its fuzzy appearance can help distinguish marginal values from average ones. During format conversion from raster to vector format reclassification of final values is applied. Based on chosen classification algorithm numeric values are being transformed into linguistic variables.

Opposite this areal approach Densham and Armstrong (1994) work with nets. Regarding suitable services analyses, they proposed location maps, supply maps, demand maps, spider maps or delta maps.

3. Recommended basic procedure for SDM and cartographic visualization

According to Greene *et al.* (2011), Eastman (2009) or Malczewski (2006a, 2006b) it is understandable that many options for SDM method classification must be consider. One of the most important point of view is the number of examined goals. Regarding this fact, basic procedures for SDM might be highlighted and

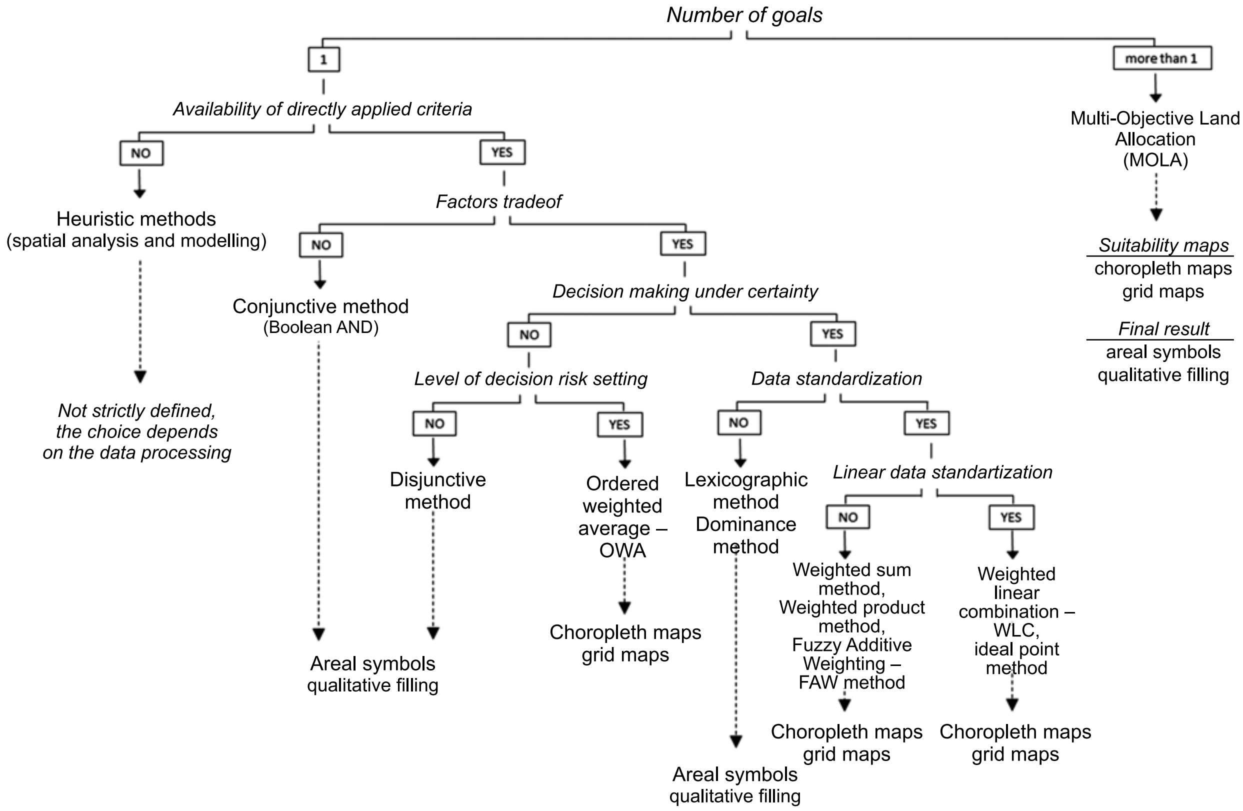

Fig. 1. Proposal of elementary SDM procedure and cartographic visualization

following cartographic visualization might be recommended. Figure 1 illustrates this approach working with one or many goals. The proposal also consider factors tradeoff, decision making under certainty, level of decision risk setting or prevailing data standardization. It was mentioned above that during SDM procedure data standardization is needed. It means original data values are transformed into mainly continuous values. Working with continuous data give us opportunity to make especially choropleth or grid maps. During data processing we must decide what classification algorithm will be used. According to chosen classification we might get different results and also following cartographic visualization depends on data format. Using composite indicators enables to assign partial value to each grid cell or administration unit but converting into linguistic variables is necessary for final decision. Following this recommendation, we can use choropleth and grid maps with bipolar colour scheme and after conversion using areal symbols with quantitative filling is satisfactory.

Following case studies documents varying approaches in using cartographic methods for cartographic visualizations of SDM results. Regarding paper range limitation detailed background of data processing is not mentioned but is linked to author's published papers.

3.1. Visualization of overall tourism influence assessment on the landscape: case study of the Nízký Jeseník Highlands, Czech Republic

This research brings one of possible options how to assess overall tourism impact on the landscape in a small area of selected municipalities of the Nízký Jeseník Highlands (Fig. 2).

For further sustainable tourism management in study area it is suitable to assess key criteria in municipalities using weighted sum method (WSM). The most important part was to propose specific attributes and evaluate their indicators. Three data sets (composite indicators) representing necessary indicators were proposed according to available data: Specific environmental area value, Tourism potential and Tourism infrastructure load. Key attribute values were applied to municipalities (basic urban areas) as a proportion in municipality area. It enabled using WSM to get valid results usable for data classification and point assigning system used for evaluating each municipality as a final sum of weighted values within each data set (composite indicator). Therefore each municipality gets its final sum value on the basis of combined calculation of attributes proportion, statistical classification (using natural break algorithm) with following point assignment and pairwise comparison (Fig. 3).

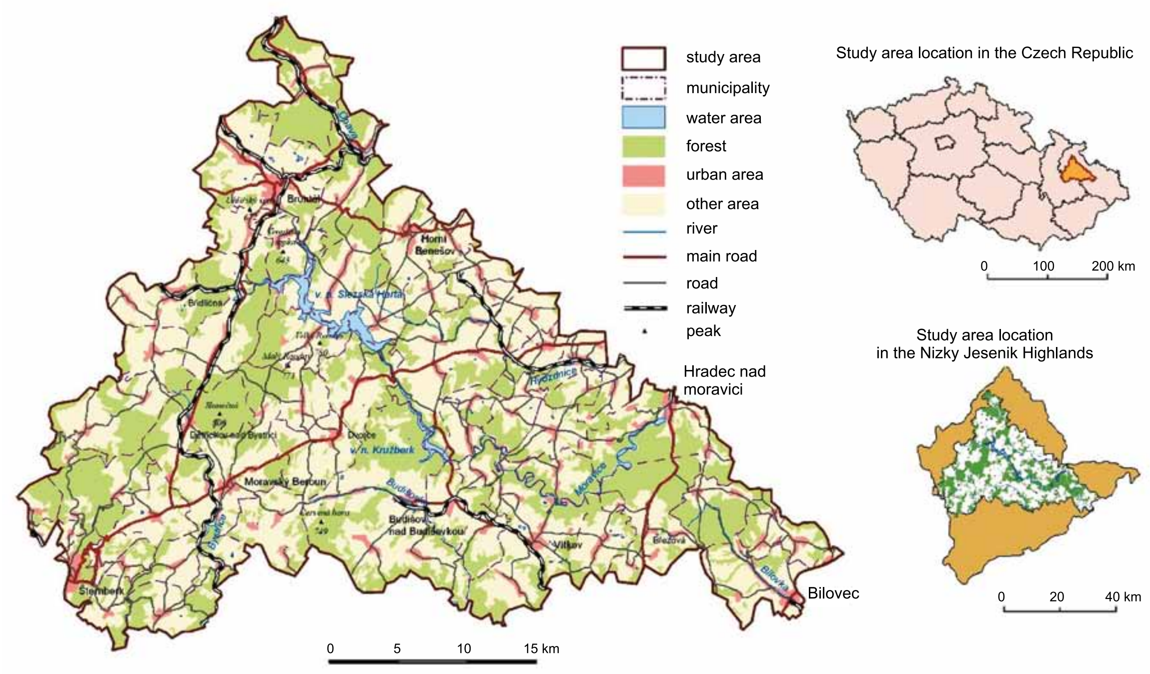

Fig. 2. Study area of the Nízký Jeseník Highlands (Ruda 2010)

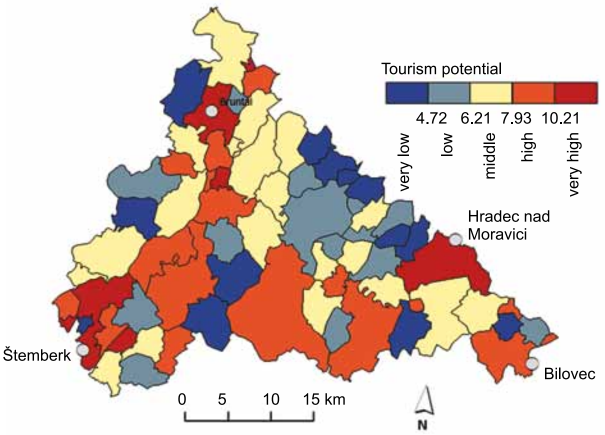

Fig. 3. Tourism potential (composite indicator values)

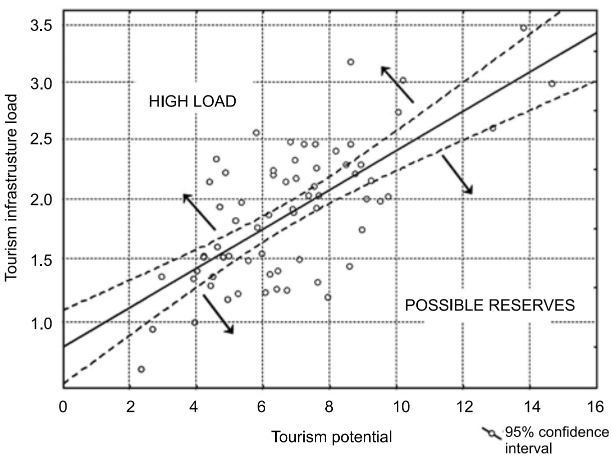

Fig. 4. Dependence of tourism infrastructure load on tourism potential (linear regression) (Ruda 2010)

Individual couples of data sets were put through correlation analysis. Correlation coefficient between tourism infrastructure load and tourism potential (correlation 0, 67) showed up the most provable interdependence. Using linear regression municipalities were distributed according to interlay regression line (Fig. 4).

For bigger validity 95% confidence interval was defined. The confidence interval enabled to mark 22 municipalities with relatively regularly distributed tourism load. Municipalities founded above the 95% confidence interval point out that the tourism load is inadequate to tourism potential, while these founded above the 95% confidence interval predicate possible reserve in tourism potential. These results can be put into connection with environmentally precious areas and show for instance highly loaded biotopes (Fig. 5) (Ruda 2010; Ruda 2014).

In the scope of regional planning, finding common attributes strengthen municipalities to make associations and so share and use advantages and diminish influence of threats or weaknesses. In this phase of decision making (focused support allocation) Grouping Analyst tool (ArcGIS for Desktop 10.1) proposed using pseudo F-statistic parameter five groups of municipalities (Fig. 6). Following visualization was based on areal symbol method with qualitative filling distinguishing one group from another (Fig. 7).

Illustrated case study documents original data processing and following generalization needed for

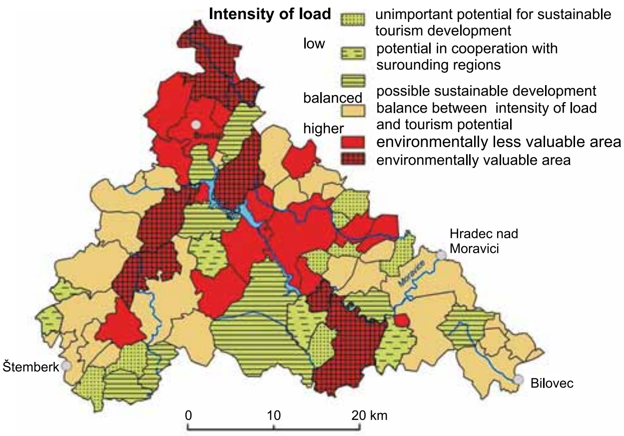

Fig. 5. Tourism infrastructure load in relation to tourism potential on the background of environmentally precious areas (Ruda 2010)

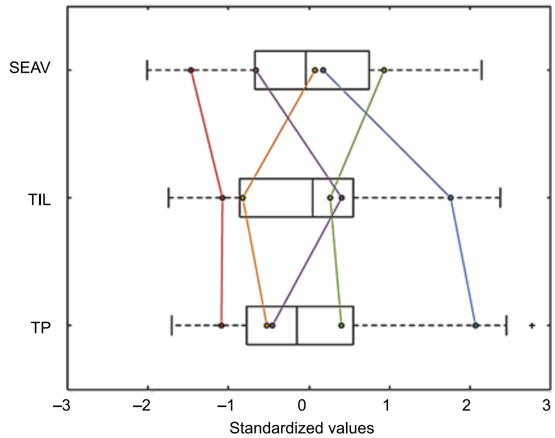

Fig. 6. Graphic representation of Grouping Analyst result unioning standardized values of SEAV (Specific Environmental Area Value), TIL (Tourism Infrastructure Load) and TP (Tourism Potential)

final outputs for decision makers. In Figure 3 it is clear that derived values represent partial output from statistical analysis in which continuous data was visualized by chropleth map. Graduated shades of one colour could have been used instead of bipolar colour scheme, but in case of differentiation from the middle (average) value using of two graduated colours is more illustrative. Following map representations (Figs 5 and 7) more generalize previous results and offer decision makers different views on derived outputs. In case of Figure 5 combination of bipolar colours differentiated by added quantitative raster highlights quantitative level (intensity of tourism load) of qualitative attributes.

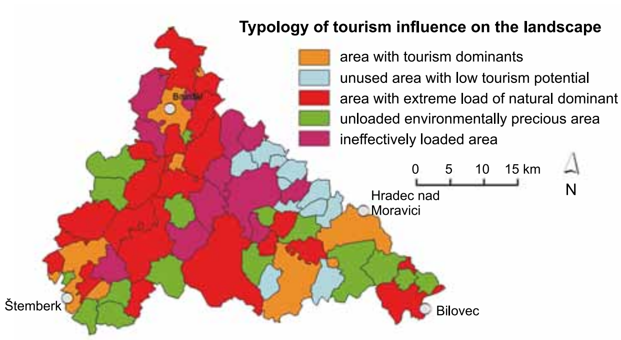

Fig. 7. Qualitative visualization of grouping analyses

3.2. Visualization of location of new public logistics centre: case study of the Vysočina Region, Czech Republic

The case study with the aim to distinguish most appropriate areas for building of new public logistics centre was situated the Vysočina Region (Ruda 2014). Key areas involving administrative districts of municipality with extended power (AD MEP) Jihlava, Havlíčkův Brod a Humpolec were preselected by the regional authority. According to updated Principles of Territorial Development of the Vysočina Region the study area was further closely specified as area involving AD MEP Jihlava without municipalities in the southwestern part, AD MEP Humpolec without municipalities in the western part an AD MEP Havlíčkův Brod with municipalities only in the southern part. The study area includes 53 municipalities (Fig. 8).

This territory is relatively highly populated and has economic activities with a good location to the D1 highway access junction. Constraints identified areas, which must be with respect to their value excluded

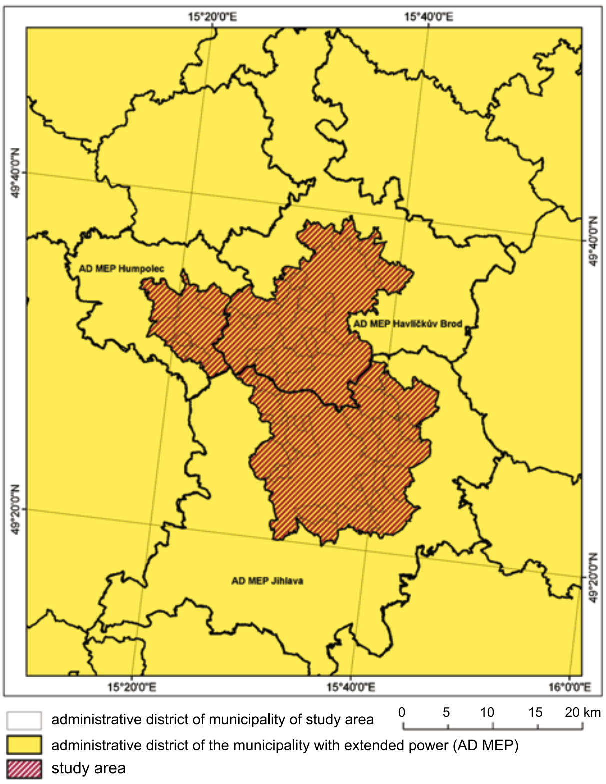

Fig. 8. Study area

Table 1. Ordered weights for scenario with low level of risk and some trade-off

order weight No.	weight 1	weight 2	weight 3	weight 4	weight 5	weight 6	weight 7
weight value	0.5	0.25	0.125	0.065	0.040	0.020	0

from suitable alternatives and can be classified as follows:

1) geological point of view
   a) mineral deposits
   b) undermined areas
2) nature preservation point of view
   a) protected mineral deposits
   b) forest with 50 m protected zone
   c) 1st and 2nd class of soil quality
   d) small especially protected areas
   e) NATURA 2000 areas
   f) territorial system of ecological stability
   g) location of specially protected plants and animals
3) historical point of view
   a) areas with archaeological foundations
   b) war graves
4) hydrological point of view
   a) water bodies
   b) flooded areas
   c) location of surface water accumulation
5) significant infrastructure point of view
   a) important objects for national security
   b) 50 m protected zone along telecommunication lines
   c) 300 m protected zone along pipelines
   d) built up areas

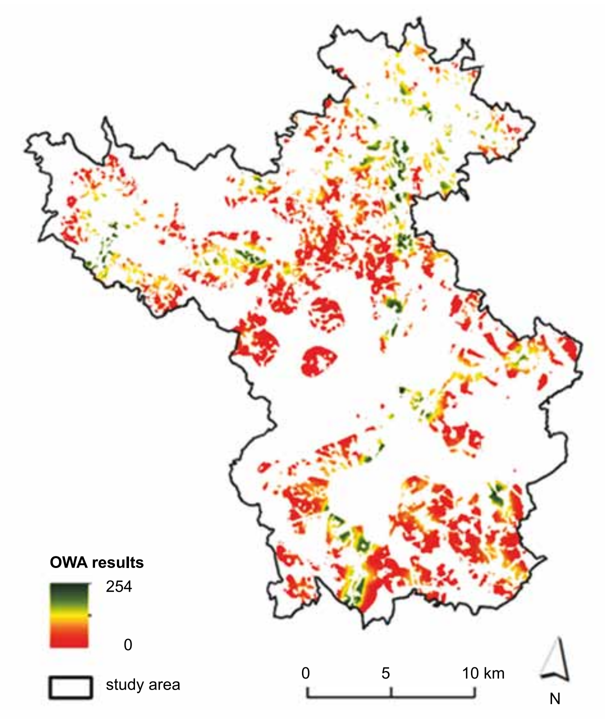

Fig. 9. Grid maps with OWA final results

Key factors identifying the area with the highest suitability were gathered into two groups: transport factors and infrastructure factors. The transport factor took into account road transport network of the first class roads and high speed roads and the distance to highway junctions and railways. Within the infrastructure factors distance from power lines (wiring), pipelines, water conduits and sewerage networks were considered. Each factor was based on the set distance. Bigger the distance is higher costs are expected.

1) Transport factor
   a) 1st class roads and high speed roads – up to the distance of 1 km
   b) highway junction – up to the distance of 3 km
   c) railway – up to the distance of 1,5 km
2) Infrastructure factor
   a) wiring – up to the distance of 1,5 km
   b) pipeline – up to the distance of 1 km
   c) water conduit – up to the distance of 1 km
   d) sewerage – up to the distance of 1 km

Spatial analysis using Ordered Weighted Average (OWA) method was facilitated by Idrisi 17.0 The Selva Edition (Idrisi). Fuzzy standardization using sigmoid monotonically decreasing function was used for data normalization. In Idrisi it is possible the use a decision making triangle to set three possible scenarios. With respect to several scenarios the most suitable scenarios giving ordered weights regarding low level of risk and some trade-off (Table 1) was subsequently developed into a final model (Ruda 2014). Output suitability map was visualized as grid maps using bipolar colour scheme reflecting grids with suitable opportunity (green colour) and less suitable opportunity (red colour for public logistics centre localization.

As documented on Figure 9, it is not very helpful for decision makers. Generalization and linguistic categories conversion must be applied. The aim was to reclassify results into five informative categories with results converted into linguistic names. Because of putting together cells with similar values Nature breaks algorithm was applied. Generated areas were compared according to their size and based on input information from regional authority polygons with area size lesser than 1 square kilometre were excluded. Final

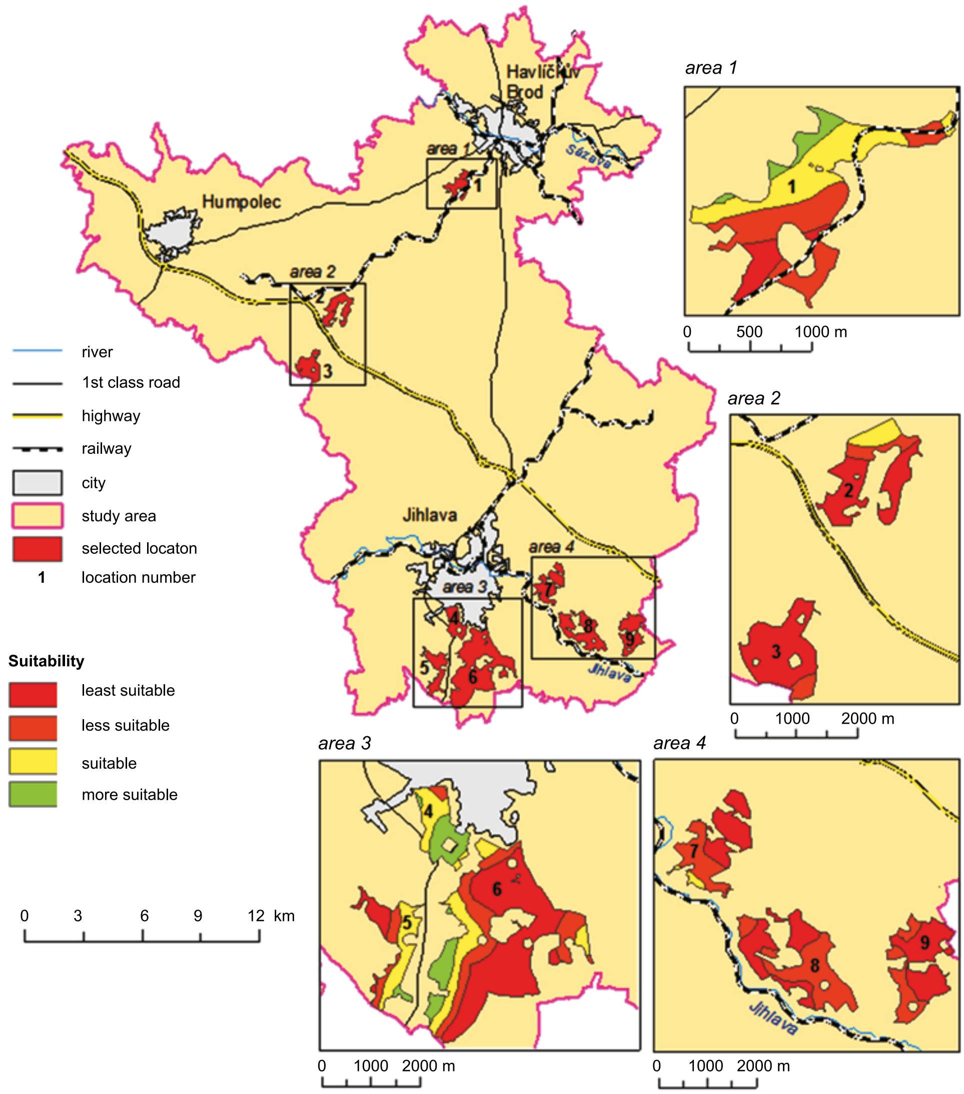

Fig. 10. Generalized categories from OWA results converted into linguistic variables

visualization with areal symbol method reflecting the suitability as in grid map is shown on Figure 10.

Conclusion remarks

Understanding the decision making process, very often it is not possible to offer decision makers final outputs ranking needed results. Mostly visualizations provide partial or final maps documenting the decision making process (constraint maps, factor maps etc.) or in the best case the real final result ranking alternatives. The process of visualization must respect cartographic rules and especially during generalization maintain accuracy without greater distortion. This can happen when reclassifying derived values or using heuristic approaches. Although thematic cartography offers many visualization method and techniques, choropleth or grid maps can be used for continuous data visualization. In case of data conversion into linguistic categories, areal symbol method with qualitative filling is beneficial. Another issue can be seen colour scheme selection. Bipolar colour schemes provide appropriate resolution of extreme and middle values and decision makers can easily work with these results.

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