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Dear friends!

You have just opened the current number of the Geography - Journal of the Czech Geographic Society, which was prepared in English on the occasion of holding the Regional Conference of the IGU in Australian Brisbane. We have tried to orientate it towards the theme seen not only as topical but also very important from geographical skills spreading point of view, that is to say the application of GIS in geographical research specifically in the ASRI products environment. More contributions have been collected and after reviews the following eight main articles and several annotations of books written in English released in geographical institution in Czechia in last years are published.

GIS Applications in geographical research are perceived as a possibility to specify traditional geographical procedures of evaluation and/or to project possibly non-traditional typological procedures on handled data files and furthermore to visualise that all. These procedures not only make research work more effective and offer alternative possibilities of perspective solutions of various issues in the territory but also have a very significant impact on the presentation of geography as in the professional as in the non-professional public. The effect of using procedures arising through GIS application in teaching process as in secondary schools as in universities, in the sphere traditionally covered by geography and lately more and more by penetrating (geo)informatics is also non-significant. Just GIS applications on different levels of decision making processes give a new, modern content to this old science when used in geography, through which a broad plenum of young people of different professions can be addressed. This up-to-date becoming involved and "image" of geography bring then significant impulses for its inner transformation and modernisation. Good luck to geography and particularly to its interconnecting with Geographical Information Systems, in which we can see hopeful future.

Ivan Bičík
The President, Czech Geographic Society

Dear readers!

The publication which gets into your hands has been published on the occasion of a very important geographic event of 2006: IGU Regional Congress Brisbane. We are very happy that we could participate in publishing the publication that helps participants in the conference to get acquainted with the work of Czech geographers and present the results achieved by Czech geographers all over the world. However, we consider it an honor for us that authors of the articles published in this publication reached a high level in terms of implementation of GIS into the geographic research and chose geoinformatic tools of the ESRI products for their work as these products are distributed and supported in Czechia by our company, ARCDATA PRAHA s.r.o.

In compliance with ESRI's policy we also provide a maximum support to university and research teams in order to help to increase the use of GIS within geographic disciplines. As the geoinformatics reveal interesting facts it should become one of the basic tools of the geographic research. GIS helps the geography to improve, use analysis etc. while on the other hand the geography is a basic theoretical resource for GIS. That is why the geography cannot exist without the geoinformatics and vice versa. The advanced geoinformatic tools provide for a higher and higher development of geographic research all over the world.

The Czech Republic is not the exception – using the state-of-the-art technologies the Czech researchers also achieve interesting results which are to be disseminated widely. Our republic is often looked at as a small country that is insignificant in terms of science or technologies. Nevertheless, this publication praises a valuable work of Czech geographic experts within various areas, namely climatology, hydrology, geomorphology, etc. The published papers present use of GIS in the geographical industry not only for a visualization but also for interesting geographical analysis. It proves forwardness in using GIS tools in Czechia that has had a long-standing tradition.

The birth of GIS technology dates back to 1960s. It is often placed into the North America. Given the development of computers and software engineering in the United States it is quite understandable. By the time the GIS technology was born Czechia belonged to a political block that did not favor exchange of experiences and information. Therefore not too many people are aware that in the late 1960s significant theoretic works within the area of territorially oriented information systems originated in the former Czechoslovakia and the first conferences took place there to discuss this discipline. No wonder that nowadays Czechia belongs to countries where GIS has got a large community of users and wide spectrum of use. And the geography is one of the most important ones.

Therefore we wish to all readers to discover many an interesting information and lesson within the pages of this publication that could help them to use geographic information systems more efficiently.

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VÍT VOŽENÍLEK

CONCEPTUAL REMARKS FOR TECTONIC GEOMORPHOLOGY BY TERRAIN MODELLING WITHIN GIS

V Voženílek: *Conceptual remarks for tectonic geomorphology by terrain modelling within GIS.* – Geografie–Sborník ČGS, 111, 1, pp. 3–14 (2006). – The paper deals with term of digital tectonic geomorphology as an integration of structural geology, geomorphology and digital terrain analysis. The author extends traditional set of methods for tectonic geomorphological research and gives general conceptual remarks for methods of tectonic geomorphology developed for the integration of tectonic geomorphology into GIS based on digital terrain modelling. The emphasis is given on selected problems: morphological features associated with fractures, feature recognition and parameter extraction, digital geomorphometry analysis, digital image processing of terrain data and spatial analysis of lineaments. The paper gives fundamental topics for understanding instead of particular algorithms and procedures.
KEY WORDS: tectonic geomorphology – terrain modelling – GIS – landforms.

The paper has been completed within project 205/02/0211 "Geography of selected natural extremes, their impacts and cartographic visualization" supported by Grant Agency of Czech Republic.

Introduction

In addition to various methods and sophisticated geophysical, geological and geodetic data handling a structural analysis of topographic features is well-established field of study in modern geomorphology, and aerial photographs and remotely sensed images have long been used within its approaches. Recent developments in information technology and digital elevation data acquisition have resulted mainly in an increasing interest in digital terrain modelling for tectonic geomorphology. Methods of surface investigation such as remote sensing and morphological analysis provide fast and relatively cheap information, complementary to traditional field geological research in order to study subsurface geology. Morphological analysis of topographic features, in particular lineaments, has long been applied in structural and tectonic studies (Hobbs 1912), and has become a fundamental tool in tectonic analyses using aerial (stereo-)photographs and other remotely sensed imagery (Siegal, Gillespie 1980; Drury 1987; Salvi 1995; Woldai et al. 2000). Although the interpretation of surface morphology in terms of geological structures is commonly applied (Fabbri 1984; Prost 1994; Keller, Pinter 1996; Voženílek et al. 2001) there are relatively enough examples of GIS implementation in such studies, and there are only few case studies involving the consistent application of available digital methods for tectonic geomorphology.

Review of literature on digital morphotectonic analysis shows that large variety of methods (and their combinations) has been used, such as shaded relief models together with remotely sensed images, three-dimensional view with image drape, digital cross-sections, slope, aspect and curvature maps, DEM histograms, and trend and spectral analysis. The most important limitations in general are that:

- most of the studies use a single method (or only a few methods) for surface feature recognition and description
- all of the studies are at the regional scale, although landform observations are at the local scale
- most of the studies use visual methods of feature (mostly lineament) extraction
- there are very few cases involving the analysis and extraction of landforms specific to tectonic structures
- most of the methods can be applied to neotectonic landforms only
- there is a lack of rigorous study of the relationship between tectonic processes, secondary geological processes, and their representation in DEMs.

Digital tectonic geomorphology

Systematic digital tectonic geomorphology analysis is limited by the lack of such studies in literature, and the non-uniform description and use of relevant digital methods in different fields of the Earth Sciences. Essentially identical methods are often used in these different fields with different names and for different purposes that makes their adoption to digital tectonic geomorphology difficult. GIS software can easily perform most of the analyses but some procedures may be very difficult to implement. Many digital analyses require the use of an integrated system of many analytical and software tools based on principal topics of interoperability.

Digital tectonic geomorphology is the integration of three components (Jordan, Csillag 2001, 2003): structural geology, geomorphology and digital terrain analysis. Tectonic geomorphology has developed sophisticated methods for the integration of structural geology and geomorphology. The application of numerical methods in geomorphology has led to the field of geomorphometry, which has developed rapidly since the availability of digital terrain data. There is, however, a gap between structural geology and digital terrain analysis.

The basic geometric properties which characterise the terrain surface at a point are elevation, properties of the gradient vector: its magnitude defining slope, and its direction angle defining terrain aspect, surface curvature, convexity and surface-specific points and lines, i.e. local maxima (peaks), minima (pits), saddle points (passes), inflection points, slope-breaks, ridge and valley lines. The relationship of local geometric attributes and tectonic structures such as relationship between slope-breaks and fractures is often straightforward (Siegal, Gillespie 1980; Drury 1987; Prost 1994; Salvi 1995).

In contrast to local geometric analysis, general geomorphology also studies the statistical and spatial characteristics and relationships of point attributes (Evans 1972, 1980). Relationships between point attributes were used by Evans (1980) to further characterise the terrain. For example, the elevation-average slope curve and the cumulative percentage area-elevation curve ('hypsometric curve') can be used to study slope conditions. By fitting a trend surface to the studied area or its parts, the overall tilt due to tectonic activity can be studied (Doomkamp 1972; Fraser et al. 1995; Guth 1997). Autocorrelation, spectral, wavelet and variogram analysis can reveal anisotropy and periodicity present in the digital elevation model. Both features often result from tectonic control on terrain morphology (Harrison, Lo 1996).

Morphological features associated with fractures

Structural discontinuities in rocks most often result in linear morphological features along the intersection of fracture plane and land surface. Linear morphological expressions of fractures include mainly linear valleys, linear ridgelines and linear slope-breaks. The main geometric characteristics of a single line are orientation, length (continuity) and line curvature. Linear fracture traces are most obvious in the case of high-dip faults of normal, reverse and strike-slip type whilst thrust faults tend to appear irregular in topography (Prost 1994; Drury 1997; Goldsworthy, Jackson 2000). Intersection of topographic surface and fold structures can also result in linear and planar features depending on the geometry and orientation of the folds with respect to the erosion surface (Ramsay, Huber 1987).

Planar features such as uniform hillsides also develop along fractures. Geometry of planar surfaces is described by uniform aspect and high and constant slope values. Shape and extent are also important characteristics. Large elongated areas with linear boundaries can be associated with faults. The measure of curvature is important in case of complex curving fracture surfaces.

Specific geomorphological features forming along faults are diverse. Asymmetric geometry of slopes across valley and ridgeline axes, as measured by uniform slope angle differences, can result from tectonic influences on the morphology. Characteristic landforms, such as depressions, pressure bulges or tilt of flats are commonly seen in fault zones. Depressions and bulges are geometric locations of local elevation minima and maxima, respectively. Characteristic shape and slope conditions describe their geometry (Keller, Pinter 1996). Tilt of flats result in uniform surface gradients.

Most of the above morphological features, such as linear valleys, asymmetric slopes and depressions may be caused by secondary processes or can be associated with lithology. For example, wind erosion may create linear patterns; planar surfaces, linear valleys and ridges and asymmetric slopes are often associated with bedding; and linear morphological features may arise from lithological contacts between different rock types.

The spatial relationships among fractures can be described either statistically by a spatial frequency analysis of the above characteristics or topologically in statistical analysis, location of individual features is not considered within the studied population. For example, angular statistics (rose diagrams) are used for analysis of orientation distribution in the study area. Spatial statistics of fault length and intersection densities are important in structural geology, too. Note also that the density number of lineaments is sensitive to the scale and resolution of the used imagery, relief and thickness of soil cover (Tirén, Beckholmen 1992). Another approach in many fracture analysis considers fracture populations as networks, and focuses on their pattern of intersection in terms of lengths, angle and frequencies, mutual dislocations and shape and size of fracture-bounded areas, from which the stress field can be quantified (Ramsay, Huber 1987). This approach is commonly known as topological analysis, where the location and relationships of individual features are considered. Intersecting lineaments define rock blocks of various scales identifiable by digital terrain analysis (Tirén, Beckholmen 1992), an important feature of, for example, shear zone regimes (Sylvester 1988).

Lithological structures within rock units may also be represented by DEM and their description might help clarifying geological and structural relationships, but these features can also obscure tectonic structures. Secondary geomorphological indicators of tectonic influence are dislocations of geomorphic surfaces, such as erosional surfaces and alluvial plains, and these surfaces are the result of uplift, subsidence or tilting. Fluvial networks are the most common indicators: the drainage network pattern often reflects the regional or even the local tectonic framework (Deffontaines, Chorowicz 1991). In the absence of further morphological evidence, these morphological features can be distinguished from features of non-tectonic origin with the use of geological information. Geological data from various sources, such as geological maps, geophysical data, remotely sensed images and field measurements also have to be incorporated in the GIS database.

Feature recognition and parameter extraction

In order to maximise the tectonic geomorphology information obtained from a DEM, a sequential modelling scheme can be created and applied. The design of the modelling scheme has been based on the following considerations (Jordan, Csillag 2001):
- the objective is the quantitative geometric characterization of landforms
- the objective is providing reproducible outputs
- analysis proceeds from simple to the more complex analysis
- outputs from modelling steps are controlled by input data and parameters
- the procedure integrates a wide-range of available methods
- multi-source information is integrated in the database
- digital terrain analysis is implemented in GIS environment.

Analysis of multi-source data mostly use GIS techniques. Figure 1 illustrates the procedure of recognition and extraction of fault-related landforms and their tectonic interpretation. Based on the study of landforms related to faults, geomorphological characteristics are translated into mathematical and numerical algorithms. Topographic features represented by DEM of test areas are extracted and characterised by digital terrain analysis. Verification of structural implications uses other data sources in GIS. The development and application of numerical methods in GIS are

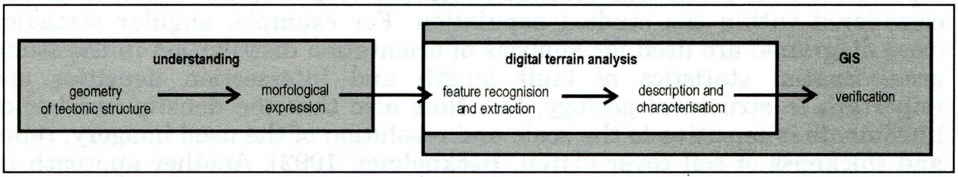

Fig. 1 – Scheme of the procedure of recognition and extraction of fault-related landforms and their tectonic interpretation

discussed in various papers (i.e. Jordan, Csillag 2001, 2003, Wood 2002, Voženílek 2002).

The components of digital tectonic geomorphology implemented with GIS are:

- numerical differential geometry
- digital drainage network analysis
- digital geomorphometry
- digital image processing
- lineament extraction and analysis
- spatial and statistical analysis and
- DEM-specific digital methods such as shaded relief models, digital cross-sections and 3D surface modelling.

The analysis within digital tectonic geomorphology proceeds from simple univariate elevation studies, through differential geometric surface analysis and drainage network analysis, to the multivariate interpretation of results using GIS technology. Reproducibility of morphological analysis is achieved by the application of numerical data processing algorithms. Each modelling module has a set of defined input parameters. Subsequent steps are based on output of previous terrain models. Prior to the spatial analysis of each terrain attribute, its histogram is studied for systematic error and statistical properties such as multi-modality. Histograms are interpreted in terms of morphometry and used for classification of terrain data. Image stretching for enhancement of visual interpretation is also based on histograms.

Digital geomorphometry analysis

Elevation and derivatives of altitude, called point attributes, form the bases for geomorphometric study of landscape (Evans 1972). The five basic parameters calculated are elevation, slope, aspect, profile and tangential curvatures (Evans 1980). For example, a peak in the elevation histogram that corresponds to a sharp increase in its cumulative graph indicates a flat planation surface. A peak in the aspect frequency histogram or a large petal in the rose diagram shows that a larger number of pixels has aspect in a preferred orientation. Where these pixels form one or more connected areas on hillsides with linear boundaries, a tectonic origin can be inferred.

Next in the analysis, bivariate and multivariate relationships between variables (derivatives and moments) can be studied. Slopes and aspects can be plotted in stereonet to study if steep slopes have preferred orientations, as steep slopes with the same orientation may be associated with faulting.

Finally, terrain ‘texture’ is conveniently studied by means of spatial statistical methods and network analysis techniques. Trend analysis, autocorrelation and spectral analysis are carried out for the entire area or specific parts of the area (e.g. basins only). The trend surface is fitted to all data points or to surface specific points, such as peaks or valley lines, to estimate regional dips, as the tilt of an area is often related to tectonic movements.

Autocorrelation, spectral and wavelet analyses reveal lineation (anisotropy) and periodicity of a landscape due to faulting or folding. The autocorrelation property can also be studied by calculating semivariograms in different directions (Curran 1988). Problems emerge from the fact that valleys often curve and there are confluences down-valley and that ridge height and spacing may vary (Evans 1972). In order to overcome the problem of converging ridges of alternating height, analysis can be limited to valley lines only. Then valley lines are defined by the digital drainage network identification method.

Digital image processing of terrain data

DEM and each terrain attribute map derived by digital terrain analysis can be viewed as raster images and hence be processed using digital image processing procedures to increasing the apparent distinction between features in the scene (Sauter et al. 1989; Fabbri 1984; Woldai, Bayasgalan 1999). Point operations of histogram slicing and contrast stretching have basically two applications. Slicing of an image histogram by dividing pixel values into specified intervals can been used to display discrete categories of elevation, slope, aspect and other terrain attributes (Lillesand, Kiefer 1994). Aspect data can been displayed and analysed by means of rose diagrams and circular statistics (Wells 1999; Baas 2000). Areas of uniform geometric attribute are then examined for area distribution, continuity and shape whilst contrast stretching was performed on grey-level images to enhance visual interpretations of the terrain models (Lillesand, Kiefer 1994).

Spatial operations of gradient filters are processed by local operators of gradient filters which can be applied only to terrain data and not to grey-scale images in order to preserve the original geometric information in terrain models. In this way, edges (valleys, ridges and slope-breaks) are extracted on geometric bases. For example, slope-breaks can be recognised as edges if change in slope in the gradient direction (profile curvature) exceeded a predefined threshold. Low-pass filters such as median and average filters are used to reduce noise and emphasise areas of similar topographic attributes. For example, aspects calculated from a smoothed DEM could reveal a hill slope of uniform aspect related to faulting (Voženílek et al. 2001). The enhanced images were then used for analysis of shape, spatial distribution and for interactive lineament extraction.

Hill shading methods producing relief maps are unusual to DEM images and are fundamental for morphostructural analysis (Simpson, Anders 1992). Hill shading increases the contrast of very subtle intensity variations of an image, much more than contouring or pseudo-colour representation do (Drury 1987). Onorati et al. (1992) used multi-image operation of false colour composites (i.e. RGB colour components) in morphotectonic studies to simultaneously analyse three DEMs. In their study colour separated geological maps and remotely sensed images were combined with a shaded relief map. These in turn were draped on the three-dimensional view of the study areas to enable the study of the relationship between geology and morphology.

Spatial analysis of lineaments

Lineaments are defined as straight linear elements visible at the Earth's surface and which are the representations of geological and/or geomorphological phenomena (Clark, Wilson 1994). In geomorphometric analysis, a linear feature can have geometric origin only and represent

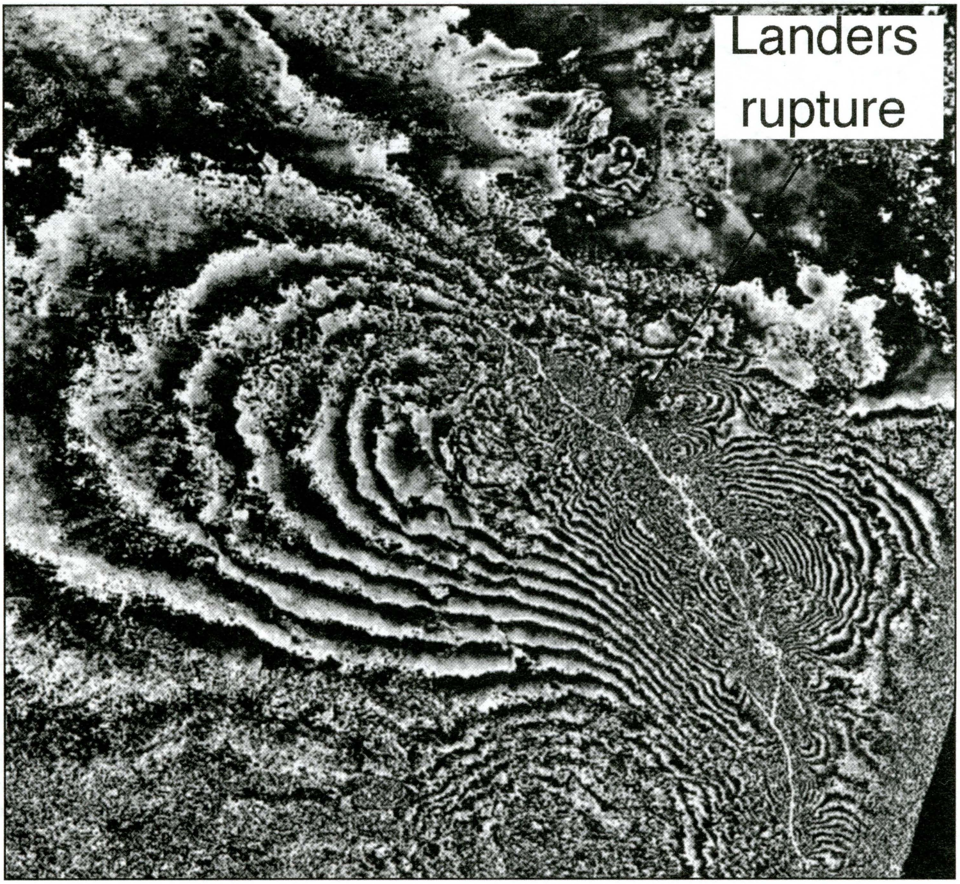

Fig. 2 – Radar SAR interferogram of ground displacement associated with the Landers Mw 7.3 earthquake (June 1992). Each fringe represents 28 mm of displacement and at least 20 fringes are visible near the fault (equal to 560 mm of displacement). Coherence is lost as the ground rupture is approached, probably because the displacement gradient is greater than 28 mm/pixel. Note the broad, asymmetric deformation in an east-west direction covering >75 km and the abrupt termination of major deformation near the ends of the fault. The detailed deformation patterns seen here can be used to constrain models of surface displacement due to the Landers rupture (Burbank, Anderson 2001).

a change in terrain elevation, such as a valley or ridgeline, slope-break or inflex line. In terms of digital modelling, a lineament is a continuous series of pixels having similar terrain values (Koike et al. 1998, Krcho 1983, 1990). Each line can be characterised by length and orientation. Distribution and relationships among lines are described by length and orientation frequencies calculated for the entire area or a sub-area. Then lineament intersection density, total length per area and frequency per area can been analysed. Two lineament extraction procedures are frequently applied:

- an automatic procedure using digital drainage extraction to identify valley and ridgelines
- interactive lineament interpretation of terrain models.

Wavelet analysis is used to identify and measure periodicity and location of lineament zones.

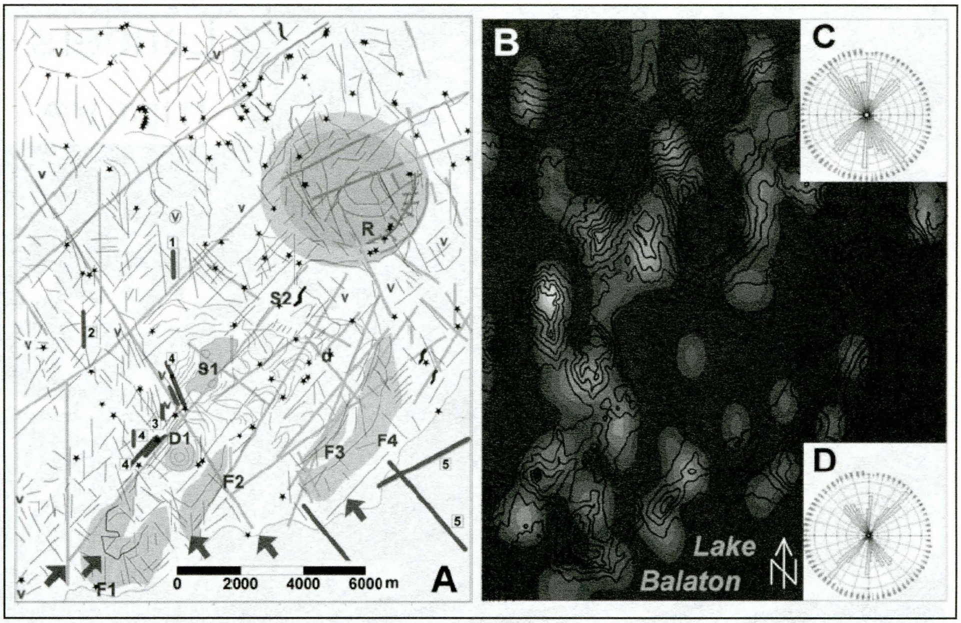

Fig. 2 – Graphic documentation for spatial analysis of lineaments (Jordan, Csillag 2003). Explanation: A – Lineament map (black lines are line features digitised from elevation images, grey polygons emphasise major morphological feature, thick light-grey lines show fracture lines extracted from geological maps, thick dark-grey lines show fracture lines recognised by early studies, asterisks represent springs and large arrows show zones of springs; D1: main depression, S1 and S2: S-shaped expressions, F1-F4: fold features, R: ring structure, d: asymmetric depressions, v: volcanic features). B – Lineament density map for N-S (N±10°) lineaments (light tones indicate higher densities). C and D – Frequency and length rose diagram of lineaments.

Conclusions

To study basic geometry of faults and associated morphological features is going to be commonly used methods of tectonic geomorphology. Also topographic parameters necessary to recognise and characterise them can be easily identified. Numerical methods to extract specific parameters are now developed and can be applied within GIS environment.

Digital terrain analysis gives reproducible results and provides quantitative landform description. It allows geomorphologists reproducibility as an improvement to traditional morphological analysis and visual image interpretation. Quantitative geometric characterisation of landforms based on DEM analysis is an advantage if compared to digital processing of remotely sensed images or analysis of grey-scale terrain images (Voženílek et al. 2001).

Evan's (1972, 1980) general geomorphometric method has been developed for all GIS packages and then adopted to digital tectonic geomorphology. So now the five basic geometric attributes (elevation, slope, aspect, profile and tangential curvatures) can be complemented with the automatic extraction of surface specific points and ridge and valley lines (Voženílek 2002). Evan's univariate and bivariate methodology is also extended with texture (spatial) analysis methods such as trend, autocorrelation, wavelet, variogram and spectral analysis and network analysis.

Digital image processing techniques of spatial operations and histogram manipulations can be integrated in the GIS procedure and applied at almost all stages of digital tectonic geomorphology analysis.

A method for the extraction of high-density drainage and ridgeline extraction can be used to create an artificial DEM to overcome problems of periodicity analyses using original topographic data. The advantage of digital drainage extraction over traditional lineament extraction methods is that identified.

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Shrnutí

KONCEPČNÍ POZNÁMKY K PROBLEMATICE TEKTONICKÉ GEOMORFOLOGIE ŘEŠENÉ MODELOVÁNÍM RELIÉFU V PROSTŘEDÍ GIS

Strukturní analýzy topografických témat jsou vedle širokého spektra tradičních metod a analýz specializovaných geofyzikálních, geologických a geodetických údajů osvědčenou metodou studia geomorfologie. Vývoj informačních technologií a metod získávání digitálních dat zapříčinily vzrůstající zájem o využití digitálních modelů terénu v oblasti tektonické geomorfologie. Metody aplikované geoinformatiky, jako např. dálkový průzkum či geomorfometrické analýzy, poskytují rychlé a poměrně levné informace a doplňují datové zdroje potřebné pro studium geologických podmínek.

Digitální tektonická geomorfologie představuje sloučení tří komponent: strukturní geologie, geomorfologie a analýzy digitálních modelů reliéfu. Tektonická geomorfologie vyvíjí sofistikované metody sloužící k integraci strukturní geologie a geomorfologie. Aplikaci numerických metod v geomorfologii se věnuje geomorfometrie, která zaznamenala největší vývoj po odhalení potenciálu digitálních modelů terénu. Přesto zde existuje určitá mezera mezi strukturní geologií a analýzami DMR.

Prostorové analýzy geomorfologických tvarů spojených se zlomy: Prostorový vztah mezi jednotlivými povrchovými tvary může být popsán jednak statisticky, prostřednictvím prostorových analýz vybraných charakteristik nebo topologicky. V případě statistických analýz, není umístění jednotlivých tvarů reliéfu zvažováno pro celé území. Například, pro ana-

lýzy rozdělení orientace jsou používány úhlové statistiky. Pro potřeby strukturní geologie jsou však důležité i prostorové analýzy, např. délky zlomů nebo křížení puklin. Hustota zlomů je závislá na rozlišení a měřítku použitých snímků, reliéfu a mocnost sedimentů. Další přístup k analýzám zlomů uvažuje strukturu zlomů jako síť a zabývá se jejich vzájemnými vztahy z hlediska jejich délky, úhlu, který svírají, tvaru a velikosti rozhraní, kde dochází k uvolňování napětí. Tento přístup je všeobecně znám jako topologická analýza, ve které je hodnocena jak poloha, tak vzájemné vztahy mezi jednotlivými tvary. Protínající se zlomy vymezují bloky hornin různých velikostí, které je možné identifikovat pomocí analýz digitálního modelu reliéfu. Litologické tvary různých horninových jednotek mohou být také reprezentovány prostřednictvím digitálních modelů terénu, což významně napomáhá při objasňování vzájemných geologických či strukturních vztahů. Druhotným geomorfologickým indikátorem tektonických vlivů jsou poruchy geomorfologických povrchů, jako např. erozní povrchy nebo údolní nivy, které vznikají působením zdvihu, poklesu či sklápění povrchu. Typickým indikátorem je říční síť. Její tvar velmi často odráží regionální nebo lokální tektonický systém. V případě, že tyto geomorfologické znaky nejsou známy, lze geomorfologické tvary lokalizovat pomoci tvarů, které sice nemají tektonický charakter, ale nesou určitou geologickou informaci.

Identifikace tvarů reliéfu a získávání parametrů: Pro získání maximálního množství informací z digitálního modelu terénu se používají metody sekvenčního modelování. V prostředí GIS se pro řešení této problematiky implementují vybrané komponenty digitální tektonické geomorfologie, např. numerická diferenciální geometrie, síťová analýza povodí, digitální geomorfometrie, zpracované digitální snímky, analýzy lineamentů, prostorové a statistické analýzy apod. Po analýze tvarů georeliéfu souvisejících s tektonikou jsou geomorfologické charakteristiky začleněny do matematických modelů. Jednotlivé tvary a typy zemského povrchu, reprezentované DMR, jsou pak charakterizovány pomocí patřičných povrchových analýz. Následná verifikace a testování důsledků jsou prováděny v prostředí GIS na datech z jiného zdroje (viz obr. 1). Podobné analýzy postupují od jednoduchých studií profilů, přes analýzy tvarů georeliéfu a síťové analýzy povodí, až ke složitým interpretacím výsledků, vše v nejčastěji prostřednictví GIS.

Digitální geomorfometrické analýzy: Vstupem do geomorfometrických studií jsou atributy elementárních (tvarové homogenních) ploch georeliéfu. Využíváno je zejména pět základních parametrů: nadmořská výška, sklon, orientace ke světovým stranám, horizontální a vertikální křivost reliéfu. Například, vrchol v histogramu nadmořských výšek, který koresponduje s ostrým nárůstem v jeho grafu kumulativních nadmořských výšek, indikuje plochý povrch. Vrchol v histogramu orientací nebo široký pruh v hvězdicovitém diagramu ukazují, že velké množství pixelů je orientováno v preferovaném, tedy námi vybraném směru. Pokud tyto pixely vytvářejí jednu nebo více spojených ploch s lineárními hranicemi na svazích kopce, lze z nich odvodit tektonický původ. V analýze jsou dále studovány vzájemné vztahy mezi proměnnými. Orientace a sklony jsou vyjádřeny v pravidelných intervalech, aby bylo možné zjistit, zda například převažuje v některém směru příkrý sklon, nebo zda se příkrý sklony ve stejném směru spojují do zlomové oblasti. Na závěr se využívají prostředky prostorových statistických metod a techniky síťových analýz. Analýzy trendu, autokorelace a spektrální analýzy jsou uskutečněny pro konkrétní oblast nebo pro vybranou část zájmového území. Trend může být odvozen buďto od všech bodů nebo pouze od vybraných bodů, např. vrcholy. Autokorelace a spektrální analýzy odhalují obrys povrchu jako důsledek vrásnění či zlomové stavby. Vlastnosti autokorelace mohou být studovány i pomocí výpočtů semivariogramu.

Zpracování digitálních snímků terénních dat: Digitální modely terénu a atributy ploch z nich odvozené lze zobrazit jako rastrovou vrstvu a z toho důvodu mohou být také zpracovány použitím procedur pro zlepšení rozlišení. K zobrazení diskrétních kategorií atributů se vytvářejí řezy histogramu, což představuje rozdělení hodnot pixlů do přesně vymezených intervalů. K zobrazení a analýzám dat orientace se užívá hvězdicový diagram a kruhové statistiky. Oblasti se stejnými geometrickými vlastnostmi jsou následně zkoumány z hlediska rozdělení, kontinuity, tvaru i dalších atributů. Kontrast je transformován do stupnice šedi (pro visuální interpretaci tvarů georeliéfu). Např. náhlá změna svahu může být rozpoznána jako hrana, pokud změna sklonu překročí předdefinovaný práh. Dolní práh, např. medián nebo průměr, se používá k redukci šumu a ke zvýraznění oblastí se stejnými topografickými vlastnostmi. Orientace terénu vypočtena z vyhlazeného digitálního modelu terénu může odhalit svahy o určitém sklonu se stejnou orientací související s tektonickými poruchami. Vrstvy jsou pak používány pro analýzy prostorového rozdělení. Metody stínovaného reliéfu, produkující reliéfní mapy, jsou základem morfostrukturních analýz. Stínování reliéfu zvyšuje kontrast obrazu mnohem lépe než pseudobarevná reprezentace. V dnešní době jsou pro vytvoření stínovaného reliéfu kombinovány barevně separované geologické mapy a obrazy dálkového průzkumu země. Z toho je nakonec vytvořen trojrozměrný obraz zájmové oblasti umožňující studium vzájemných vztahů mezi geologií a geomorfologií.

Prostorové analýzy lineamentů: Lineamenty jsou definovány jako přímé lineární elementy viditelné na zemském povrchu a reprezentující určité geologické či geomorfologické fenomény. V geomorfometrických analýzách mají lineární tvary vždy geometrický základ a reprezentují změny v převýšení povrchu, jako např. údolí nebo brázdy. V případě digitálního modelování, jsou lineamenty chápány jako kontinuální série pixlů o stejné hodnotě. Rozdělení a vzájemný vztah mezi liniemi jsou charakterizovány prostřednictvím délky a četnosti orientací v zájmové oblasti.

Obr. 1 – Schéma postupu určování a odvozování povrchových tvarů souvisejících se zlomy a jejich tektonická interpretace.

Obr. 2 – Interferogram posunů povrchu souvisejících se zemětřesením o síle 7,3 Mw v oblasti Landers rupture (červen 1992) vyhotovený pomocí radaru SAR. Každý pás představuje posun o 28 mm a poblíž zlomu je vidět nejméně 20 pásů (což odpovídá posunu o 560 mm). Směrem ke zlomu klesá soudržnost, patrně proto, že gradient posunu je větší než 28 mm/pixel. Všimněte si široké asymetrické deformace ve směru východ–západ >75 km a náhlého ukončení hlavní deformace u konců zlomu. Podrobný model zdejší deformace může být využit k prokázání modelů posunu povrchu způsobeného Landers rupture (Burbank, Anderson 2001).

Obr. 3 – Grafická dokumentace prostorové analýzy lineamentů (Jordan, Csillag 2003). Vysvětlivky: A – mapa lineamentů (černé čáry jsou liniové znaky digitalizované z obrazů převýšení, šedé mnohoúhelníky zdůrazňují hlavní morfologické znaky, tlusté světle šedé čáry znázorňují zlomové linie vytažené z geologických map, tlusté tmavě šedé čáry znázorňují zlomové linie identifikované prvními studiemi, hvězdičky znázorňují prameny a velké šipky pramenné oblasti; D1: hlavní pokles, S1 a S2: projevy se tvaru písmene S, F1-F4: vrásové útvary, R: prstencová struktura, d: asymetrické poklesy, v: sopečné útvary). B – mapa hustoty lineamentů pro lineamenty ve směru sever-jih (sever ±10°) (světlé odstíny označují vyšší hustotu). C a D – frekvenční a délkový růžicový diagram lineamentů.

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PAVEL MENTLÍK, KAREL JEDLIČKA, JOZEF MINÁR, IVAN BARKA

GEOMORPHOLOGICAL INFORMATION SYSTEM: PHYSICAL MODEL AND OPTIONS OF GEOMORPHOLOGICAL ANALYSIS

P. Mentlík, K. Jedlička, J. Minár, I. Barka: *Geomorphological information system: physical model and options of geomorphological analysis.* – Geografie–Sborník ČGS, 111, 1, pp. 15–32 (2006). – The paper has two main aims. Firstly, to postulate a physical geodatabase model of a geomorphological information system based on the already existing logical geodatabase model. Secondly, to define processes of geomorphological analysis based on the physical geodatabase model. The structure of the physical model follows the logical model and is divided into three parts: adopted layers (hydrology, geology, topography and others), basic layers (elementary forms, digital elevation model and derivatives, documentation materials, genetic groups of landforms, morphodynamic phenomena, basin based features and geomorphic network) and special layers (morphostructural analysis, comprehensive geomorphological analysis and so on). The geodatabase modelling methodology was used for developing the physical geodatabase model. The geomorphological analysis is based mainly on the layer of elementary forms (defined according to their morphology and morphometry) and the derived layer of morphogenetical forms (determined by genesis of landforms). The traditional methods of geomorphological mapping and also more recent concepts of geomorphological analysis were used. The concept is presented in the context of research in the surroundings of Prášilské jezero (lake) in the Šumava (Mts.). ESRI products were used to carry out the project.
KEY WORDS: geomorphological information system (GmIS) – geomorphological analysis – geomorphological mapping – glacial forms.

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Introduction

Geomorphological Information System (GmIS) as a special type of geographic information system (GIS) focused on collecting, maintaining and analyzing geomorphic information is a very good tool for geomorphological analysis. This idea has been mentioned by several authors (e.g. Barsch, Dikau 1989, Dikau 1992, Minár 1996, Kusendová 2000, Voženílek et al. 2001). However, some problems remain which we would like to solve.

The primary idea of GmIS is not based on a special technical solution. In fact, only common GIS tools are used here. However, the configuration and connections of the thematic layers (particularly the position of the layer of elementary forms as a base of the system in our case) and also the structure of the database are characteristic features of GmIS.

One of the goals of this paper is to present an example of implementation of geomorphological analysis into Geomorphological Information System. An example from the surroundings of Prášilské jezero (lake) in the Šumava Mts. (the Czech Republic) is presented here (Fig. 7, 8, 9 and 10).

Description of the creation of the physical model of a geomorphological database is the other goal. This model is a necessary condition for implementing the geomorphological analysis in GmIS environment. However, before this, it is necessary to introduce a logical model of GmIS database. In connection with defined goals, two aspects of GmIS can be distinguished: geomorphological and technical.

From a geomorphological point of view GmIS is defined as an environment suitable for an analysis of georelief (mainly geomorphological analysis) in an exact way and also for comprehensive administration of geomorphological data and/or data useful for geomorphological research.

From a technical point of view, GmIS is, however, an environment providing storage and management of geomorphological data and also possibilities for particular predefined analysis of the data. The uniform delimitation of geomorphological units and some predefined techniques of geomorphological analysis should be an integral part of the system.

The core of geomorphological investigation in GmIS is geomorphological analysis based on the fundamental concept of geomorphology which says that activities of geomorphological processes are explicitly represented in the shape of the georelief. This means that analysis of georelief provides correct information about the origin and development of a landscape as well as relevant data about activities of recent and present-day processes. However, the exact methodological procedure of geomorphological analysis has not been clearly defined yet, although some authors (e.g. Urbánek 2000a, b) postulate particular steps of the analysis. It is possible to transform and renew Urbánek's concept and to use it in GmIS. This provides an environment for geomorphological analysis because it is possible to manage a huge amount of information and to deal with special operations which provide exact data. The significance of this approach is increasing because of the number of new methods and techniques of research being used in geomorphology. An example could be the progress of GIS and GPS techniques as well as the application of various methods using results of research in physics, chemistry or biology (various dating methods, scanning electron microscopy, pollen analysis etc.).

The following important features of geomorphological analysis can be defined in GmIS:

Precision: there are two things in geomorphological analysis which should be particularly precise: firstly, the definition of the geomorphological forms should be as precise and as clear as possible. Secondly, it must be possible to repeat all the steps of a particular analysis again.

Flexibility: two aspects of flexibility of geomorphological analysis can be defined:

- geomorphological analysis should be open to various inputs (analysis providing extra information about particular geomorphological forms),
- it is also necessary to enable analysis in various types of georelief. This means providing methods of definition of extra categories of geomorphological forms and specifications for a particular user.

Stability: the technical background of geomorphological analysis should be as stable as possible. It is necessary to postulate the main steps of the analysis in the physical model of Geodatabase of GmIS and to connect it with other parts of GmIS.

Generally it is possible to say that geomorphological analysis in GmIS is a process for systematically increasing knowledge about georelief. All steps of the process should be exactly defined and reversible (it must be possible to repeat a particular analysis again). The main aim of the geomorphological analysis is to postulate a hypothesis (ideally theory) of the genesis of georelief.

Outline of logical model of geomorphological database

The logical model can represent a user's point of view of the comprehensive geomorphological database – the core of GmIS. Our model consists of three main parts, which are composed of layers or groups of layers (adapted from Minár et al. 2005):

Adopted layers – layers which have been taken from external sources, such as hydrology, geology, topography and others.

Basic layers – layers which are created by a geomorphologist; by field survey or by derivation from adopted layers or using them in combination. This group is composed of layers of elementary forms[1], a digital elevation model (DEM) and its derivatives, documentation materials, genetic groups of landforms, morphodynamic phenomena, basin based features and geomorphological network.

Special layers – layers created by special geomorphological analysis, such as morphostructural analysis, comprehensive geomorphological analysis, geomorphologic hazard evaluation and so on.

The logical model is described in Minár et al. (2005). An ArcMap project is a way of visualizing the logical model in a computer. It is also a common user interface in which the user – a geomorphologist – works (see Fig. 1).

The physical model comes from the logical model and it is a real representation of data of GmIS in a spatial database. The physical model is closely connected to a database or to a file oriented data structure. We selected ESRI Geodatabase structure for storing the GmIS data.

Physical model of geomorphological database

The scope of this contribution does not allow the complete physical model of the database and all the algorithms of geomorphological analysis to be shown. Only the selected core components are presented. Creation of the physical model involves developing its structure and populating the structure with real data. The physical model follows the structure of the logical model, but there are exceptions which come from the limitations of the spatial database structure[2]. There are only two serious limitations influencing the GmIS structure: topology relations cannot be built among datasets; there can be only one level of datasets (it is not possible to create subdatasets).

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[1] The elementary forms are basic mapping segments of georelief characterized by maximum homogeneity (constant value) of some relevant morphometric characteristics (altitude, slope, various curvatures, ...) and bounded by discontinuity lines of some of these characteristics – see e.g. Minár (1996).

[2] General description of ESRI Geodatabase can be found e. g. in Arctur & Zeiler (2004).

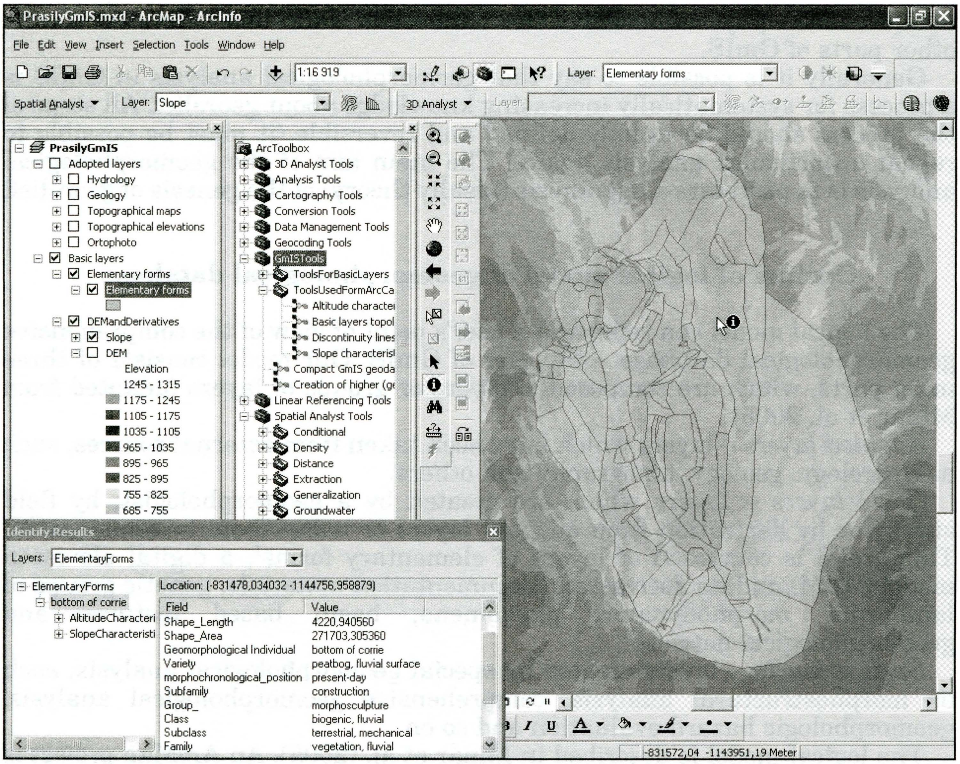

Fig. 1 – ArcMap Project reflecting some aspects of logical model. Screenshot from ArcMap 9.0; the area under consideration dealt with in this paper is presented here.

Our physical model of the geomorphological database is only divided into the dataset "AdoptedLayers"[3] equivalent to the adopted layers from the logical model, and into the dataset "GeomorphologicalLayers", where all basic and special geomorphological layers are stored. This is because it is necessary to maintain topology among them. All non spatial tables are stored in the geodatabase root directory. The symbology of ESRI reverse engineering diagrams is used in the figures displaying the physical model – see e.g. Arctur & Zeiler (2004). The legend to this symbology is explained in Fig. 2.

Adopted layers are created and populated by converting data from external sources, i.e. external digital databases, files or scanned paper maps. These processes are common in geographical information systems (GIS) and are not described here.

The geomorphological layers dataset is the core of the geomorphological database. Its structure (without attributes) is shown in Fig. 3.

Firstly it is necessary to create DEM. Interpolation from the contour lines has been used in our case. Other raster layers, such as slope, aspect and curvatures are derived from it. Further documentation materials layers are populated from field survey.

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3 All names in the geomorphological database in the figures follow naming conventions for ESRI Geodatabase, see e.g. ESRI 2005 or Jedlička (2005). For better legibility the full terms are used in the following text.

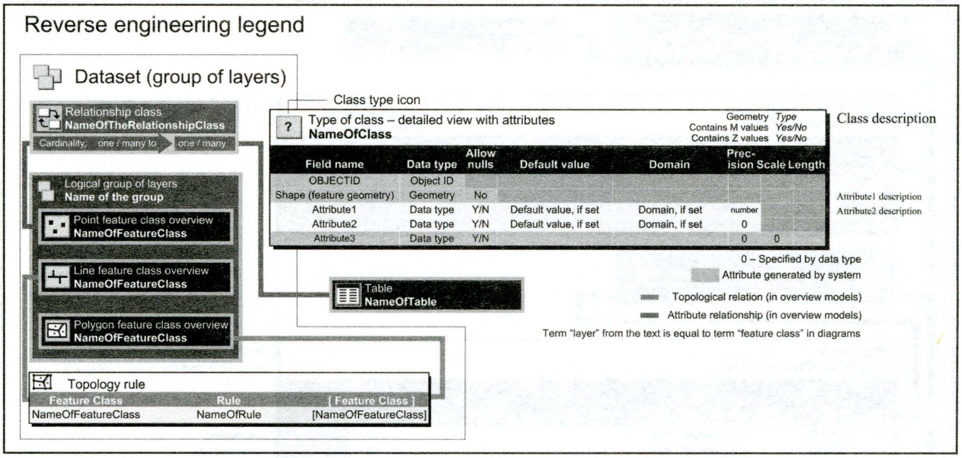

Fig. 2 – Legend of ESRI reverse engineering diagrams according to Arctur & Zeiler (2004); created by ESRI Geodatabase Diagrammer in Microsoft Visio.

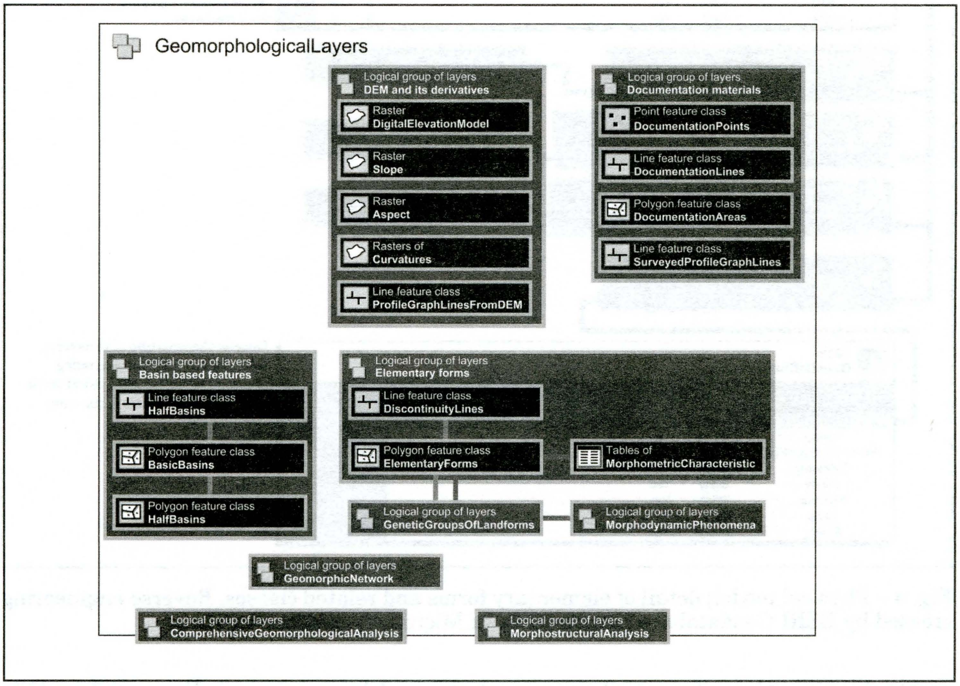

Fig. 3 – Physical model; overview of geomorphological layers. Reverse engineering created by ESRI Geodatabase Diagrammer in Microsoft Visio.

Elementary forms are created interactively from DEM and its derivatives in an ArcGIS environment and documentation materials from geomorphological mapping. Basin based features can be created using the hydrological functions of ArcGIS.

The layers of the genetic group of landforms, morphodynamic phenomena and geometric network are created furthering the process of geomorphological

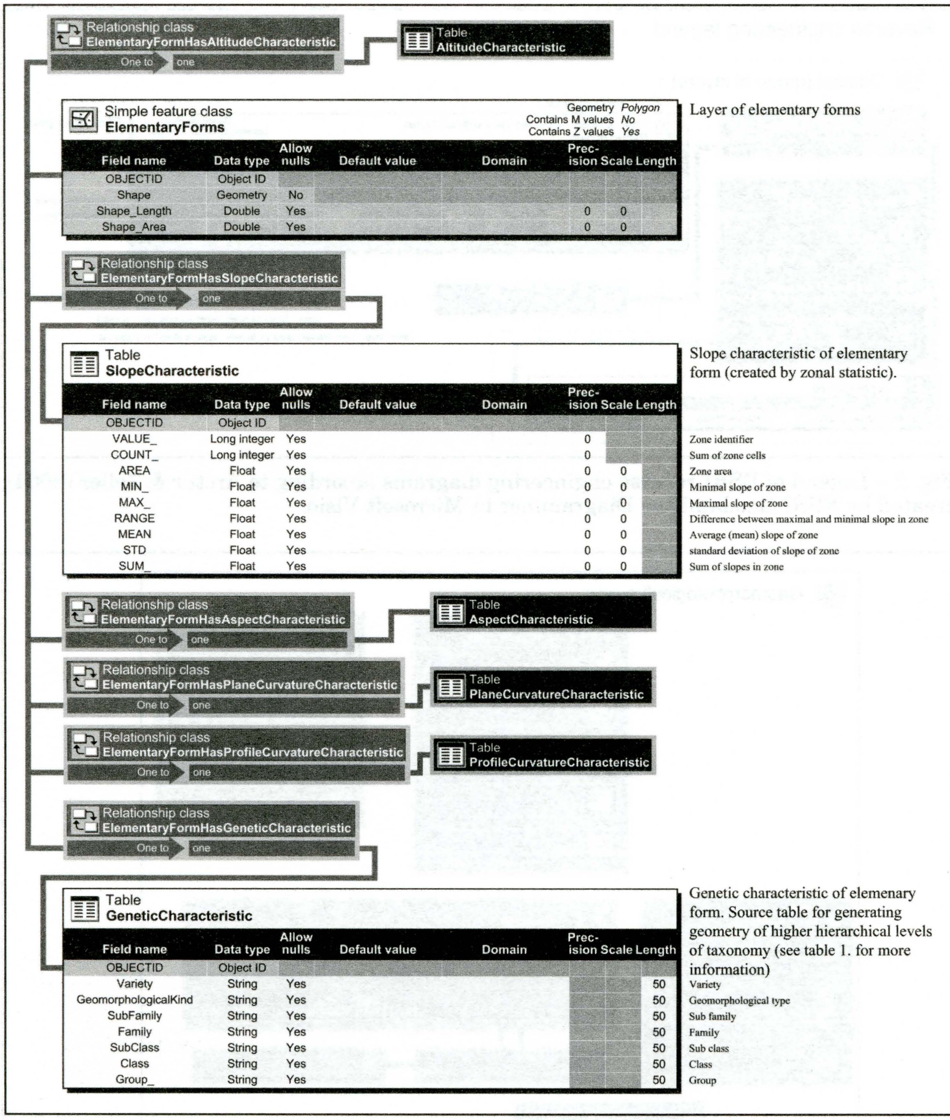

Fig. 4 – Physical model; detail of elementary forms and related classes. Reverse engineering created by ESRI Geodatabase Diagrammer in Microsoft Visio.

analysis. Creation of special geomorphological layers is not discussed in this article.

Details of the physical structure are presented in the example of elementary forms and connected spatial and attribute layers. The elementary forms are related to several attribute tables (see Fig. 4), which describe elementary forms of altitude, slope, aspect and curvature characteristics. All these related tables have the same attribute fields as the slope characteristic. These tables are created by zonal statistics in GIS. The process was automated for the purposes of GmIS (the automation is depicted in Fig. 6 and

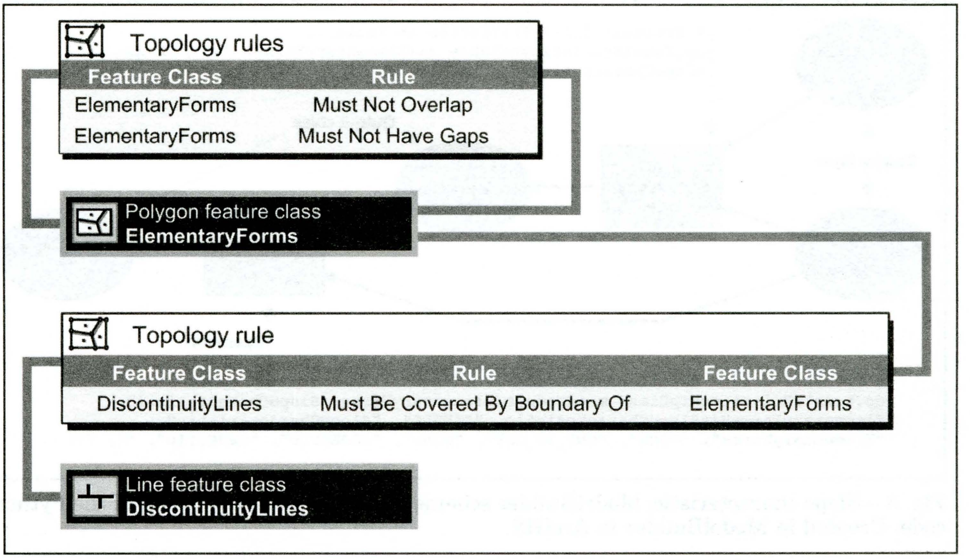

Fig. 5 – Physical model; detail of elementary forms and Discontinuity lines topology. Reverse engineering created by ESRI Geodatabase Diagrammer in Microsoft Visio.

described below the figure) and it can be run whenever the geometry of the elementary forms is changed. Then, the information in the attributes is always consistent with the geometrical representation.

The situation in the case of the table of genetic characteristics is more complicated, because operator entry is necessary. The geomorphologist has to enter information at least into the field of lowest taxonomic level (generally "variety" or "geomorphological kind"). The higher hierarchic levels can be derived automatically in the case of an existing full morphogenetic system of landforms (the rules for listing every unit of lowest hierarchical level into a higher taxon must be defined). There are also important spatial relations among layers in the geomorphological database. Most of them can be explored without special tools. The standard GIS identification and spatial query tool are sufficient. But in cases where geometry of one layer is dependent on the geometry of another layer, it is necessary to use some kind of topological tool. An example of topological relations set up in the geodatabase between elementary forms and discontinuity lines is shown in Fig. 5.

In traditional geomorphological maps elementary forms should cover the whole area of interest (the rule "elementary forms must not have gaps" is set up) and also they should not overlap, because one form describes just one "piece of land" and the spatial relation is one to one (so the rule "must not overlap" is added). If fuzzy boundaries occur, topological exception can be used. Next, discontinuity lines should spatially match the boundaries of elementary forms, so the rule "discontinuity lines must be covered by boundary of elementary forms" is added.

After the topology has been set up, the GIS environment allows the user to easily maintain spatial relationships among all layers which are involved. As is discussed above, when the database model is well developed, a lot of the geomorphological analysis steps can be performed using common GIS tools. For other cases, it is possible to create special GmIS

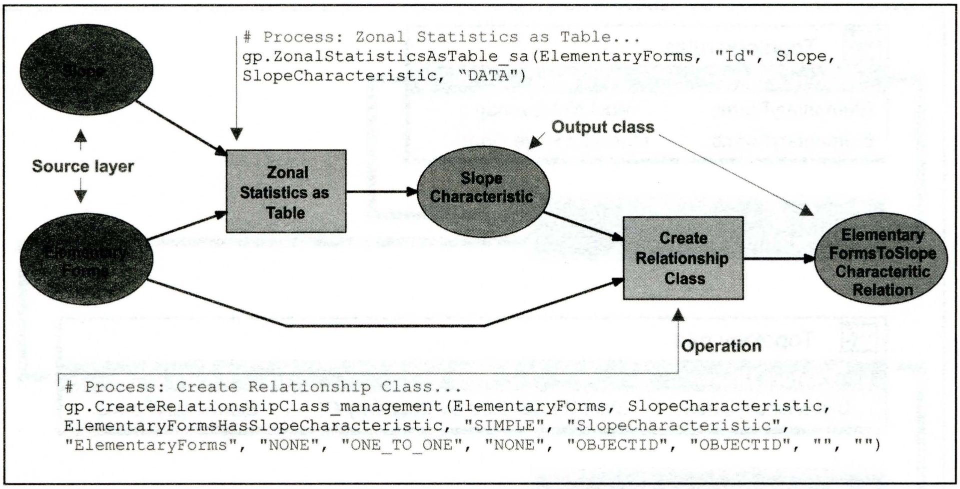

Fig. 6 – Slope characteristic; ModelBuilder scheme and example of core parts of the Python code. Created in ModelBuilder in ArcGIS.

tools, for example using ModelBuilder – a graphical user interface for Python programming language in the ESRI products. It is also possible to directly write a Python code in the classical editor. Both of these alternative entries have been used and combined during the development of geomorphological analysis tools. An example of the tool code schemed in ModelBuilder is shown in Fig. 6.

Zonal analysis (see i.e. Tuček 1998) is applied here to two source layers. Cells of raster of slopes are statistically evaluated in each zone – elementary form. Results of the analysis are stored into a “SlopeCharacteristic” table in the geodatabase. One to one relationship between slope characteristic table and elementary forms is created in the next step. Altitude, aspect and curvature characteristics are created using similar models.

Geomorphological analysis

The case study of geomorphological analysis in GmIS, which was carried out in the surroundings of Prášilské jezero (lake), is described in the following part of this article. Some theoretical and methodical problems of geomorphological analysis are discussed simultaneously.

The correct delimitation of geomorphological forms is a crucial step of geomorphological research. Although geomorphologists should investigate the surface of the Earth as a whole, very often more attention is paid to some particular parts of georelief. This is because some landforms are more significant (outcrops, planation surfaces etc.) than others (mainly different parts of slopes). Hence a unified principle for delimiting landforms (geomorphological forms) is highly important because the results of comprehensive geomorphological analysis (complex geomorphological maps or a hypothesis for the development of the area of interest) should deal with all parts of the georelief equally.

Although mainly glacial forms are presented in the area under concern, gravitation, fluvial and suffusion forms also exist there (Fig. 10).

Table 1 – Features used for analysis of genesis of geomorphological forms with examples from the surroundings of Prášilské jezero (lake) (units used for geomorphological analysis are highlighted by the bold frame).

Systematic unit[4]	Characteristics used to define a particular class	Examples of particular classes in the surroundings of Prášilské jezero (lake)
Group	General geomorphological factors	Exogenetic forms
Class	Affiliation of the geomorphological agents to the partial geospheres	Cryogenetic class (corries, moraine walls, cryoplanation terraces)
Subclass	Specification of the types of energy and substratum of particular geomorphological agent	Subclasses of glacial (corries), nival (nivation hollow) and cryoplanation forms (cryoplanation terraces) etc.
Family	Character of geomorphological conditions and the basic mechanism of geomorphological process	Family of mountain glaciers forms, nival forms created by nivation or snow avalanches etc.
Subfamily	Definition of specific geomorphological processes in particular family	Accumulation or destruction forms in particular families
Geomorphological kind	Genetically homogenous and morphologically delimited part of georelief	Corries, moraine walls, dellens etc.
Variety	Parts of a morphogenetical form with different genesis	'Permanent slope erosion furrows' or track of debris flows in the walls of corries etc.

The layer of elementary forms therefore represents the core of GmIS and also the basic part of geomorphological analysis. A significant and uniform principle for delimitation of the elementary forms (Minár 1996) is very appropriate in this case. Morphological homogeneity of elementary forms is related to their genetic and dynamic homogeneity. Therefore all information which is obtained during geomorphological analysis can be connected by this layer. The other higher geomorphological individuals (composed form, geomorphic regions of higher order) are generated from this basic layer usually by defining specific attributes in the Geodatabase (Table 1 and Table 2).

The main aim of geomorphological analysis is the investigation of the genesis of georelief (Demek ed. 1972). Basically, elementary forms have homogenous morphometric characteristics and the boundaries between them are defined as discontinuities of the morphometric characteristics. More significant boundaries of elementary forms also represent the frontiers between morphogenetic forms. The definition of these boundaries is an important part of geomorphological analysis (the phase of differentiation – Table 2).

Each geomorphological individual can be classified according to its genesis. The genetic classification of georelief segments according to Minár (1996) was

[4] These systematic units create the part of the physical model Table Genetic Characteristics (Fig. 5).

Table 2 – Summary of steps geomorphological analysis in GmIS

Step of geomorphological analysis		Process (processes) of geomorphological analysis	Output in GmIS
Identification		Definition and delimitation of the area of interest	Layer presents boundary of the area of interest
Differentiation	1st phase	Delimitation of elementary forms	Map of elementary forms of the area of interest
	2nd phase	Identification of the main and obvious morphogenetical forms	Primary map of georelief
	3rd phase	Spatial connection of elementary forms or morphogenetical forms with documentation points	Assigning further information to layers of elementary forms and/or morphogenetical forms
Systematization		Swinging system analysis of georelief	Secondary map of georelief
Analysis of present day geomorphological processes		Definition of geomorphological varieties which have been created by present-day geomorphological processes	Map of geomorphological varieties (defined by present-day geomorphological processes)
Analysis of morphochronology		Postulation of particular geomorphosystems for each stage of development of the area of interest.	Special morphochronological map
Summary of geomorphological analysis		Creation of hypothesis for development of the area of interest	Clarification of attributes of layers
Verification of hypothesis		Using various (non-geomorphological) methods of research for verification of the hypothesis	Clarification of attributes of layers

adapted and then used in the surroundings of Prášilské jezero (lake) – Table 1. The systematic units are presented by genetic attributes in the geomorphological database (Fig. 4 – table of genetic characteristics).

The process of geomorphological analysis in GmIS can be summarized as follows[5] (Table 2):

Identification: definition of the area under concern. A layer representing the boundary of the area of interest is the output of this phase in GmIS.

Differentiation – 1st phase: delimitation of elementary forms according to their morphology and morphometric characteristics (Fig. 3 – tables of morphometric characteristics or Fig. 4 – tables related to elementary forms) – the map of elementary forms of the area of interest is the output of this phase in GmIS (Table 2).

Differentiation – 2nd phase: identification of the main and obvious morphogenetical forms according to their genesis on the taxonomic level of geomorphological kind (primary morphogenetic forms). The corries, moraine

[5] The particular phases of the analysis partly concur with the steps of geomorphological analysis according to Urbánek (2000 a, b).

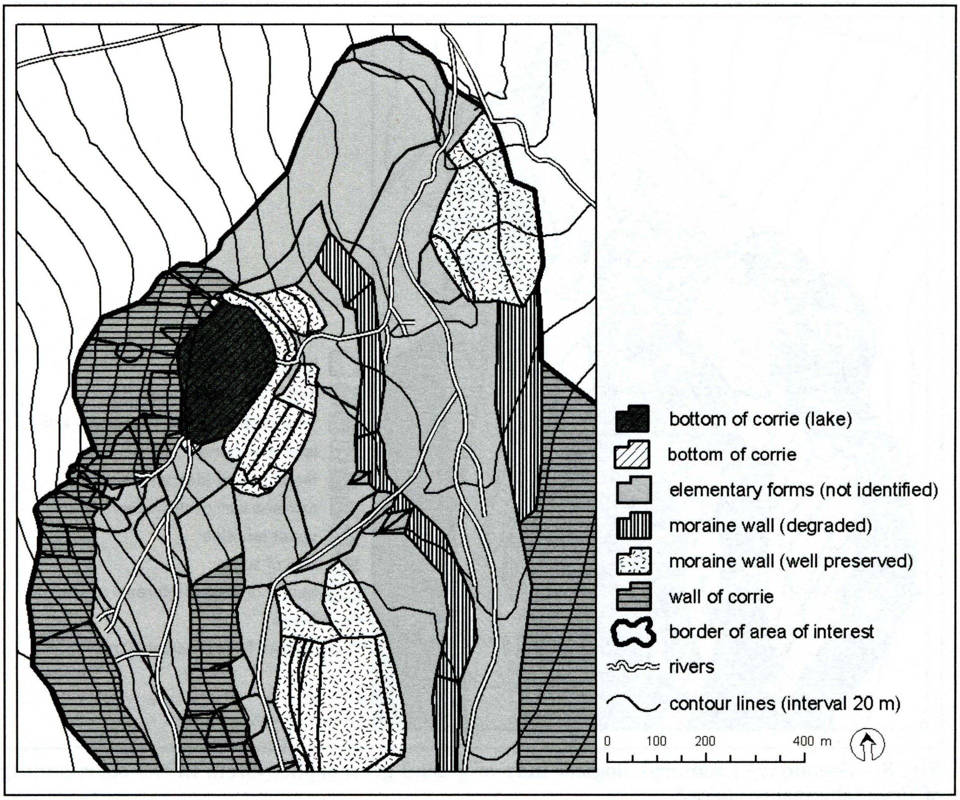

Fig. 7 – Primary geomorphological map of the glacial geomorphosystem in the surroundings of Prášilské jezero (lake).

walls and remnants of planation surfaces were identified in the surroundings of Prášilské jezero (lake) – the primary geomorphological map is the output of this phase in GmIS (Fig. 7).

Differentiation – 3rd phase (the information flow phase): spatial connection of primary morphogenetical forms with documentation points (Fig. 3) and other specific layers (the layer of rock formations etc). These layers provide more exact information about the genesis of the particular forms.

Only morphogenetic forms were defined in this part of the analysis while other elementary forms obtain information from other layers. However, the spatial position of these forms in relation to the other, which had already been identified, was very important for the following analysis.

Systematization: reconstruction of geosystems (present-day or fossil) of the landscape. Relief in Central Europe is generally polygenetic. This very often means dealing with fossil geomorphosystems during geomorphological analysis. It is highly important to clearly define all geomorphosystems which can be found in the area of interest at this level of research. The morphogenetical forms defined so far, were used as the base of the operation. According to the relationship between the undefined forms and defined forms in the geomorphosystem, we can identify the forms which have not been defined so far. This process was carried out in consequent steps. Gradual definition of morphogenetical forms brought new information about its

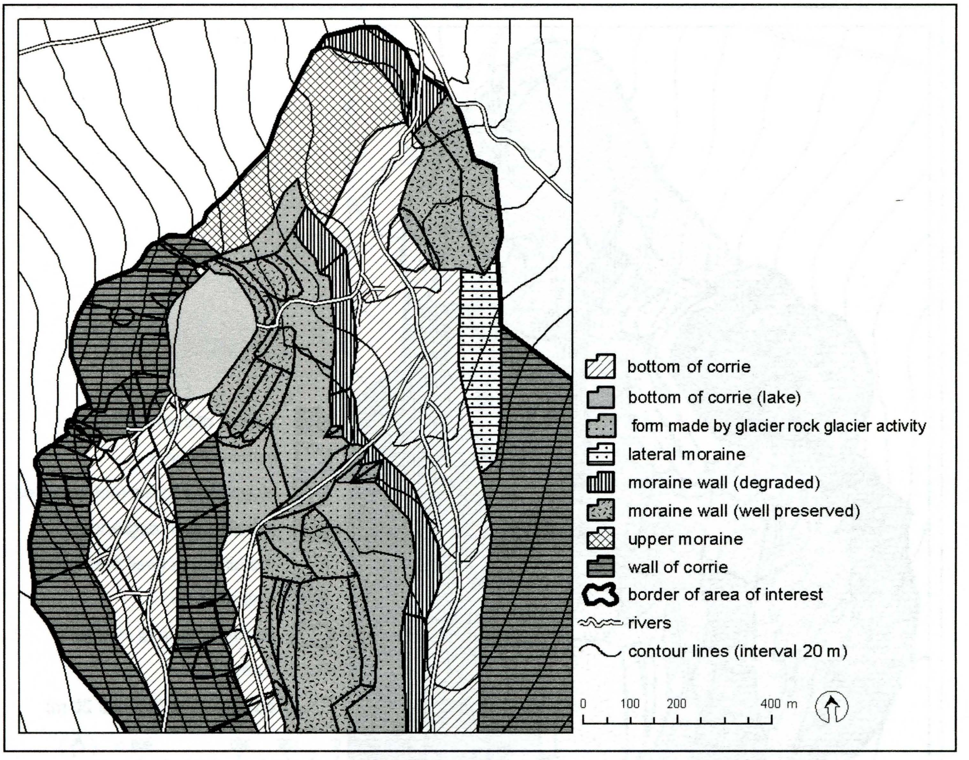

Fig. 8 – Secondary geomorphological map of glacial geomorphosystem in the surroundings of Prášilské jezero (lake)[6].

neighbours (this process is called 'the swinging system analysis of georelief'). The secondary map of georelief is the output in this phase (Fig. 8). This map expresses morphogenetical forms in the area of interest and covers the whole area without any remnants of undefined elementary forms in a particular geomorphosystem. Certainly, the relevance of the identification of particular morphogenetical forms is different and these differences should be registered in the geodatabase.

Further geomorphological analysis consists of the following two steps in this stage: analysis of present-day processes and analysis of morphochronology.

Analysis of present-day geomorphological processes: the morphogenetical forms which have been defined during the geomorphological analysis so far, create the main features of the georelief in the area of interest. But these forms are seldom homogenous. The main features of georelief in our area of interest were created during the Pleistocene, when the geomorphological processes were more powerful than at present. Hence these main features of landscape have been changed by present-day geomorphological processes. These heterogeneities can represent geomorphological varieties – parts of morphogenetical forms with a different genesis (Table 1). For example, the corries disturbed by tracks of debris flows or 'permanent slope erosion

[6] All glacial geomorphological forms (each part of glacial geomorphosystem) in the surroundings of Prášilské jezero (lake) are identified in this phase of geomorphological analysis.

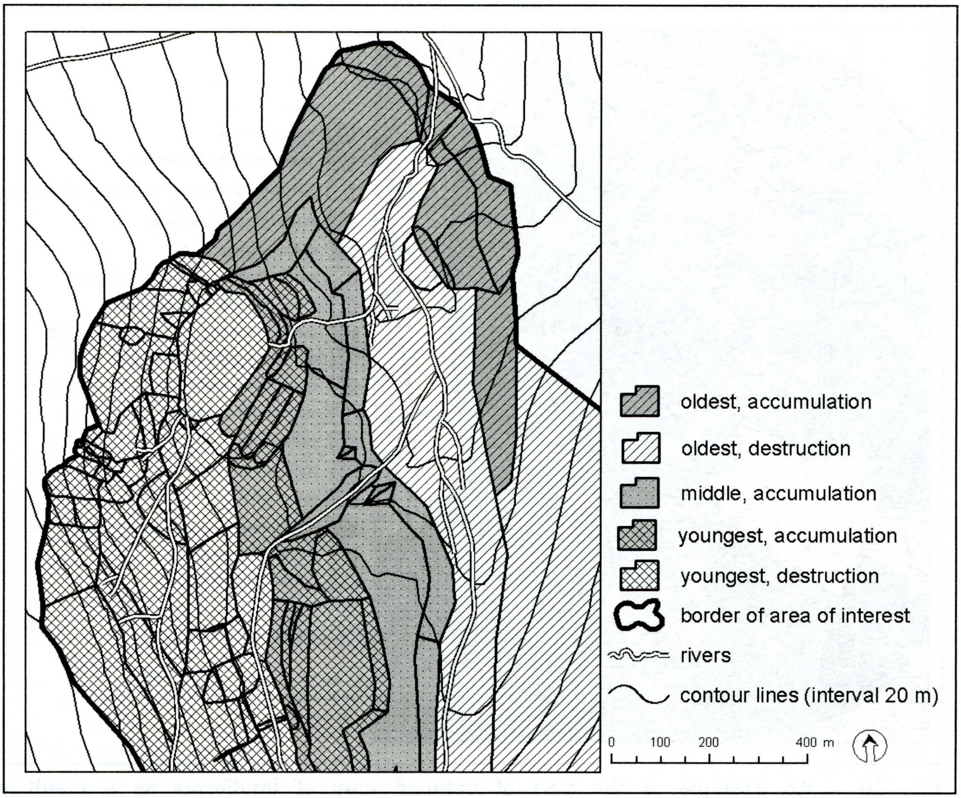

Fig. 9 – Morphochronological map of the surroundings of Prášilské jezero (lake).

furrows' have been investigated as geomorphological varieties of the corries in the surroundings of Prášilské jezero (lake) (Mentlík 2004, Mentlík 2005a).

The information about the type of the process or the stage of evolution of the particular form could be registered in the Geodatabase as an attribute (Fig. 4 – table of genetic characteristics). The processes could be fossil or present-day. Active and passive forms were distinguished according to the presence or absence of present-day morphogenetically relevant processes in the particular form (see Mentlík 2004, 2005b).

Analysis of morphochronology: we investigated the age of particular morphogenetical forms in this stage of geomorphological analysis by using various methods of relative dating (Schmidt hammer test, analysis of roughness of rock surfaces etc.) and numerical dating (AMS and conventional radiocarbon dating) (e.g. Mentlík et al. 2005 or Břízová & Mentlík 2005). The aim of this phase of geomorphological analysis was to postulate particular geomorphosystems for each stage of development of the georelief. The morphochronological map is the output of this phase in GmIS (Fig. 9).

Summary of geomorphological analysis (postulation of hypothesis for development of the area of interest): The aim of this penultimate stage of geomorphological analysis is to postulate the hypothesis for the genesis of the area under concern. This hypothesis should cover all five main aspects of georelief (Demek ed. 1972) – investigation of morphology and morphometric characteristics by means of elementary forms of relief, morphogenesis by

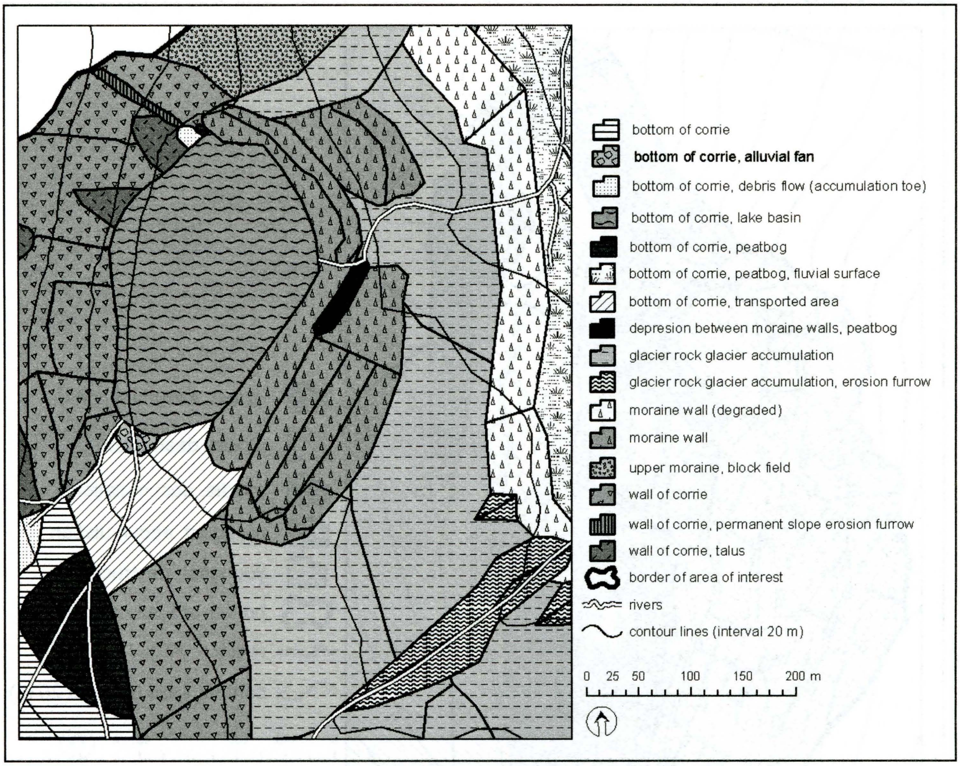

Fig. 10 – An example of the part of detailed map of landforms as a result of geomorphological analysis

means of particular morphogenetical forms and morphodynamics by means of investigation of present-day geomorphic processes, which define geomorphological varieties in our case. Morphochronology is expressed by particular geomorphosystems of development of georelief in the area of interest and morphochronological maps (Fig. 10).

Verification or falsification of the hypothes: The hypothesis has to be verified or falsified by some independent and significant methods in the last stage of geomorphological analysis. A wide range of various methods is used for this. However, geological methods are the most common (for example scanning electron microscopy, analysis of heavy minerals, X-ray analysis of clay minerals, and other particularly sedimentological methods such as analysis of shape and roundness of clasts etc.), even though some biological methods (mainly pollen analysis) are also frequently used. It is necessary to stress that an interdisciplinary approach is highly important in this stage of geomorphological analysis. If the results of this parallel research were not in agreement with the results of the geomorphological analysis, it would be necessary to repeat the whole process again trying to find the reason (or reasons) for the discrepancy.

The analysis of shape and roundness of clasts as well as scanning electron microscopy were used in this phase in the surroundings of Prášilské jezero (lake) (Mentlík et al. 2005). Finally, the results of geomorphological analysis and the results of the other methods were connected and the final hypothesis for the development of the area under concern was postulated.

In GmIS the results of the research are connected with particular elementary forms or geomorphological kind respectively. The hypothesis of genesis of the particular area could be tested owing to this spatial connection.

Conclusions

The physical model of the geomorphological database based on the logical model postulated in Minár et. al. (2005) is presented in this paper. The concept is derived from the comprehensive approach to geomorphological information system creation (Barsch & Dikau 1989; Dikau 1992; Minár 1996) based on layer structure of the database and fundamental considerations of geomorphological space, time, and basic data in mutual relations. However, the model is open, allowing incorporation of particular approaches to geomorphological (geomorphic) information system creation focused on solving specific geomorphological problems (e.g. Zhu, H. & Schneider 1999; Tachikawa et al. 2003).

Our physical model is composed of three major groups of layers: adopted, basic and special layers (creation of special geomorphological layers is not discussed). The model structure allows easy and safe data handling by setting up relationships and topologies. Relationships maintain attribute integrity among layers and tables. Topologies maintain spatial integrity of the spatial data by rules. There can also be marked exceptions from rules for special cases. A well defined database structure also allows a geomorphologist to perform many geomorphological analysis steps using common GIS tools. Special analysis steps can be programmed in various languages. ESRI ModelBuilder and Python were used in GmIS.

The concept of geomorphological analysis in GmIS was used in research of the surroundings of Prášilské jezero (lake) in the Šumava Mts. (Czechia). The layer of elementary forms (Minár 1996), which are defined according to their morphology and morphometric characteristics, is postulated as the core of the analysis. All data are connected with this layer and subsequently provide the information for particular analyses. However, morphogenetical forms (defined according to their genesis) are used as the fundamental units during the geomorphological analysis. Seven steps of geomorphological analysis are suggested in the frame of the presented GmIS with the following main advantages:

- The analysis uses a uniform approach for delimitation of landforms.
- The analysis covers the whole area of interest and deals with all parts of the area equally.
- The process is reversible and it is possible to repeat it and to investigate particular steps separately. The geomorphological analyses provide partial outputs, which can be interpreted separately.
- The process provides opportunity for verification of the hypothesis of evolution of the area of interest in an exact way (the verification of the hypothesis is in fact a part of the analysis).

In the future, building of GmIS will continue. New tools and modules, intended for construction of various special geomorphological layers, will be added. The proposed design of the GmIS can also be modified – the creation of GmIS in regions with different types of georelief (and with different data availability) will probably require a slightly different structure to the system. Only experiences from several completed systems can lead to the creation of a more universal design of GmIS. Thus the GmIS should become a robust tool for geomorphological research.

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Software, programming languages and other tools:
The following software was used for this project:
ArcGIS Desktop, ArcINFO license – for implementing both logical and physical data model.
ESRI Diagrammer and Microsoft Visio – for ESRI Geodatabase reverse engineering.
GRASS – for DEM interpolation.
ModelBuilder and Python – for geomorphological analysis process diagrams.
VisualBasic for Applications and ArcObjects – for CAD data conversion to GRASS.

Shrnutí

GEOMORFOLOGICKÝ INFORMAČNÍ SYSTÉM: FYZICKÝ MODEL A MOŽNOSTI GEOMORFOLOGICKÉ ANALÝZY

Předkládaný článek navazuje na naši předešlou studii Geomorfologický informační systém – základní myšlenky a možnosti praktického využití (Minár et al. 2005). Geomorfologický informační systém (GmIS) je speciální typ Geografického informačního systému (GIS), který je zaměřen na sběr, správu a analýzu geomorfologických dat. Cílem článku je prezentovat fyzický model GmIS a případovou studii jeho implementace z okolí Prášilského jezera na Šumavě. Studie prezentuje aplikaci geomorfologické analýzy a interdisciplinárního výzkumu a jejich integraci v GmIS, při využití jeho analytických a databázových funkcí. Je zdůrazněna potřeba stabilního, přesného a flexibilního modelu GmIS pro geomorfologické účely.

Nejprve je představen již dříve definovaný logický model, (Minár et al. 2005), který je založen na třech logických skupinách vrstev:
- převzaté vrstvy – vrstvy z vnějších zdrojů
- základní vrstvy – obsahující data určovaná požadavky geomorfologického výzkumu, jež jsou odvozována z převzatých vrstev nebo získávána geomorfologickým mapováním; jádro systému tvoří vrstva elementárních forem reliéfu (cf Minár 1996)
- speciální vrstvy – data odvozená z prvních dvou skupin vrstev za využití speciálních geomorfologických metodických postupů (např. morfostrukturní analýza, komplexní geomorfologická analýza atd.).

V příspěvku je dále popisován fyzický model GmIS, a to na úrovni jednotlivých vrstev (obr. 4). Detailně je popisováno jádro fyzického modelu – vrstva elementárních forem reliéfu a atributové vazby jednotlivých forem na tabulky morfometrických charakteristik (výškové, sklonové, orientace sklonu svahu, vrstevnicová a profilová křivost) a morfogenetických charakteristik (tabulka 1). Popsány jsou i možnosti využití topologických vazeb na příkladu vazeb mezi vrstvami elementárních forem a jejich hranicemi.

Popis struktury modelu pak přechází v popis procesů, které v něm probíhají. Je navržen způsob technické realizace automatizace procesů v GmIS s využitím grafického i textového (objektově orientovaného) vývojového prostředí.

Geomorfologická analýza v GmIS je prezentována na příkladu z okolí Prášilského jezera na Šumavě. Koncept geomorfologické analýzy vychází z prací Urbánka (2000a,b). Tento základní koncept je doplněn a transformován tak, aby umožňoval využití v GmIS. Takto definovaná geomorfologická analýza se skládá ze sedmi základních částí (tabulka 2): (identifikace, diferenciace – dále rozdělené do tří fází, systematizace, analýzy recentních geomorfologických procesů, analýzy morfochronologie, shrnutí geomorfologické analýzy spolu se stanovením hypotézy vývoje zkoumaného území a verifikace této hypotézy). Základem geomorfologické analýzy v GmIS je vrstva elementárních forem reliéfu. K jednotlivým elementárním formám, jež jsou definovány na základě jejich morfologie a morfometrie, jsou připojována konkrétní data získaná v průběhu prováděných analýz.

Pro potřeby geomorfologické analýzy, která se zabývá zejména genezí jednotlivých forem, jsou na atributovém základě vymezovány tzv. morfogenetické formy vznikající spojením elementárních forem reliéfu na základě jejich geneze. Tato geomorfologická individua

v podstatě odpovídají tradičním geomorfologickým formám. Verifikace hypotézy vývoje reliéfu zájmového území je prováděna různými (zejména geologickými) metodami.

Tvorba GmIS bude pokračovat i v budoucnu, zejména by měly být připraveny speciální nástroje a moduly umožňující zautomatizování některých kroků geomorfologických analýz. U celého systému je třeba počítat s úpravami pro specifické typy reliéfu.

Obr. 1 – Zobrazení základní struktury logického modelu v projektu aplikace ArcMap a vymezení zájmového území v okolí Prášilského jezera.
Obr. 2 – Legenda k diagramům reverzního inženýrství podle Artur & Zeiler (2004); vytvořeno nástrojem ESRI Geodatabase Diagrammer a aplikací Microsoft Visio.
Obr. 3 – Fyzický model; přehled geomorfologických vrstev. Reverzní inženýrství vytvořené nástrojem ESRI Geodatabase Diagrammer a aplikací Microsoft Visio.
Obr. 4 – Fyzický model; detail elementárních forem a souvisejících tříd. Reverzní inženýrství vytvořené nástrojem ESRI Geodatabase Diagrammer a aplikací Microsoft Visio.
Obr. 5 – Fyzický model; detail topologie mezi elementárními formami a jejich hranicemi. Reverzní inženýrství vytvořené nástrojem ESRI Geodatabase Diagrammer a aplikací Microsoft Visio.
Obr. 6 – Charakteristika sklonu svahu. Schéma v ModelBuilder a ukázka jádra kódu v jazyce Python. Vytvořeno v ModelBuilder v ArcGIS.
Obr. 7 – Ukázka části primární geomorfologické mapy okolí Prášilského jezera.
Obr. 8 – Ukázka sekundární geomorfologické mapy okolí Prášilského jezera.
Obr. 9 – Ukázka části morfochronologické mapy okolí Prášilského jezera.
Obr. 10 – Část podrobné geomorfologické mapy okolí Prášilského jezera.

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JAKUB LANGHAMMER

GEOINFORMATIC ASSESSMENT OF EXTREME FLOOD CONSEQUENCES - CASE STUDY: FLOOD IN AUGUST 2002 IN CENTRAL EUROPE

J. Langhammer: *Geoinformatic assessment of extreme flood consequences – case study: flood in August 2002 in Central Europe.* – Geografie–Sborník ČGS, 111, 1, pp. 33–50 (2006). – The extreme flood events in the last decade in Central Europe served as a unique opportunity to study the impact of environmental changes on runoff process, to test the methods of their efficient assessment and to determine the applicability of the findings in effective flood protection measures. The paper presents the assessment of impact of environmental changes in landscape on the course and consequences of extreme floods. Assessment draws on selected indicators of environmental transformation related to rainfall-runoff processes, flood wave formation and transformation, and local retention capacity. The solution is based on geostatistical approach and applies to the Otava river basin located in the core zone of the extreme floods in August 2002 in Central Europe and representing area with high level of heterogeneity in terms of physicogeographic and social and economic aspects. The results of the presented research indicated evident links between physicogeographic characteristics of river basins, their anthropogenic transformation, and responses to extreme runoff situations. However the results hasn't proved the current intensity of river network shortening, riverbed transformation or floodplain and landscape modifications to be the main driving force of extremity of the flooding that occurred in August 2002 in Central Europe.
KEY WORDS: Floods – Riverbed modifications – Stream shortening – Floodplain – GIS – Rule-based classification.

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1. Introduction

After the extreme floods that hit the Central Europe during the last decadethere were broadly debated questions on how much the unexpected flood extremity was affected by long-term modification of the landscape, how the environmental changes affected the runoff process, flood wave progress and flood induced consequences and if there are efficient ways to reduce the flood risk via restoration of the natural environment (Konvička et al. 2002, Kender et al. 2004, Just 2003).

The above mentioned extreme flood served as a unique opportunity to analyze the past and current changes in the landscape and to test the methods of efficient assessment and modeling their relations to the runoff process and flood consequences and to transform the findings into improvements of flood protection measures.

The article is focused on the analysis of relations among flood consequences and selected indicators of landscape vulnerability in the area located in the core zone of the flood in August 2002 as the main result of research project released after the catastrophic flooding in 2002. The research was focused on following three fundamental tasks:

1. Assessment of intensity and spatial differetiation of historical and present anthropogenic impact on landscape in indicators related to the runoff process.
2. Analysis of consequences of the extreme flood in August 2002 in the core zone of the flood.
3. Analysis of relations among the indicators of landscape modification and observed flood consequences.

The analysis of human impact on runoff process mainly in relation to extreme events is one of the current topics in hydrologic research as it is related to the phenomenon important for effective protection of lives and properties against the natural hazards. The methods applicable for the analysis of this process are multiple and are dependent mainly on the objective of research, selected indicators and spatial scale (Anselmo, Galeati et al. 1996; De Roo, Odijk et al. 2001; Nachtnebel, Konečný 1987; Niehoff, Fritsch et al. 2002; Stover, Montgomery 2001). At the local scale the physically-based runoff models or process-based approaches are usually applied. The larger and complex basins require application of different tools – empirically-based or statistical models.

This article presents the geostatistical approach based on GIS analysis and geostatistical analysis techniques namely the rule-based classification, applied in the research project as an integrative technique to identify the spatial and statistical relations between the landscape vulnerability and observed flood effects. This approach allows bridging the gap between spatially accurate data sources and the needs of assessment of large-scale complex river basins aimed to finding solutions for reducing the flood risk in the landscape.

2. Material and Methods

2. 1 Research Area

The research area is represented by the Otava river basin located in the core zone of the extreme floods in August 2002. The Otava river basin with total area of 2986 km^2 is situated at the south-western part of the Czech republic at the border with Germany (Figure 1) and is marked by diverse physicogeographical features as well as varying intensity of anthropogenic pressure.

The southern part of the river basin is located in the upper area of the Bohemian Forest (Šumava) formed by leveled surfaces with altitude over 1 000 meters asl. This area has prevailing natural character with scarce settlements and a forestation ratio exceeding 80 percent. Intensity of human activities is continously growing downwards to the north western lowland part of the river basin.

The backbone of river system in the river basin is formed by the Otava, Blanice, and Volyňka rivers. These streams were since the middle age subject rectification and modifications of riverbed and floodplain due to the growing settlement, agriculture, timber floating and transport (Langhammer 2004).

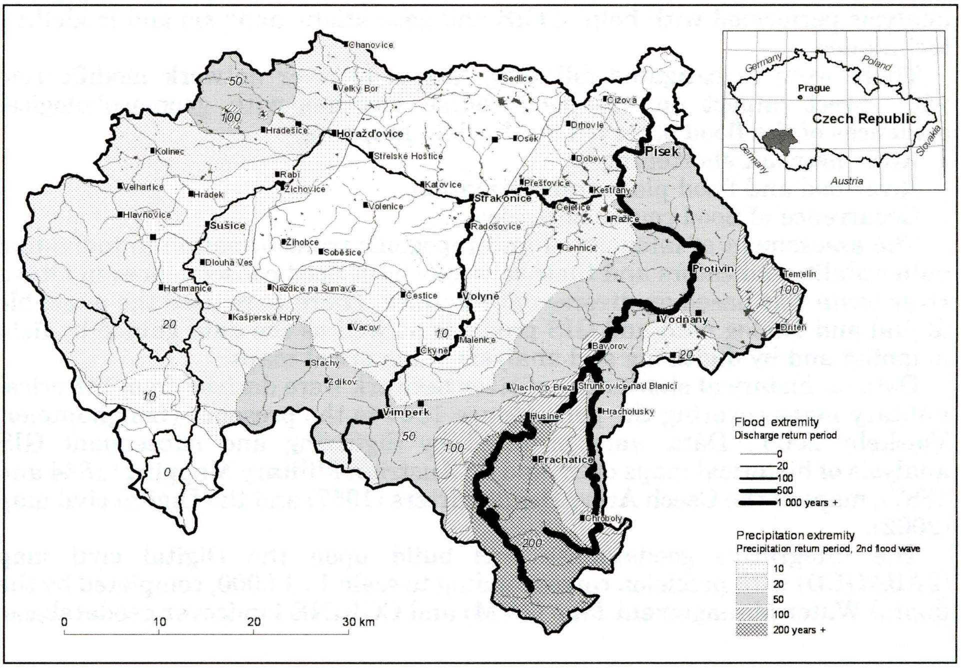


Fig. 1 – Otava river basin. The research area represents one of the core zones of the Central European extreme flood in August 2002. In the eastern part of the basin – the Blanice catchment were recorded precipitations over 300 mm during two consecutive events.

Because of its geography and the windward effect of northwestern slopes of Bohemian Forest, Otava river basin is a region with frequent occurrence of floods. Since 1888 we can observe 12 floods with return period exceeding 10-years flood whose origin is dominantly in summer frontal rainfalls (Vlasák 2004). As the Otava river is drained to the Vltava river dam cascade, the mitigation of peak flood in this region is critical for the effective flood protection of the down parts of the Vltava river basin including the city of Prague.

In August 2002, the Otava river basin was affected by two waves of extreme precipitation. The first wave hit the region on August 6–7, 2002 and the second on August 11–14, 2002. The overall precipitation volume in the basin was 0.737 km^3. The spatial distribution of the precipitation in the basin was highly asymmetric reaching the highest volumes in the mountainous parts of the river basin with maximum precipitation exceeding 340 mm for the both periods. The hydrological response of the river basin to the intensive rainfall was more extreme than the causal precipitation. The extremity of peak discharges observed during the second flood wave exceeded on Blanice river 1000-years return period while the recurrence of rainfall reached 100–250 years (ČHMÚ 2003).

2. 2 Methodology and data sources

The assessment of landscape vulnerability indicators and their relations with observed consequences of extreme flood in August 2002 in the Otava river basin was based on complex hydrological and physicogeographical analysis performed with help of GIS and geostatistic analysis and modelling techniques.

There were investigated following factors of river network modification with direct impact on the flood course together with geomorphological evidences of the flood observed by the field mapping:

- River network shortening
- River-bed and flood plain transformation
- Occurrence of flood course obstacles.

The assessment of intensity of anthropogenic transformation in individual vulnerability indicators and their relations with flood consequences in Otava river basin was based on diverse data sources. There were used the available digital and analog data and GIS products as well as the data gained by field mapping and by digitizing and analysis of historical maps.

Data on historical shortening of river network were derived from historical military maps covering the period since 1844 to the presence (Langhammer, Vajskebr 2005). Data were acquired by digitizing and subsequent GIS analysis of historical maps of 2nd and 3rd Austrian Military Mapping (1844 and 1887), maps of the Czech Army Headquarters (1957) and the Digital civil map (2002).

The integrative geodatabase was build upon the Digital civil map (ZABAGED) with precision corresponding to scale 1 : 1 0000, completed by the digital Water Management Map (ZVM) and CORINE landcover geodatabase.

2. 3 Mapping of flood consequences and of riverbed transformation

Data on geomorphologic evidences of the flood, information on current intensity and character of river network and floodplain modifications and identification of flood course obstacles were acquired by field mapping based on newly developed and tested methodology. The methodology was designed to allow treatment of large area, involvement of a higher number of mapping staff with keeping accuracy and consistency of results. Results of field mapping were digitized and integrated in the geodatabase to enable further processing and analysis.

Main principle of the new methodology of mapping of watercourses and floodplain modifications was to split the watercourses into segments marked by homogeneity in at least one of the observed parameters while allowing the variability of their length. In the course of field mapping, individual river segments are indicated on maps, identified by codes, and values were recorded in prepared forms. It was decided to develop a new methodology that could exactly fit the project needs instead of use some of the current methods of ecomorphological assessment (e.g. Rosgen 1996; Vlček, Šindlar 2002) due to their complexness and focus on parameters different from the project needs.

Watercourse anthropogenic modifications were evaluated in five key parameters – stream route, longitudinal profile modifications, river-bed modifications, floodplain modifications, and occurrence and nature of flood control measures (Table 1).

The indicators of anthropogenic modification intensity were assessed for the whole river segment while the character of individual changes was investigated separately for left and right banks. Individual segments were marked by system of uniform coding so that they could be linked to the corresponding geodatabase features (Langhammer 2005).

Table 1 – Main parameters of watercourse and floodplain modifications selected for the field mapping

Parameter	Conditions
Stream route	Straight / Sinuous / Meandering / Braided / Branched
Longitudinal profile modifications	No modifications / Low steps (water level difference <50 cm) / Medium steps (50 - 100 cm) / High steps (> 100 cm)
River-bed modifications	No modifications / Partially modified / Modified / Channelled into tubes
Floodplain modifications	Natural vegetation (meadows, wetland, forest etc.) / Agriculturally used areas / Anthropogenic area – discontinuous development, roads / Anthropogenic area – continuous development
Flood control measures	None / Flood control dykes / Polders, abandoned river arms (meanders) / Ponds and waterworks

Table 2 – Landforms assessed by field mapping as geomorphological evidences of the flood effects

Gravitational forms: Landslides, landslide areas **Fluvial forms:** *Accumulative forms:* Alluvial (dejection) cone Terrace Flood plains Older (Holocene) fluvial / flood accumulation Recent fluvial accumulation *Erosion forms:* Erosion furrow, source areas of erosion runoff Shifted river-bed, abandoned river-bed Significant damage to banks, bank caving Broken mounds Recent cuts of watercourses into flood plain sediments Rock steps in river-beds	**Anthropogenic forms:** Weirs Flood control obstacles Anthropogenically reinforced slopes Anthropogenic mounds, heaps Damaged or destroyed bridge Bridge, foot bridge Improperly located structures in floodplain **Other:** The maximum observed water level Dips (in valleys, on slopes) Drainless depression Isolated boulder

Mapping of geomorphologic evidences of the flood was performed on the basis of reduced legend of a geomorphologic map that contained phenomena related to flood effects plus features potentially affecting the course of flood. As in the previous case the mapping wasn't aimed at creating a complex geomorphologic map, but at collecting data on flood consequences and progress fitting the needs of project solution and required for further joint analysis. The mapping was focused on the landforms stated in the Table 2.

2. 4. Data analysis

The geostatistical analysis was based on data matrix generated from the GIS geodatabase. Original and derived spatial data of different topological characteristics were integrated into stream segments representing the

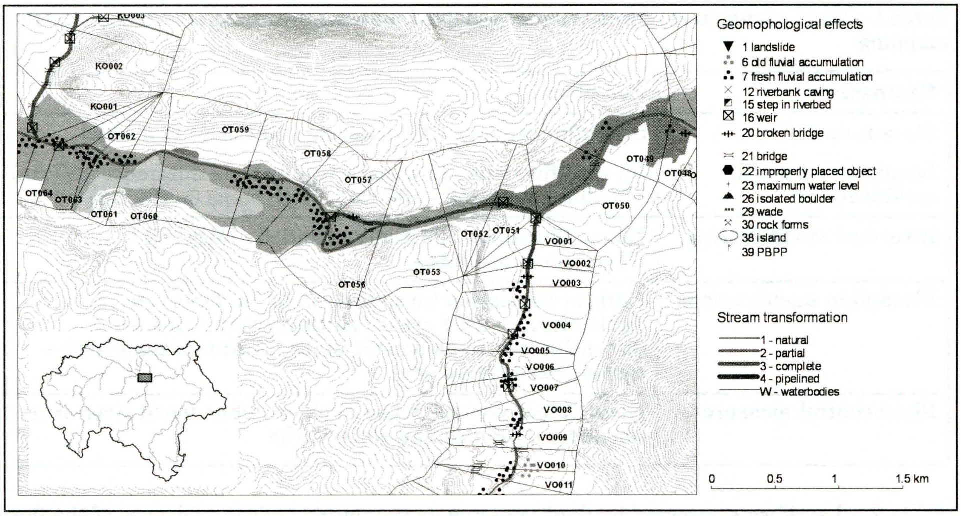


Fig. 2 – Integration of data sources into the elementary river segment using the GIS. Example shows the area of confluence of the Otava and Volyňka rivers.

elementary spatial unit for analysis (Figure 2). Each segment was extended by buffer zone of 500 m in which were integrated information from individual analytical layers – geomorphologic mapping, assessment of the river network shortening, analysis of land use changes and current state, relief digital model analysis etc. The geodatabase maintenance, data sharing, and analysis were performed on the ArcGIS platform. The special analysis and visualizations were made with the GIS MapInfo Professional / Vertical Mapper.

As the main analysis method, presented in this article was selected the rule-based classification. This technique based on database querying process allows analyzing the spatial coincidence of different types of flood effects and individual indicators of landscape transformation on the level of the basic spatial units – the river segments (Figure 1). The statistical analysis on data extracted from the GIS was performed in the XLStat statistical software and the results were imported back into the original geodatabase.

3. Results

3. 1 River network shortening

The most of watercourses in European cultural landscape was in the course of last centuries intensively rectified to improve transport conditions, to drain agricultural areas, to protect towns and cities from floods, or to leave a wider space for urbanization and industrialization of the landscape. Shortening of the river network have a significant negative impact in relation to the process of flooding. Stream rectification is inducing consequent increase of the slope of affected river segment and changes in riverbed geometry which is both resulting in speeding of the flow velocity, and in increasing of the destructive force of the flood wave in affected areas.

Analysis of historical shortening of the river network (Figure 3) in the Otava river basin proved that in average values this region shows similar

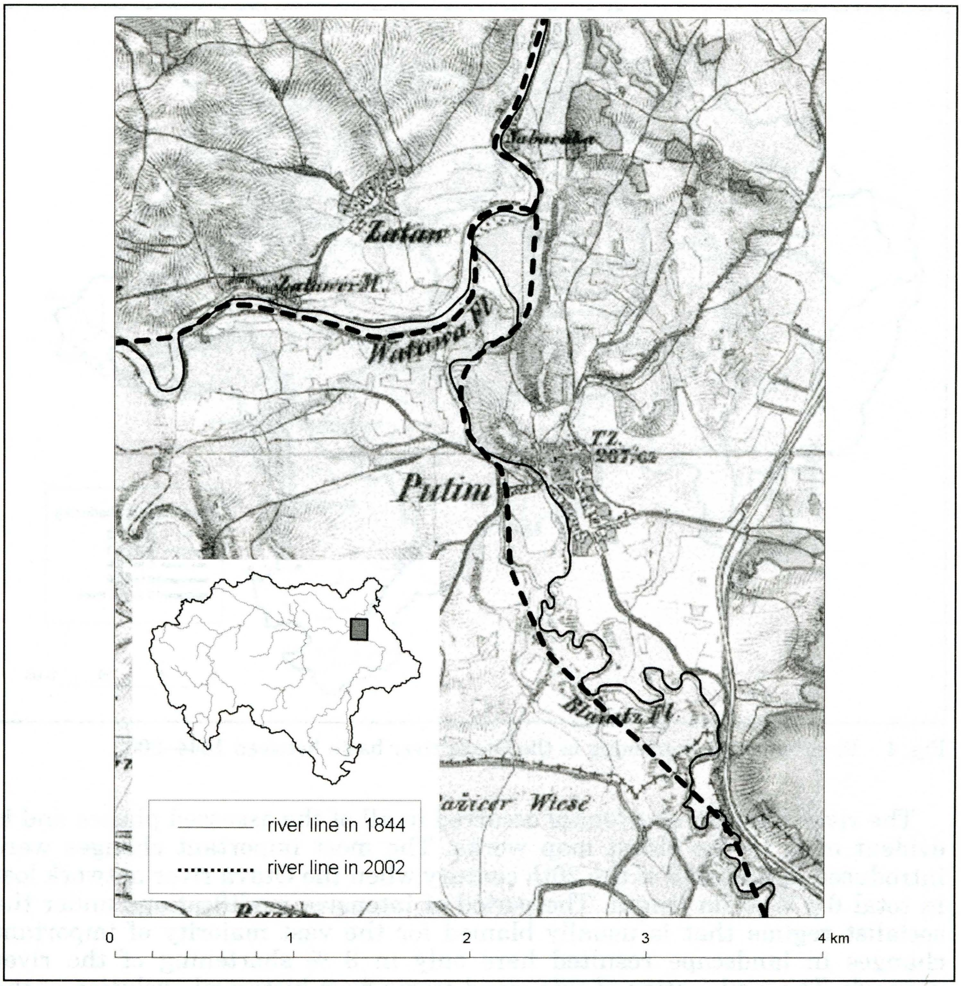


Fig. 3 – Overlay of waterlines of Digital civil map on the georefferenced digital image of the 2nd Military Map with digitized waterlines.

intensity of stream rectification as the most of streams in the Central Europe. Over the last 150 years, the length of the river network backbone has been cut from 611.6 km to current 555.9 km, i.e. by 9.1 percent.

The detailed assessment based on analysis of historical maps showed the fundamental spatial differentiation of this process in the Otava river basin. The maximum intensity of stream rectification in period 1844–2002 is reaching up to 40 % of the original river length in the Otava and Blanice down river courses located in the agricultural regions in lowland part of the river basin. To the contrary, the streams in headwater mountainous areas weren't significantly affected due to the terrain morphology and smaller pressure on land-use and the shortening rates here are generally not exceeding 4 %. Shortening of the Otava mid and downstream areas, where the rivers were subject to modifications already in the 18th century mainly due to the timber flowing in average accounts for 10% of the original length (Figure 4).

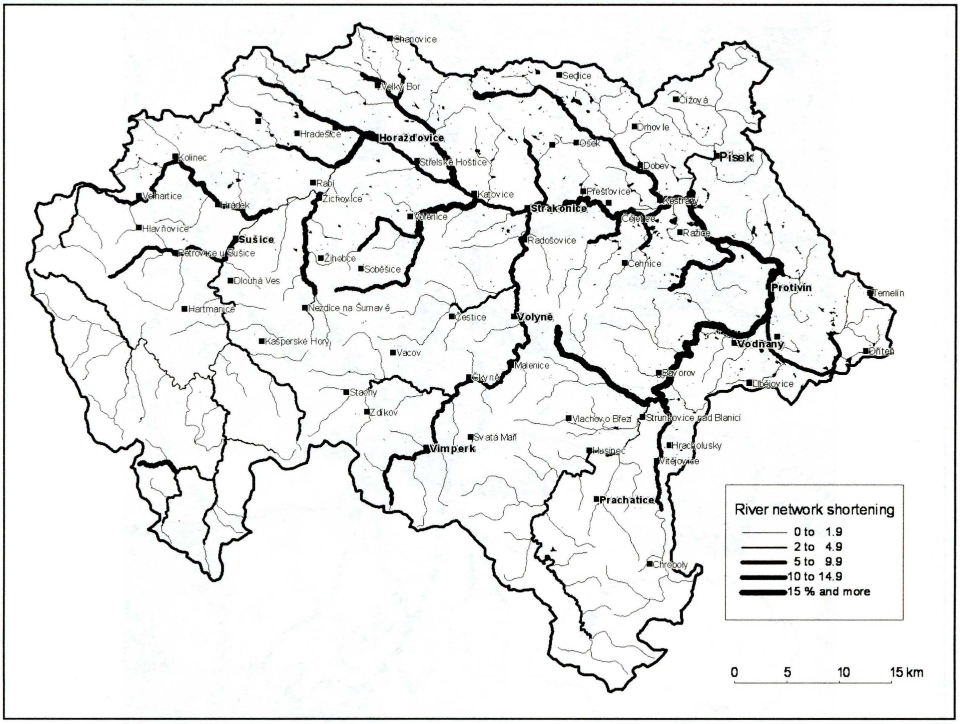


Fig. 4 – River network shortening in the Otava river basin between 1844–2002

The river network shortening occurred in all of the assessed phases and is evident even in the oldest map works. The most important changes were introduced in first half of the 20th century when the Otava river network lost in total 6.6 % of its length. The period of intensive modifications under the socialist regime that is usually blamed for the vast majority of important changes in landscape resulted here only in 3 % shortening of the river network. The explanation of this trend stems from historical evolution of the area. Due to the favorable conditions the Otava river basin was subject of intensive settlement, agriculture and other activities already since the middle age and thus the most important changes in river network were done in the history. So the stream rectifications made in 1970´s and 1980´s affected predominantly the small streams draining agricultural fields that were not subject of the assessment and thus are not appearing in the results.

The experience from field mapping of flood effects after the extreme floods in July 1997 and August 2002 shows that water course rectification is usually accompanied by acceleration of erosive and accumulative processes. The performed rule-based classification proved this relation although the overall statistical correlations between the watercourse shortening rate and intensity of the 2002 flood consequences are weak.

The rule-based classification was based on occurrence of at least one of the above-mentioned flood consequences (accumulation, river bank erosion, landslide, destruction of structures in floodplain) in the assessed river segment in coincidence with stream shortening rate for the period 1844-2000 exceeding specified threshold (Table 3).

Table 3 – Results of rule-based classification of stream rectification intensity impact on flood consequences.

	Shortening > 2 %	Shortening > 5 %	Shortening > 10 %
Total number of river elements	725	725	725
Shortening □ consequences	42,9 %	30,1 %	9,4 %
Shortening □ no consequences	52,7 %	32,8 %	14,8 %
No shortening □ consequences	2,8 %	15,6 %	36,3 %
No shortening □ no consequences	1,7 %	21,5 %	39,6 %
Share of shortened segments	95.6 %	62.9 %	24.1 %
Share of segments with flood consequences	45.7 %	45.7 %	45.7 %
Share of the shortened segments on the segments with consequences	94.0 %	65.9 %	20.5 %
Share of the consequences in shortened segments	44.9 %	47.8 %	38.9 %

The results of classification showed that relations between stream segment rectification and flood consequences depended on the threshold value of river network shortening used as an input criterion. The most numerous occurrences of flood consequences in modified segments were detected at the minimum shortening level. With the threshold set to 5 % which indicates the moderate shortening values the number of segments affected by flood effects is at 66 %. If the threshold is shifted to 10 %, which means in the Otava river basin an above average value, the share of segments with flood consequences drops to 20 %.

3. 2 Riverbed and floodplain transformation

Analysis of current intensity of the hydrographic network and flood plains anthropogenic modifications was based on field mapping of the state of backbone of the Otava river network and the consequences of the flood in August 2002 in total length of 610 km. From the results of mapping stored in GIS were extracted four main parameters of riverbed and floodplain transformation – stream route modifications, longitudinal profile, river bed modification and floodplain transformation.

The anthropogenic alterations currently affects 42,8 percent of the total length out of which 26,3 percent represent partial and 16,4 percent complete modifications (Figure 5).

The transformation intensity is however spatially highly diffentiated. The largest extent of changes is detected in downstream areas with intensive agricultural activities and dense population. The absolutely highest rate was found in the downstream of the Blanice river basin where almost 100 % of major watercourses length is classified as partially or completely modified. Extensive modifications involve also streams at mid and downstream courses of Otava, Volyňka, Ostružná and other rivers. To the contrary, the rivers in the headstream areas in mountainous parts remain practically untouched by anthropogenic activities.

From the view of flood progress control a highly important factor is the spatial structure of anthropogenic modifications. Long and compact modified sections speed up the flow and are leading to concentration of bank erosion, accumulation of material and intensive damage upon hitting unmodified zones, mainly in meanders and bends. The highest attention should be paid to pipelined segments that despite their short length pose considerable risks

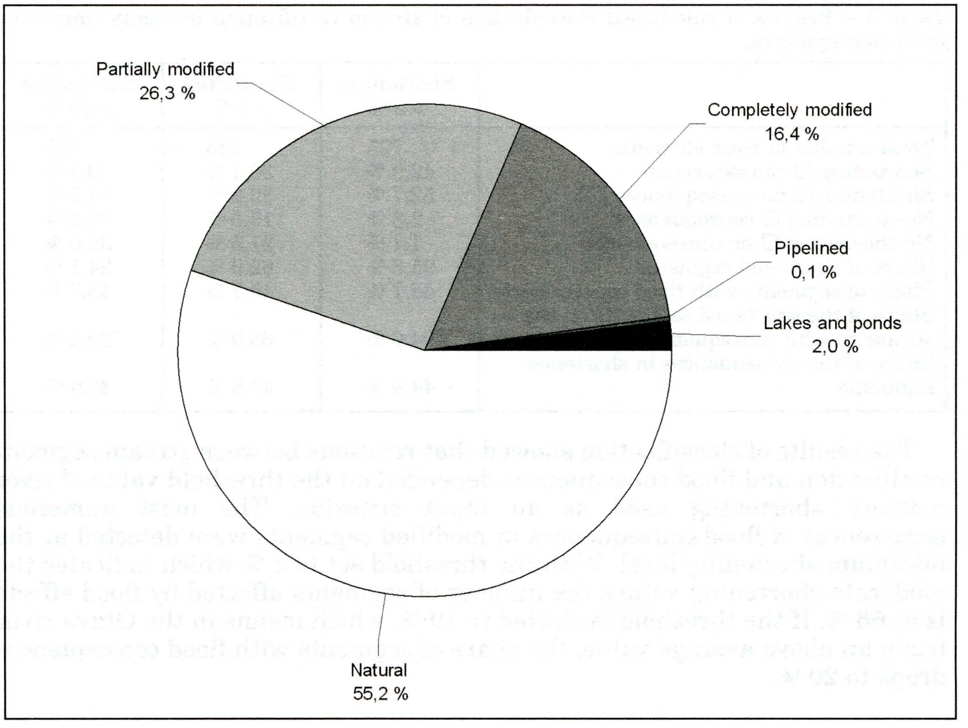


Fig. 5 – Anthropogenic transformation of riverbed – total shares of main categories of riverbed modification intensity at Otava river basin. Data from mapping of anthropogenic transformation of streams and floodplains in Otava river basin (Vilímek, Langhammer et al. 2004).

of damage due to their easy blockage by the material transported by the flood. This leads to creation of temporary water storages and subsequent break of the provisional dam resulting in local flash flood wave with destructive effect. Such problems were identified i.e. at the Losenice river at the slopes of Bohemian Forest where this process lead to serious damages on buildings and infrastructure during the flood in August 2002.

Another important factor affecting the runoff process during the flood is the land-use structure of flood plains. Importance of this factor is critical at situations when the water level exceeds the limits of the river bed or flood protection dykes and the area of the floodplain is involved in the runoff process. During the flood in August 2002 this occurred mainly in the lowland parts of the river basin during the second flood wave when the water level exceeded the flood plain bottom often even by several meters (Figure 6).

In conditions of such extreme events the structure of land cover of the flood plain can importantly affect the progress of the flood, the efficiency of flood wave transformation and the extent of damages. The analysis of land-use structure in the floodplain of the Otava river network pointed to the inadequate use of this area in regard to the flood protection needs – as much as 63 % of the total flooded area is of agricultural use, while 44 % of the total floodplain area is occupied by arable land. Meadows and pastures, forming the natural environment of the floodplain represent only 16 %, forests 11 %, wetlands and water bodies 1.4 % of the floodplain area. The intensity of

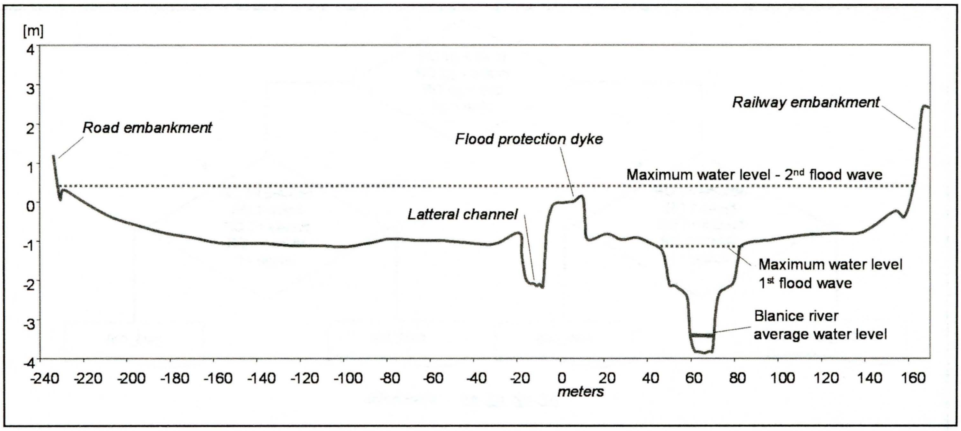


Fig. 6 – Cross section of the floodplain of the Blanice river by Protivín with marked water levels of 1st and 2nd flood wave in August 2002. Data from field mapping of consequences of flood in 2002 in Otava river basin (Langhammer 2006).

floodplain land-use differs significantly among individual subcatchments. Extreme values are reached at the Blanice and Otava downstream areas, where the shares of all anthropogenically modified surfaces in floodplains (agriculture, settlement, industry, transport) are exceeding even 90 % of the total floodplain area.

The rule-based classification was based on application of individual thresholds for each parameter of stream modification intensity and the comparison of resulting value with the occurrence of the flood consequences in coincident river segment (Figure 7).

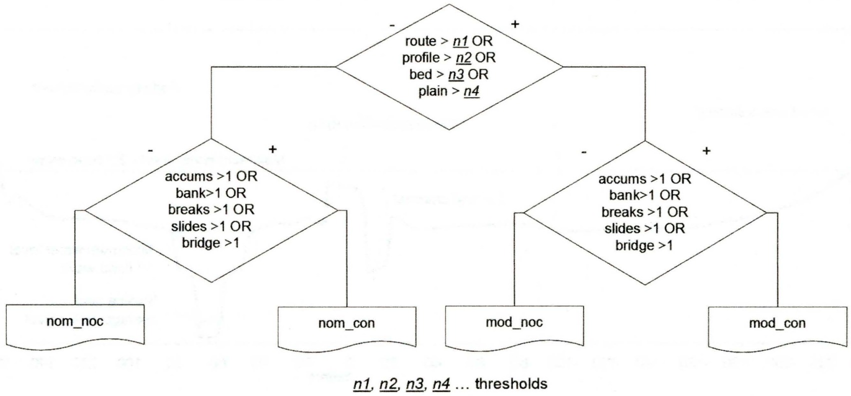
With respect to relations between watercourse modifications and flood consequences, it was of a vital significance to find that over 92 % of identified flood consequences were located in segments partially modified by anthropogenic activities according to at least one parameter.

The analysis indicated the strongest relation in the case of stream route and floodplain modifications – over 85 % of identified flood consequences were located in straight or sinuous segments, almost 60 % of detected flood consequences were located in segments affected by agriculture or settlement.

Relations between river-bed modification intensity and the flood consequences found in coincident and consequent segments are of inverse trend (Table 4). The flood consequences observed by the field mapping were identified in 49 % of river segments affected by partial or moderate modifications (level 2 and superior) but only in 11 % of entirely modified or pipelined segments (level 3 and superior). This results are in some aspects contradictory to the theories (i.e. Just, 2003) assuming that the higher modification intensity of the stream results in larger extent of flood induced effects.

3. 3 Flood course obstacles

For the extent of flood damages related to the extreme events is one of the key factors the occurrence of obstacles impeding water flow in the flood plain. Structures and objects located in the flood plains like inadequately designed bridges, weirs or improperly located objects in flood plains staying in normal



Explanation to abbreviations:

classification criteria

route, profile, bed, plain
intensity of watercourse modification in parameters:
stream route, longitudinal profile, riverbed transformation, floodplain modification

accums, bank, breaks, slides, bridge
number of following flood effects in river element:
fresh fluvial accumulations, bank cavings, dam breaks, landslides, damaged bridges

resulting classes of relationship between stream modification and flood effects

nom_noc no modification - no consequences
nom_con no modification - consequences
mod_noc modification - no consequences
mod_con modification - consequences

Fig. 7 – Decision tree for classification of relations between riverbed transformation and flood consequences

Table 4 – Results of rule-based classification of stream and floodplain modification impact on observed flood consequences

	Stream routing >1	Longitudinal profile >1	Riverbed modification >1	Floodplain modification >1	Overall modification > 1	Overall modification >2
Total	829	829	829	829	829	829
Modification → consequences	311	83	180	217	336	306
Modification → no consequences	347	89	199	244	399	368
No modification → consequences	54	282	185	148	29	59
No modification → no consequences	117	375	265	220	65	96
Share of modified segments	79.4 %	20.7 %	45.7 %	55.6 %	88.7 %	81.3 %
Share of segments with flood consequences	44.0 %	44.0 %	44.0 %	44.0 %	44.0 %	44.0 %
Share of the modified segments on the segments with consequences	85.2 %	22.7 %	49.3 %	59.5 %	92.1 %	83.8 %
Share of the consequences in modified segments	47.3 %	48.3 %	47.5 %	47.1 %	45.7 %	45.4 %

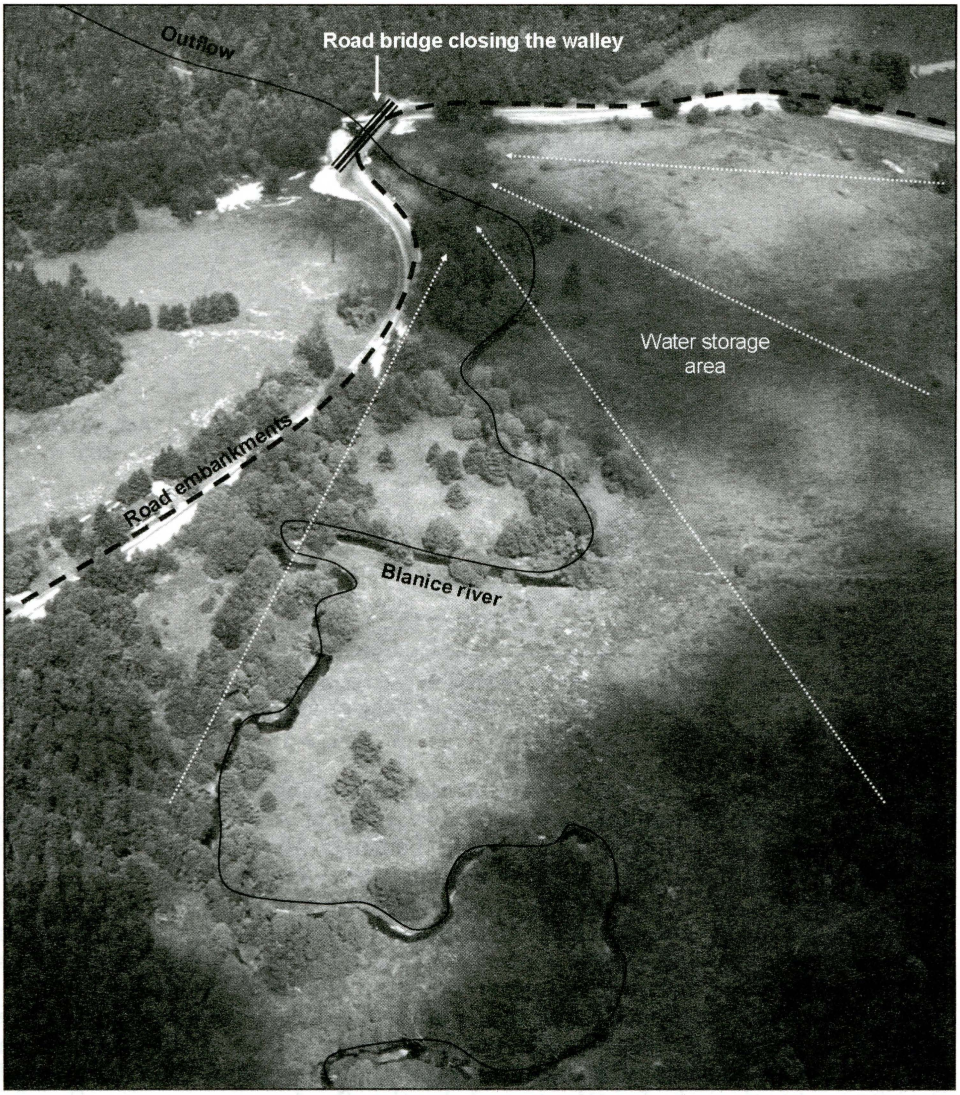


Fig. 8 – Inadequately Located Bridge on the Upstream Blanice River Impeding Flow During Floods (Photo Langhammer 2003)

conditions outside of the inundation zone during extreme flooding may become important flow obstacles. With help of material carried by the flood they cause temporary blockages, which after their breaking can trigger the local flash flood. Such processes accelerate accumulative and erosive processes and the destroyed structures become source of material carried by the flood wave and may amplify problems further down the stream.

This process is illustrated by the event caused by the road bridge on the upstream Blanice river during the 2002 flood (Figure 8). The small and relatively unimportant local road bridge is located at the end of shallow but large valley. Because of its inadequate design capacity it was during the first

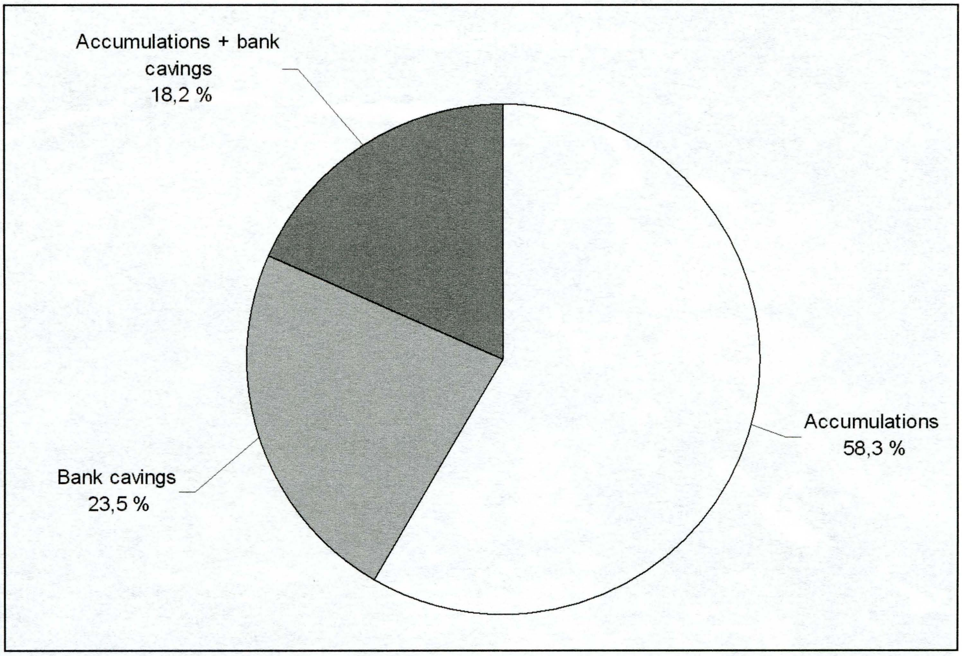


Fig. 9 – Structure of flood consequences related to the occurrence of steps and weirs. Data from mapping of anthropogenic transformation of streams and floodplains in Otava river basin (Vilímek, Langhammer et al. 2004).

flood wave blocked by transported material and turned the upstream valley in temporary lake accumulating enormous volume of water. After the collapse of the bridge the triggered flash flood reached after several kilometers Husinec river dam endangering seriously its safety and stability.

The classification of relations between occurrence of flood course obstacles and observed flood consequences was based on following structures which were selected as potential flow obstacles in river-beds and flood plains: steps in river-beds, weirs, bridges, improperly located objects in floodplain.

The detection of these potential flood course obstacles was performed in the actual and preceding stream segments because of nature of their impact on the flood course. Assessment results proved the importance of occurrence of structures in river bed with regard to the flood consequences. Special importance has the consecutive occurrence of steps in subsequent segments – when evaluating the impact of steps on occurrence of fluvial accumulations and bank cavings in coincident segment only 8 % of river segments were corresponding to this criterion. If the detection of presence of the step or weir is extended also to the preceding river segment, the share of segments with respective flood consequences increases to 13 %.

The flood consequences related to the weirs are differetiated according the nature of prevailing geomorphologic process (Figure 9). The most frequent are fluvial accumulations (58 %) followed by bank cavings (23.5 %), simultaneous occurrence of both accumulations and bank cavings is recorded in 18 % of segments.

4. Discussion

The classification of the impact of watercourse shortening, river-bed and flood plains anthropogenic modification and flow obstacles on observed flood consequences proves surprisingly weaker relations in the areas of high intensity of anthropogenic modification of river-beds and flood plains. This applies mainly to the downstream areas of the Blanice and Otava, the two main watercourses of the river basin. Here is recorded maximum intensity of watercourse, riverbed and flood plains modifications, but relations between the state of anthropogenic transformation and flood consequences aren't clearly proved.

This may be caused by unprecedented extremity of the flood in August 2002. In downstream areas, the flood wave filled the whole area of the flood plains with water levels exceeding by several meters the level of floodplain. Therefore the impact of anthropogenic modifications of watercourses was weakened. To the contrary, in upstream and midstream areas, where flood wave waters mostly did not leaved the river-beds or spilt into a narrow floodplain area, the impact of anthropogenic interventions on flood consequences increased. These findings are in line with current results of research in the field in various geographical conditions (Naef, Scherrer et al. 2002; Niehoff et al. 2002; Robinson, Cognard-Plancq et al. 2003; Sear, Newson 2003).

5. Conclusions

The results of presented research indicated the links between anthropogenic transformation of the streams and the response of river basin to the extreme flooding.

The research proved that the relations between individual indicators of landscape vulnerability and observed flood consequences may differ according the geography, intensity of the overall anthropogenic impact on river basin, basin scale, extremity of the causal precipitation and mainly extremity of resulting runoff response of the river basin.

River network shortening and river-bed modifications have important influence on the progress of the flood, flood wave shape, velocity and on possibilities of its effective control and transformation. However during extreme flood events when whole flood plains are involved in the runoff process their effect down significantly. In case of the flood in August 2002 in the core zone of the flood the effect of these factors was remarkable during the first flood wave. During the second flood wave which came some days later and because of preceding saturation of the river basin resulted in runoff response that in some catchments exceeded 1000 years return period, the role of these landscape and river network modifications was marginal. On the contrary, very important impacts have the modifications of flood plains and mainly the occurrence of the potential obstacles to the flood course. The analysis proved the effect of improperly located objects in the floodplain, insufficiently designed structures or bridges impeding the water flow during the extreme flooding on the extent of flood consequences.

Geostatistical analysis of relations between landscape modifications and consequences of the flood in August 2002 in the Otava river basin proved that these relations are remarkable even at the regional level but that they cannot be considered as the main driving force of unprecedented extremity of the assessed flood and its consequences. These findings are applicable in the process of improvement of flood protection design and management. The restoration of streams and landscape thus can be considered as important complement to the structural measures but there is always necessary to take into account the limits of these measures on flood mitigation and their varying effect under different flood extremity levels.

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Shrnutí

GEOINFORMATICKÉ VYHODNOCENÍ SOUVISLOSTÍ EXTRÉMNÍCH POVODNÍ – PŘÍPADOVÁ STUDIE: POVODNĚ V SRPNU 2002 VE STŘEDNÍ EVROPĚ

Předložené výsledky výzkumu ukazují vztahy mezi antropogenními změnami vodních toků a reakcí povodí řek na velké povodně. Výzkum potvrdil, že vztahy mezi jednotlivými ukazateli zranitelnosti krajiny a pozorovanými následky povodní se mohou lišit podle zeměpisných poměrů, intenzity celkového vlivu člověka na povodí řeky, velikosti povodí, extrémního charakteru dotyčné přeháňky a zejména podle extrémní odtokové reakce povodí řeky.

Zkrácení říční sítě a úpravy říčního koryta mají velký vliv na postup záplav, tvar povodňové vlny, rychlost a možnosti jejího účinného řízení a změny. Avšak při extrémních povodňových situacích, když jsou do odtokového procesu zapojeny celé říční nivy, se jejich účinek se výrazně snižuje. V případě povodní v srpnu 202 byl v hlavní povodňové zóně účinek těchto činitelů významný v první povodňové vlně. Během druhé povodňové vlny, která přišla o několik dní později a vlivem předchozí saturace povodí řeky došlo v některých povodích k více než tisícileté vodě, byla úloha těchto změn krajiny a říční sítě pouze okrajová. Naopak velký vliv mají změny říčních niv a zejména výskyt možných překážek postupu povodní. Analýza prokázala vliv nevhodně umístěných objektů v říční nivě a špatně navržených budov či mostů zabraňujících průtoku vody při extrémních povodních na rozsah povodňových škod.

Geostatistická analýza vztahů mezi změnami v krajině a následky povodně ze srpna 2002 v povodí řeky Otavy ukázala, že tyto vztahy jsou pozoruhodné i na regionální úrovni, ale nemohou být považovány za hlavní hybnou sílu bezprecedentního rozsahu záplav a jejich následků. Tyto poznatky lze využít při zlepšování projektů a správy protipovodňových opatření. Obnova vodních toků a krajiny může být tedy považována za důležitý prvek strukturálních opatření, ale je vždy třeba brát do úvahy limity těchto opatření na zmírnění záplav a jejich proměnlivý účinek při různé síle povodní.

Obr. 1 – Povodí řeky Otavy. Zkoumaná oblast je jednou z hlavních zón extrémních povodní ve střední Evropě v srpnu 2002. Ve východní části povodí podél řeky Blanice byly zaznamenány ve dvou po sobě následujících vlnách srážky přesahujících 300 mm. Vysvětlivky vpravo dole: síla povodně (xletá voda), rekordní srážky (xleté extrémy, druhá povodňová vlna).

Obr. 2 – Zanesení údajů do základního úseku řeky za pomoci GIS. Příklad ukazuje oblast soutoku řek Otavy a Volyňky. Geomorfologické následky: sesuv, staré říční naplaveniny, čerstvé říční naplaveniny, vymletí říčního břehu, stupeň v říčním korytě, jez, rozbitý most, most, nevhodně umístěný object, maximální stav vody, osamělý balvan, brod, sklaní útvary, ostrov.

Obr. 3 – Přenesení vodních toků z digitální civilní mapy na georeferenční digitální zobrazení 2. vojenské mapy s digitalizovanými vodními toky. Plně – linie řeky v roce 1844, tečkovaně – linie řeky v roce 2002.

Obr. 4 – Zkrácení říční sítě v povodí Otavy v období 1844–2002.

Obr. 5 – Antropogenní změny říčního koryta – celkový podíl hlavních kategorií intenzity změn říčního koryta v povodí Otavy. Údaje z mapování antropogenních změn vodních toků a říčních niv v povodí Otavy (Vilímek, Langhammer et al. 2004). Shora ve směru hodinových ručiček: částečně změněno, úplně změněno, vedeno v trubkách, jezera a rybníky, přírodní

Obr. 6 – Příčný řez říční nivou Blanice u Protivína s vyznačením úrovně první a druhé povodňové vlny v srpnu 2002. Údaje z terénního mapování následků povodně z roku 2002 v povodí Otavy (Langhammer 2006). Zleva nad tečkovanou čárou: silniční násep – ochranný povodňový val – maximální stav vody (druhá povodňová vlna) – železniční násep. Zleva pod tečkovanou čárou: postranní kanál – maximální stav vody (první povodňová vlna) – průměrný stav vody v Blanici.

Obr. 7 – Graf ke stanovení vztahů mezi změny říčního koryta a následky povodní. Horní kosočtverec: směr, profil, dno, niva. Levý i pravý kosočtverec: naplaveniny, břeh, průlom, sesuvy, most, n1 – prahy. Vysvětlení zkratek: klasifikační hlediska: směr, profil,dno, niva. Iintenzita změn vodního toku v parametrech: směr proudu, podélný profil, změna řečiště, změna říční nivy. Naplaveniny, břeh, průlomy, sesuvy, most; počet následujících povodňových následků v řece; čerstvé říční naplaveniny, vymleté břehy, průlomy hrází, sesuvy půdy, poškozené mosty. Výsledné třídy vztahů mezi změnami řeky a následky povodně: žádné změny – žádné následky, žádné změny – následky, změny – žádné následky, změny – následky.

Obr. 8 – Nesprávně umístěný most na horním toku Blanice zabraňující průtoku vody při povodních (foto Langhammer 2003) Shora ve směru hodinových ručiček: odtok, silniční most uzavírající údolí, oblast akumulace vody, řeka Blanice, silniční násep.

Obr. 9 – Struktura následků povodní ve vztahu s výskytem stupňů a jezů . Údaje z mapování antropogenních změn vodních toků a říčních údolí v povodí Otavy (Vilímek, Langhammer et al. 2004). Shora ve směru hodinových ručiček: naplaveniny a vymleté břehy, naplaveniny, vymleté břehy.

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PETR DOBROVOLNÝ, KATEŘINA KEPRTOVÁ

SPATIAL ANALYSIS OF DAMAGE CAUSED BY STRONG WINDS AND GALES IN THE CZECH LANDS SINCE AD 1500

P. Dobrovolný, K. Keprtová: *Spatial analysis of damage caused by strong winds and gales in the Czech lands since ad 1500.* – Geografie–Sborník ČGS, 111, 1, pp. 51–69 (2006). – The aim of this article is an analysis of the spatial distribution of places with damage done by gales and windstorms in Czechia in the course of the last 500 years. Descriptive documentary data derived from historical climatology are used for this analysis and the specific features contained within these data are mentioned. Using ArcGIS tools, thematic maps of the locations damaged by gales for each century are presented and the spatial distribution of the places is characterized. This spatial distribution is connected to a large degree with the quantity and quality of available historical sources. However, spatial analysis enables the characterization of the most affected localities and also the most significant cases, "the windstorms of the century".
KEY WORDS: spatial analysis – documentary evidence – windstorm – damage – the Czech Republic.

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Introduction

Meteorological extremes are a perennial cause of substantial material damage and loss of human life. An increase in the frequency and intensity of extreme weather events has often been considered one of the possible consequences of contemporary climate change (Houghton et al. 2001). Precise data about these phenomena from the instrumental period are very limited. An alternative source of information for the temporal and spatial variability of extreme weather conditions from pre instrumental period may be found in written historical records. This field of scientific study, known as historical climatology, deals with the reconstruction of climate based on data of anthropogenic and natural origin, the clarification of causes of climate changes in the past and the evaluation of the impacts they have had on human life and the environment before regular instrumental observation came into practical use (Brázdil 2000). For Central Europe, written records appear to be one of the richest sources of information about the weather and climate in the past. These include reports of personal origin (annals, chronicles, memoirs), visual daily weather records, diaries, personal correspondence, documents relating to contemporaneous economic matters, original newspaper reports and others. These data, as they extend back over a period of up to a thousand years, can be used for the reconstruction of climate (Brázdil and Kotyza 1995a). In the region of the Czech Republic, the number and reliability of weather reports have been of better quality especially since the 16th century. One of the characteristics of these data is the greater attention given to extreme weather events. Chronicles, newspaper reports and personal correspondence are particularly rich in mentions of weather that diverges from the ordinary.

Although historical weather reports have tended to be analysed in terms of aspects of time in recent years, they also have a great potential for the study of spatial variability of extreme weather events. The quality and quantity of historical records led naturally to time changes being prioritised in the early development of methods in historical climatology. Considering the growing number of historical sources, it is now possible to include a spatial differentiation of the phenomena in their interpretation. Studies emphasizing the space differentiation of meteorological or climatic conditions derived from documentary sources can be divided into two groups. The first group includes papers describing the spatial patterns of individual cases of extreme weather events (Dobrovolný and Brázdil 2003a). The other group is based on contributions consisting of descriptions of prevailing circulation patterns. Once information about meteorological conditions from several locations in West and Central Europe becomes available, it is possible to reconstruct the prevailing circulation or the position of the main air pressure systems. Reconstructions of prevailed circulation patterns based on the interpretation of documentary sources have been carried out by, for example, Lamb (1986) or Kington (1988). The growing reliability of reports coming from a rising number of locations has even enabled, in addition to the subjective circulation classifications mentioned, the use of the objective methods of multivariate statistics (Luterbacher et al. 2002; Jacobeit et al. 2003). However, the potential for reconstructing the circulation pattern of a particular past extreme weather event eventually encounters a time resolution barrier. The quality and quantity of historical climatology data enable reconstructions to be carried out at present only at the level of monthly, seasonal or annual averages.

Comparison between present and historical extreme weather events can assist our overall understanding of such extremes. One of the largely unexplored aspects of the current global warming is the role played by the human society. One of the reasons for searching out an alternative source of information in the past is the possibility to characterize natural climatic variability in pre-industrial times and, consequently, to comprehend the influence of anthropogenic factor on the climate. Furthermore, cases of historical extremes contribute to a better definition of potentially threatened areas. One of the most important aspects of these records is detailed description of their progress. However, most cases record only the impacts of these events.

The aim of this article is to describe the spatial variability derived from historical records concerning the damage done by gales and windstorms in Czechia in the course of the last 500 years. The detailed climatological analyses were carried out by Brázdil et al. (2004). First of all, the fundamental characteristics of the data are given, together with their specific features. Methods useful for the analyses of spatial variability based on spatial autocorrelation are described in the third part. The fourth part includes the basic characteristics of the spatial analyses of the records with the help of the methods mentioned. It also presents some thematic maps of the locations damaged by gales for each century, produced in ArcGIS. The spatial distribution of each category is compared with the theoretical distribution, and the specific features of the places are discussed. The character of the damage caused by windstorms is described in the fifth chapter.

The database of historical climatology

The fundamental material consists of records of the occurrence of strong winds and gales on the territory of the Czech Republic over the last 500 years. These can be found in the database of historical climatology compiled at the Institute of Geography, Masaryk University in Brno, over recent decades. The database for the Czech Republic is in parallel with data for other regions – for example, the HISKLID database in Germany, or EURO-CLIMHIST, which includes almost the whole area of Europe (Schüle and Pfister, 1994). The examples mentioned, apart the other things, support the production of simple schemes and maps that concentrate upon the spatial aspect of historical reports. In other parts of the world for example Mikami (1992) made an evaluation of daily records of the weather taken from personal diaries and transformed them into historical synoptic maps of Japan.

Individual records can differ widely in quantity, quality and accuracy of time evaluation, depending on the origin of data or even the personality of the author. For example, descriptions of the consequences of historical windstorms, those that did a great deal of damage, are often highly detailed and extensive when recorded in chronicles or newspaper reports. On the other hand, notes of daily observations may include concise descriptions of weather, written in the specific style of the author. In spite of such a wide range of various sources in the historical record, five fundamental attributes may be often derived for each of them: the date of the event, the place of occurrence, a concise description of the type of event, the actual text and the original source. These five attributes may be further extended during the interpretation process.

The degree of accuracy in dating specific events differs in many ways. However, it is possible to distinguish four levels: year, season, month and day. Quite a large number of the records are dated to around a reasonably specific period of time, for example religious feast-days (Easter, Christmas, etc) or annual events (harvests, carnivals etc.). Therefore special attention needs to be paid to sorting out events, especially those related to the winter period. It has often been possible, from further documents or other similar records, to allocate a year to the given record. There was quite a large set of reports whose proper time specification needed individual approach and often was based on a comparison of several records. This is the case of all reports dated only by religious holidays (for example records 'before Easter'). An examination of the records in their wider context is nearly always required.

To be able to map the events it is important to deal with their spatial aspect. In many cases, the records mention some settlement or at least a part of it. If the report mentions a location that no longer exists or, in some cases, a minor location that has become part of a vast settlement, the matter needs an individual approach. Quite a large number of records, especially older ones, are not related to individual places. They describe such larger areas as mountains, forest regions, districts or whole lands (Bohemia, Moravia, and Silesia – Fig. 1). In the same way, cases in which locations are known by the same name need to be treated individually. Reports from surrounding countries also play an important role in the process of interpretation.

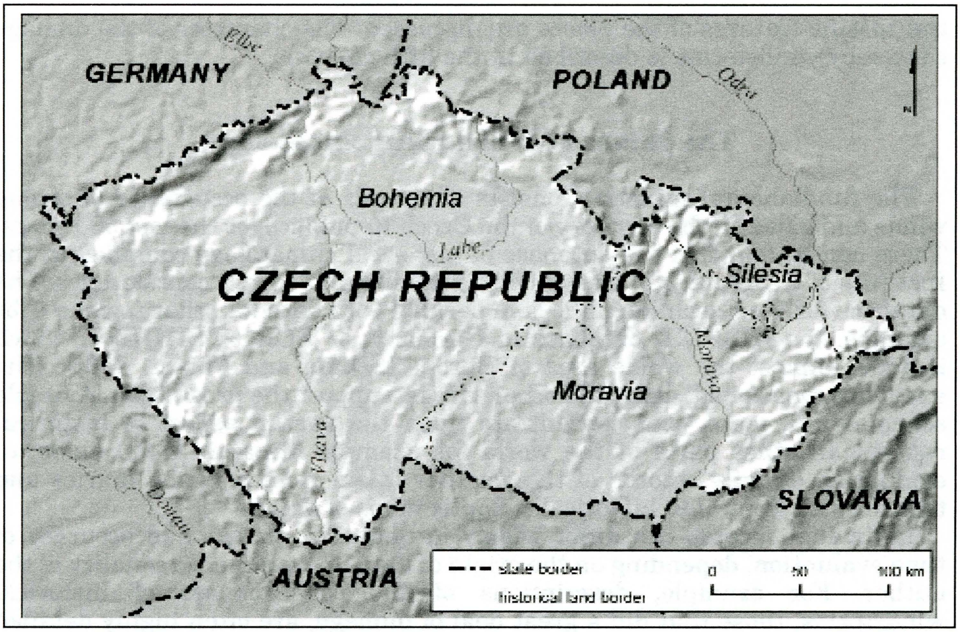

Fig. 1 – The territory of Czech Republic with the names of its historical lands

The third substantial step is to classify the events into individual types. Verbal descriptions of weather conditions and related phenomena can vary considerably from case to case. They may be represented by only a few words or several pages (Fig. 2). Especially in the sixteenth and seventeenth centuries, reports of the occurrence of extreme meteorological events may often be hidden within a colourful depiction of unusual phenomena in the atmosphere connected with stormy activity, perceived as a "miracle" in which people sought various missions or revelations. The description of a gale during a storm recorded on 14 March 1576 at Čestín in central Bohemia is one such example (Paprocký, 1602): "... When the storm broke out ..., people saw evil spirits in it, as if riding three stalls and, having passed the mansion, they turned to the sheep-pen, lifting it up and toppling it, so that where it had stood an empty place remained." The character of these reports and the explanation of the phenomena observed was, of course, a reflection of very limited knowledge of atmospheric processes and their physical nature. Furthermore, in many cases the consequences of event are described rather than the phenomenon itself. Nevertheless, from such accounts it is then possible to evaluate the intensity of the phenomenon and its impacts on society at the time.

Methods of mapping and the study of spatial distribution

The file of historical weather reports corresponds to a large degree with the quantity and quality of available sources. It is clear that many events have remained hidden from the eyes of chroniclers or, in other cases, have not, for various reasons, been excerpted yet. The facts may often be fragmentary and may not contain comprehensive data of the spatial extent of the event or the

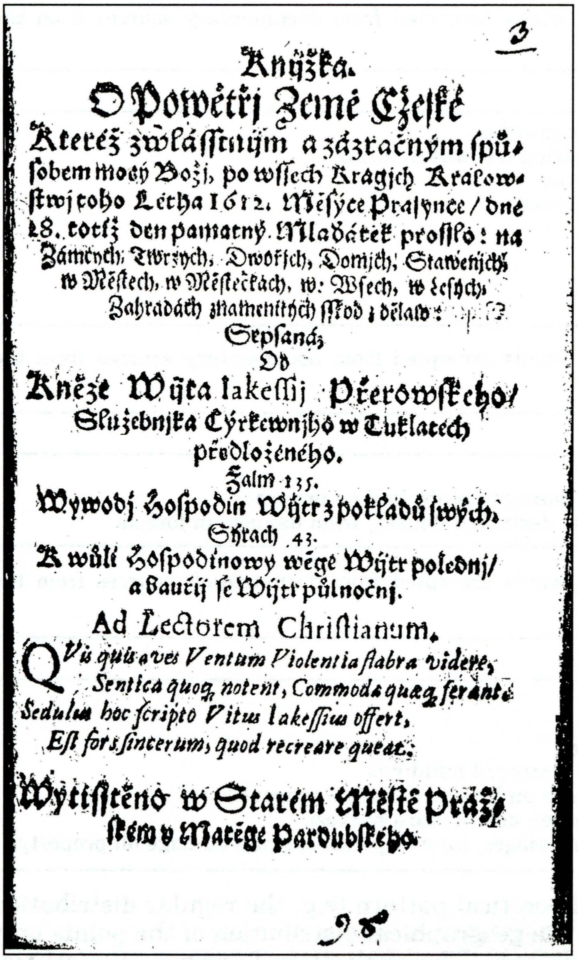

Fig. 2 – The title page of a moral tract by the priest Vít Jakeš Přerovský, written in reaction to a disastrous windstorm in the Czech Lands on 28 December 1612 (Brázdil et al. 2004a)

damage done by it. Despite of the missing parts of the puzzle, it is possible to define the damage from the viewpoint of spatial distribution and also to specify the main affected areas for individual kinds of damage.

Dobrovolný and Fukátko (2003) describe the process of transforming historical data from an original analogue database into detailed digital form. A set of tools for this process has been developed with the support of ArcView GIS. This enables a step-by-step separation of the original historical data for individual locations and the addition of other descriptive attributes. These tools are capable of storing such additional information as, for example, the accuracy of data, the intensity of the event, and characteristics of the damage. Their main contribution is to the selection of certain types of events and to their presentation in the form of thematic maps. In the case of windstorms, individual cases have been examined to define the basic types (Table 1) and the extent and character of damage (Tables 2 and 3).

The cartographic presentation of events plays an important role in the description of spatial configuration. This can be done in either point or area form. Considering the problems mentioned above with the fullness of historical reports, the damage has been related to the places mentioned in the report. These places have been presented as points for the subsequent analysis of spatial variability. As Lee and Wong (2001) point out, the study of a particular spatial configuration (in our case locations with damage from strong wind) may be compared with the theoretical configuration. There are three types of theoretical configuration: clustered, regular, and random. Two of the methods applicable are discussed at a later point.

Nearest neighbour analysis is an easy method, useful for the description of spatial configuration of points (Lee and Wong 2001). The method is based on a comparison of two variables – an observed average distance between the two nearest locations within the investigated area and the average distance of the

Table 1 – Classification of strong winds excerpted from documentary sources from the viewpoint of the recorded event

Code	The type of event
T0	wind without detailed specification
T1	squall (i.e., gusty wind during a thunderstorm)
T2	tornado – proved occurrence
T22	tornado – probable occurrence
T222	dust devil
T3	strong wind, blizzard
T4	gale
T5	violent windstorm

Table 2 – Classification of strong winds excerpted from documentary sources from the viewpoint of the extent of damage

Code	Extent of damage
E0	damage not mentioned
E1	damage of lesser extent, damaged roofs, broken branches
E2	areally extensive damage, destroyed houses, wind damage in forests

Table 3 – Classification of strong winds excerpted from documentary sources from the viewpoint of the character of damage

Code	Character of damage
DO	casualties (lost lives)
DL	wind damage in forests
DP	small damage on buildings
DB	considerably damaged or destroyed buildings
DS	uprooted fruit trees, damage on hop-gardens and vineyards
DU	damage on field crops, garden and orchard harvest
DJ	other damage (upturned carriages, injured persons, small damage on property)

two nearest locations of the theoretical pattern (e.g. the regular distribution of points in space). In reality, the geographical distribution of the points only exceptionally forms an even pattern. The application known as R-statistics may be used for testing whether a definite distribution of the points in the area studied has a certain pattern. It is determined as the proportion between the observed and the expected average separation distance of the nearest neighbours in a certain area:

$$R = \frac{r_{obs}}{r_{exp}}$$

The figure r_{obs} can be determined when the distance between the given point and all its neighbours is given. Then the shortest distance has to be found – the nearest neighbour. This process is repeated for all the points. The average figure is calculated from all of the shortest distances. To work out the average distance of the nearest neighbour for a theoretical random distribution the following expression is used:

$$r_{exp} = \frac{1}{2\sqrt{(n/A)}}$$

where A is area of the study region and n is number of points. Spatial distribution of points approaches a cluster distribution for all cases with

$R < 1$ ($r_{obs} < r_{exp}$). On the other hand, the distribution approaches the regular one if $R > 1$ ($r_{obs} > r_{exp}$).

This method works only with the position of points in space. It does not consider the value of their attributes – in our case the number of the recorded cases of windstorms causing some damage in the location or the number of individual types of damage. Both parameters, the position and attributes, are evaluated by methods based on the concept of spatial autocorrelation. It is assumed that most processes change in space more or less continually. The near points would have similar values of the examined phenomenon and vice versa. Moran's Index (Moran's I) is among the most frequently used coefficients of spatial autocorrelation (Lee and Wong 2001). The following notation is used in the equations presented:

x_i – value of the studied attribute at point i

c_{ij} – measure of similarity of attribute at points i and j

w_{ij} – measure of similarity of distance between points i and j; $w_{ii} = 0$ for all the points

n – number of points in the study area

s^2 – variance of all x values.

In Moran's I, the similarity of values of the attribute at points i and j is given as follows:

$$c_{ij} = (x_i - \bar{x}) \, . \, (x_j - \bar{x})$$

Moran's I is then set as:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \cdot w_{ij}}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \cdot (x_i - \bar{x}) \cdot (x_j - \bar{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

The measure of positional similarity of points i and j (w_{ij}) is generally considered as the inverse value of the distance between these points. Therefore the more distant points are of less importance and the less distant points of more importance:

$$w_{ij} = 1/d_{ij}$$

The interpretation of Moran's I is based on the comparison of the value calculated for a specific set of points with an expected value. The equation for the expected value calculation of Moran's I has been introduced by, for example, Lee and Wong (2001). The value of the Moran's I is often expressed in the form of a standardized value (Z-score), which is a measure of the distance in standard deviations of a sample from the mean. If the achieved value of the Z-score is outside the interval (–1.96;+1.96) then the studied spatial distribution of points differs significantly from the random one at a level of $\alpha = 0.05$.

Analysis of spatial distribution of places with damage done by wind

As mentioned above, the character of description of strong wind events in documentary sources, their temporal and spatial extent has changed

Table 4 – Numbers of strong winds in the territory of Czechia during the last millennium determined according to documentary sources

Period	Number of cases
before 1500	47
1500–1599	249
1600–1699	298
1700–1799	344
1800–1899	698
1900–1999	787

significantly over recent centuries. This will, of course, also be reflected in the spatial analysis of damage from strong winds in Czechia. The overall number of cases for individual centuries is given in Table 4. The low frequency of data on strong winds up to the year 1500 does not permit their serious evaluation (Brázdil and Kotyza 1995a). A marked increase in the number of reports on strong winds begins in the 16th century. Figure 3 presents the spatial distribution of places reporting wind damage during the 16th century. Within this "older" period we can assume that a number of cases of windstorms cannot be found in the historical records, especially those concerning areas of borderland mountains with lower populations. If the database includes 47 cases of windstorms from the period before 1500 AD, then in the 1500 to 1599 period, 249 cases are related to 112 locations. Most cases for the 16th century are derived from reliable records kept in larger settlements.

The highest number of reports is related to Prague (42 cases), where records of strong winds are represented relatively regularly for the whole 16th century. Altogether, 30 cases of strong winds are documented from the region of south-eastern Moravia, based on daily records kept by Jan of Kunovice (Brázdil and Kotyza 1996). Next, according to the number of records, follows Litoměřice (29 cases), for which the main sources have been records from the Memorial Book of Litoměřice, 1570–1607. Also frequently represented are Náměšť nad Oslavou

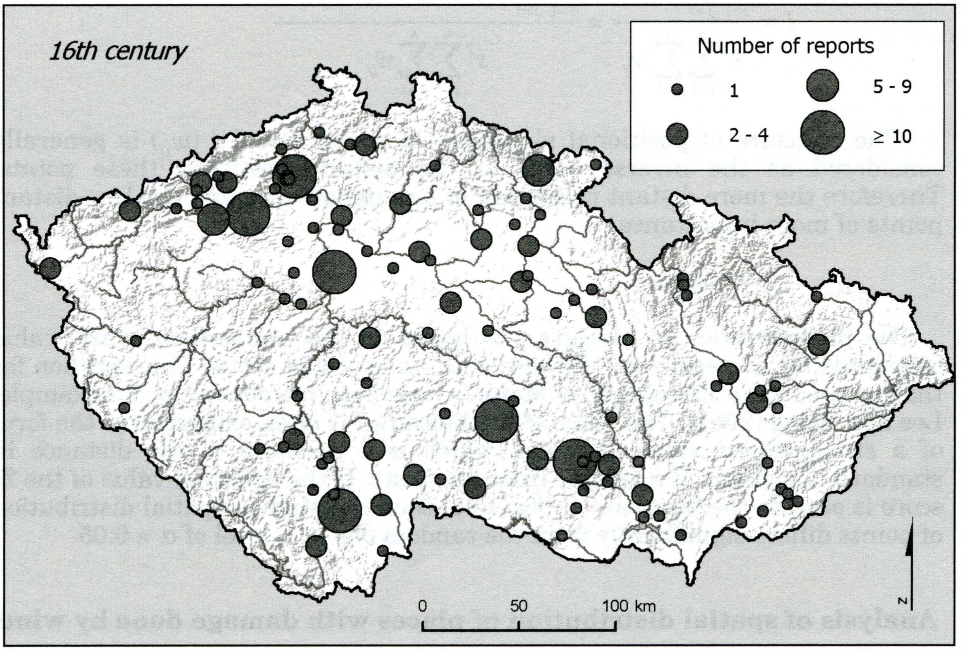

Fig. 3 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 16th century

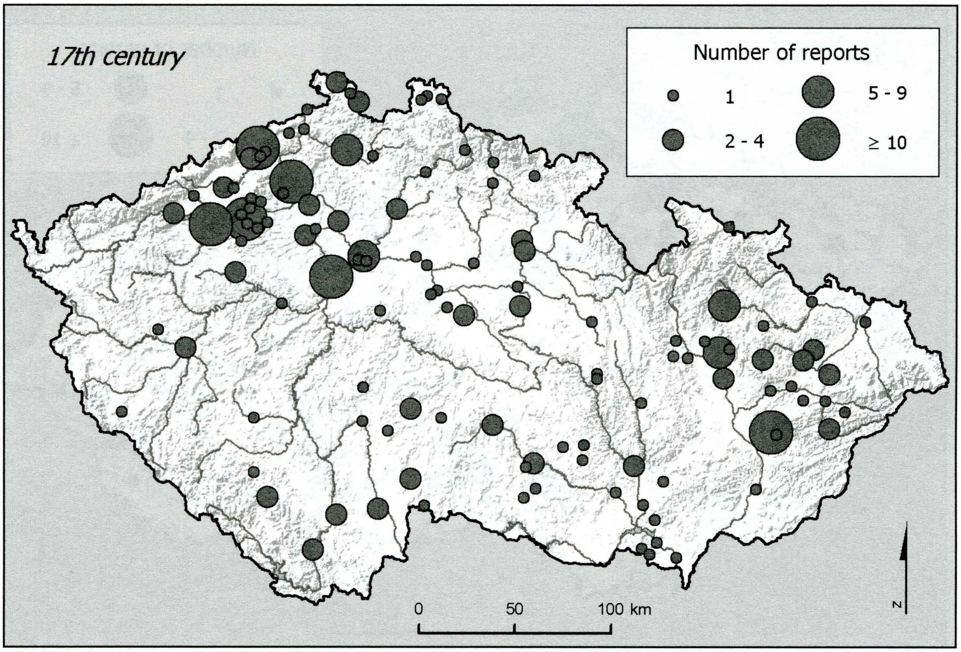

Fig. 4 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 17th century

(24 cases), thanks to the daily records kept by Karel Starší of Žerotín (Brázdil and Kotyza 1995b), followed by České Budějovice (21 cases), Louny (18 cases) and Jihlava (14 cases). The given locality in these records also reflects the place, which the author lived in, as it may be in some cases different from the place of occurrence of a windstorm mentioned. This is a further reason for the higher number of reports for the above towns. A more frequent localization of places in central and north-western Bohemia is evident from spatial distribution, while the lowest number of places is related to western Bohemia and to Silesia. Of 15 reports that do not mention an actual place and have a rather general character, 13 are related to Bohemia and 2 to Silesia.

For the 17th century, 298 cases of strong winds have so far been established. Overall, reports of strong winds are related to 121 actual places in the territory of Czechia (Fig. 4). As in the case of the 16th century, these localities often express where the author of the report lived. The highest number of strong winds was recorded in Prague (47 cases) again, next at Krupka in the north-western Bohemia region (31 cases), Louny (18 cases), Litoměřice and Žatec (both 11 cases). The high number of records from Krupka is linked with the memorial book kept by Michel Stüeler (Brázdil et al. 2004b). In Moravia, the highest frequency information (11 cases) appears in the Chronicle of Holešov (Fialová 1967). In comparison with the preceding century, more reports appear for central Moravia and Silesia, whereas the minimum of places in western Bohemia is joined by a lower number of places in the southern half of Czechia. Among the larger territorial units, 82 cases of strong winds concern central Bohemia.

For the 18th century, 344 cases of the occurrence of strong winds have been established in the territory of Czechia. A greater number of authors

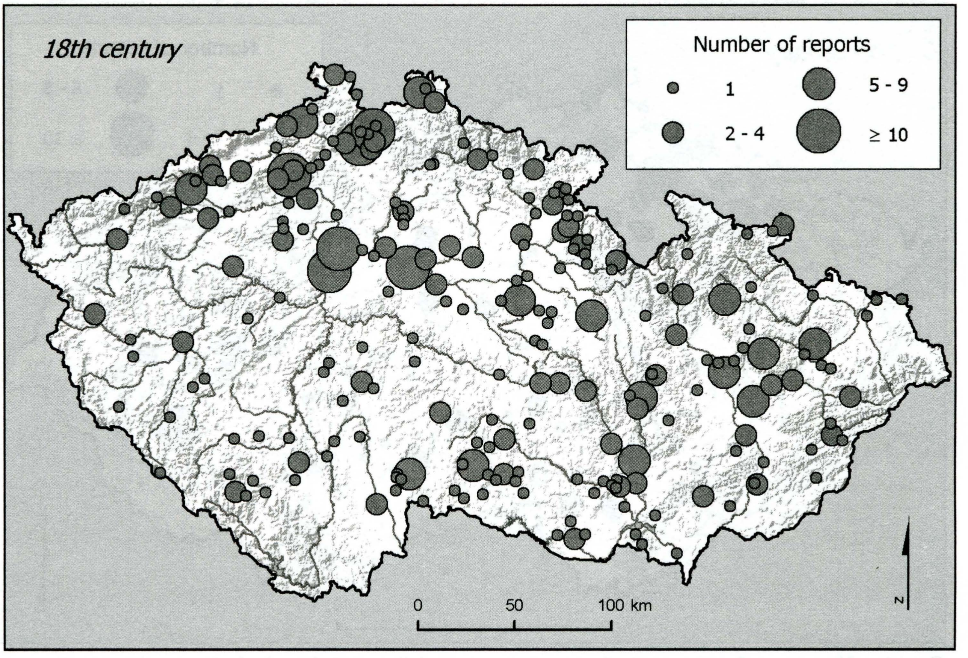

Fig. 5 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 18th century

describe windstorms of particularly large areal extent compared with the previous period. The character of sources and source material also changes in the course of the 18th century. New sources appear (e.g. newspapers) and it becomes possible to more utilize community and family chronicles or personal diaries with regular daily records. At the same time, the number of records of an economic character also increases, above all from forestry management. Reports of winds relate to a total of 236 places in Czechia (Fig. 5).

Similar to the preceding centuries, a high number of reports again comes from Prague (86 cases), central and north-western Bohemia. However, the number of documented gales from the region of the Bohemian-Moravian Highland, the Nízký Jeseník (Highland), central Moravia and from higher-situated border places increases conspicuously. With the increase in the number of reports, locations with natural presumption for the occurrence of strong winds (places exposed to the prevailing airflow, places in higher altitudes, etc.) start to be reflected in their spatial distribution. A lower number of wind calamities was observed in the 18th century in the region of western Bohemia, the Bohemian part of the Bohemian-Moravian Highland and also around Ostrava. As well as these, 35 events are related to larger regions with respect to the place of occurrence.

The chronology of strong winds in the 19th century includes 698 cases. As the density of the records grows, the number of events documented rises, both in terms of more sources and a higher number of places. Particularly for the latter half of the 19th century, the daily press becomes a very important source of data. The material collected relates to 402 places (Fig. 6) and in another 38 cases the reports concern extensive regions.

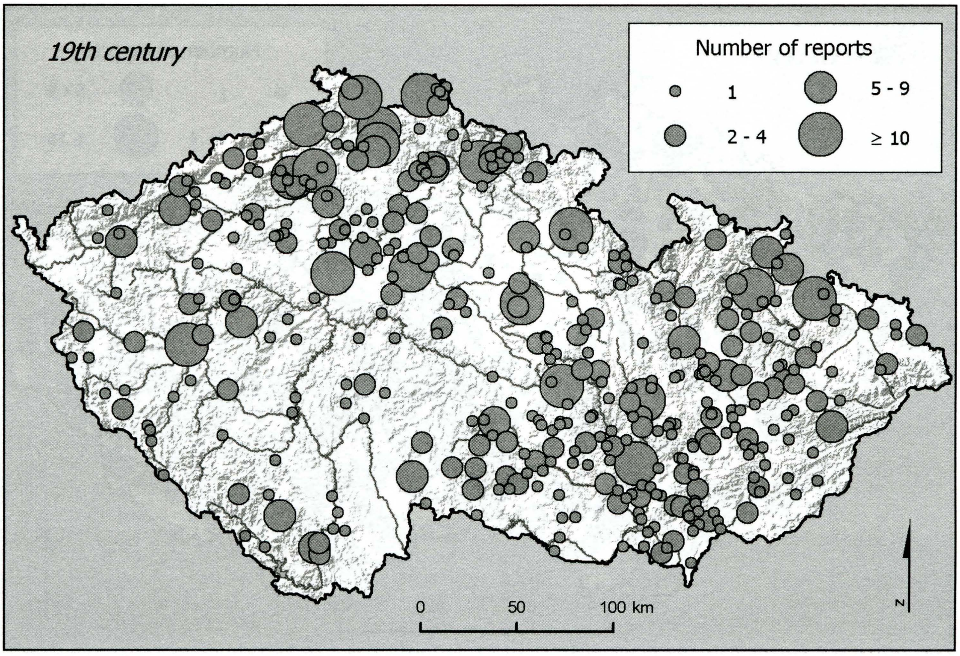

Fig. 6 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 19th century

A higher density of reports for Moravia is evident from Fig. 6. In Bohemia, north-western, north and north-eastern regions of country are the most markedly represented. Essentially fewer strong winds in the 19th century were established in the region of western Bohemia and also in the Bohemian part of the Bohemian-Moravian Highland. Frequent reports come from Jablonné v Podještědí (182 cases), Noviny pod Ralskem (119 cases), Litoměřice (67 events), Děčín (24 events), Brno and Frýdlant (22 events each).

As may be expected, the 20th century is represented by the highest number of cases in the database of strong winds – almost 800 records. This markedly higher number of reports is above all the result of systematic excerption of sources that, for the earlier period, have not so far been fully utilised (newspapers) or are not available. At the same time, this number of records indicates to what extent so far collected documentary evidence for the 16th-19th centuries underestimate the actual numbers of strong winds.

Regardless that both the character of the input material and the nature of the reports themselves change in the 20th century, from the point of view of comparability the same criteria have been used for the inclusion of individual strong winds into groups, considering both the types, and the extent and character of the damage done. Reports about wind calamities relate to 780 places altogether (Fig. 7). A relatively notable number of reports do not mention a particular place; wind damage is related to a broader region, from the whole of the Czech Republic down to individual border mountains, parts of districts, etc. Most reports about strong winds are associated with large towns: Brno (116), Prague (86), Ostrava (45), Jihlava (35), Olomouc (32) and Plzeň (23). Since the Moravian editions of individual newspapers have started to be excerpted, the numbers of gales for Moravian districts are higher than

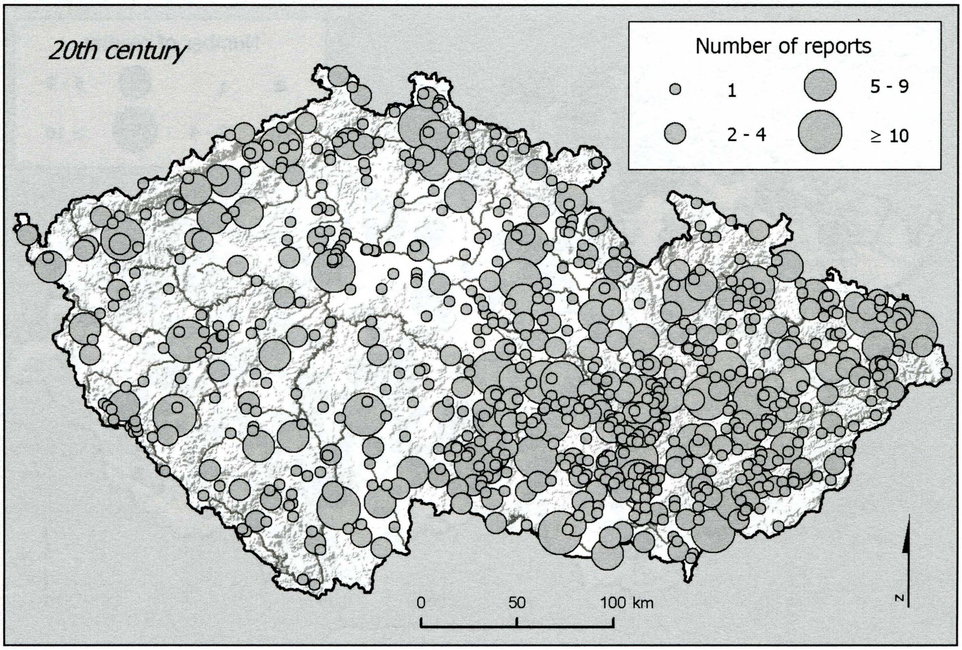

Fig. 7 – Number of strong wind reports recorded for individual places in the territory of Czechia during the 20th century

for districts in Bohemia. This holds above all for the region of the Bohemian-Moravian Highland, the Jeseníky (Mountains) and partly for south-eastern Moravia. Central Bohemia appears to be a region with a lower number of settlements affected by wind calamities. This is probably linked to the fact that primary attention is paid to Prague when wind disaster strikes. Furthermore, a total of 490 strong winds have been quoted for large territorial units such as the border mountain regions.

The spatial distribution of frequency of windstorm records in the territory of the Czech Republic for individual centuries has been also evaluated with the aid of nearest-neighbour analysis and the method of spatial autocorrelation based on calculation of Moran's Index. The results are shown in Table 5.

The distribution of locations for the records of wind damage for the 16th, 17th and 20th century can be characterized as random when evaluated in Moran's I values, whereas the distribution from the 18th and 19th centuries can be classified as clustered. The reason for this lies rather in the quantity and credibility of the data evaluated than in meteorological causes or the physical-geographical predispositions of individual regions within Czechia. The clustered character in the distribution of places with the wind damage is due to a high number of reports from the locations from which the visual daily observations were excerpted. This is the case of observations made by Joseph Dominik Freisler in Jablonné v Podještědí or records made by Anton Lehmann in Noviny pod Ralskem during the first third of the 19th century. Short reports about strong winds prevail in both sources. Due to the specific utterance and subjective evaluations of weather events of authors such type of reports sometimes considerably overestimates the real number of windstorms.

Table 5 – Spatial statistics of places with the strong wind events in Czechia for individual centuries. Statistically significant values for the level of α = 0.05 are in bold types.

Period	Nearest neighbour analysis				Moran's I		
	observed	expected	R statistic	Z – score	observed	expected	Z – score
1500–1599	12 971.2	13 874.2	0.9349	–1.3178	–0.0312	–0.0090	–1.1635
1600–1699	11 992.5	14 069.5	0.8524	**–3.1065**	–0.0164	–0.0083	–0.5395
1700–1799	8 871.3	10 602.0	0.8368	**–4.7361**	0.0101	–0.0044	**2.2160**
1800–1899	6 796.5	8 333.6	0.8156	**–6.9596**	0.0256	–0.0026	**6.1184**
1900–1999	5 324.4	6597.4	0.8071	**–9.9595**	–0.0052	–0.0014	–1.4048

The final results of the nearest neighbour method indicate a clustered character in all except the 16th century. The ability of this method to evaluate the spatial distribution of point patterns is, however, less significant comparing to Moran's I values. The nearest neighbour method does not address the numbers of reports from individual locations but only their mutual distancing. Lower number of documentary evidence about strong winds and gales for 16th century can be the cause of this different evaluation comparing to 17th – 20th centuries.

Characteristics of damage done by gales and windstorms

It is often possible to derive the extent and nature of damage from a great number of reports on historical windstorms. However, the proportion of reports that enable interpretation of such information varies over time. Moreover, it depends largely on changes inherent in certain types of reports and also on individual authors.

In the 18th century, for example, František Jan Vavák from the central Bohemian village of Milčice, mentioned 30 cases of strong winds for the period from 1774 to the end of the 18th century and for a half of them he also gave an account of actual damage. Further, in the memoirs of Jiří Václav Paroubek of Líbeznice (Třebízský 1884-1885), a village north-east of Prague, 21 notes of strong winds for the period 1740-1770 may be found; actual damage to property is mentioned in only seven cases. Further, the highest number of cases for the first third of the 19th century was documented by Joseph Dominik Freisler in his records from Jablonné v Podještědí (182 cases) and by Anton Lehmann for Noviny pod Ralskem (119 cases). In both sources, short reports about strong winds in the 19th century prevail, lacking notes about damage. In general, it can be said that the percentage of reports including data about actual damage caused by winds has grown progressively. This proportion is rather low in cases of daily records from the 19th century and indicates, in particular, an over-estimated number of windstorms.

Figure 8 presents the nature of damage done by strong winds in the 16th century. The nature of individual records may be influenced by the prevailing economic and social situation. In general, damage of various degrees to buildings dominates within the larger settlements in Bohemia. Minor damage to roofs is typical of more solid urban dwellings; cases of total destruction tend to be confined to rural dwellings of lighter structure. A vast number of reports that do not specify the types of damage in southern Moravia is associated with the daily records of Karel Starší of Žerotín.

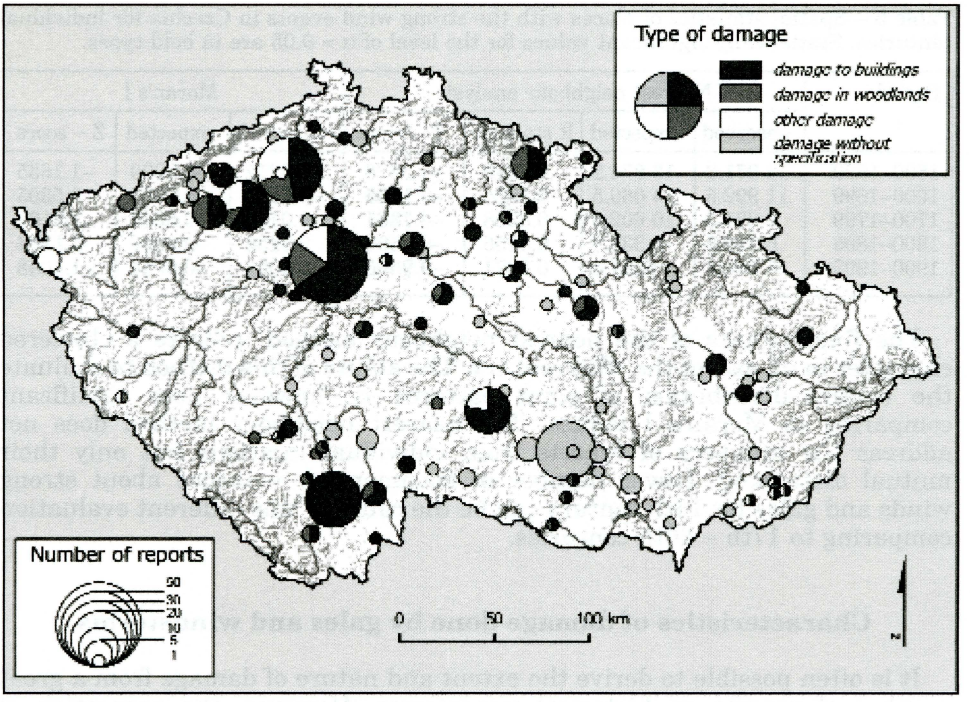

Fig. 8 – The main types of damage caused by strong winds and gales during the 16th century

In more distant periods of the past, records of damage to woodlands and the rural landscape are somewhat rare. This can be deduced from the number of forest calamities (Fig. 9). They are less frequent during the 16th and 17th centuries. According to Vicena et al. (1979), human pressure on forests began in earnest at the beginning of the 18th century. The increased number of historical records mentioning forest calamities in the 18th and 19th centuries might be connected with improved registers of forest management, with the planting of the same-age monocultures and also with the shift of tree species planted in non-indigenous altitudinal environments. Málek (1985) gives a number of reports on the occurrence of the forest calamities resulting from wind in the territory of the Bohemian-Moravian Highland from the 19th and 20th centuries. In a similar way, the historical-climatological database includes information about the damage done by gales and strong winds in the forests surrounding Děčín (North Bohemia) from the first half of the 19th century (Nožička 1962). All these gales fall in the period 1813-1845 and are characterized as spatially extensive windstorms with great damage that certainly affected other places as well.

As can be seen from Figure 9, the increased frequency of wind calamities in forests, with especial reference to the 19th and 20th centuries, is associated with the areas of borderland mountains and also with the area of the Bohemian-Moravian Highland. The greater number of these cases in Moravia when compared with Bohemia is especially due to the quality and amount of excerpted material. In the same way, reports of forest wind calamities in the 19th century may be more common in the middle altitudes of the highlands

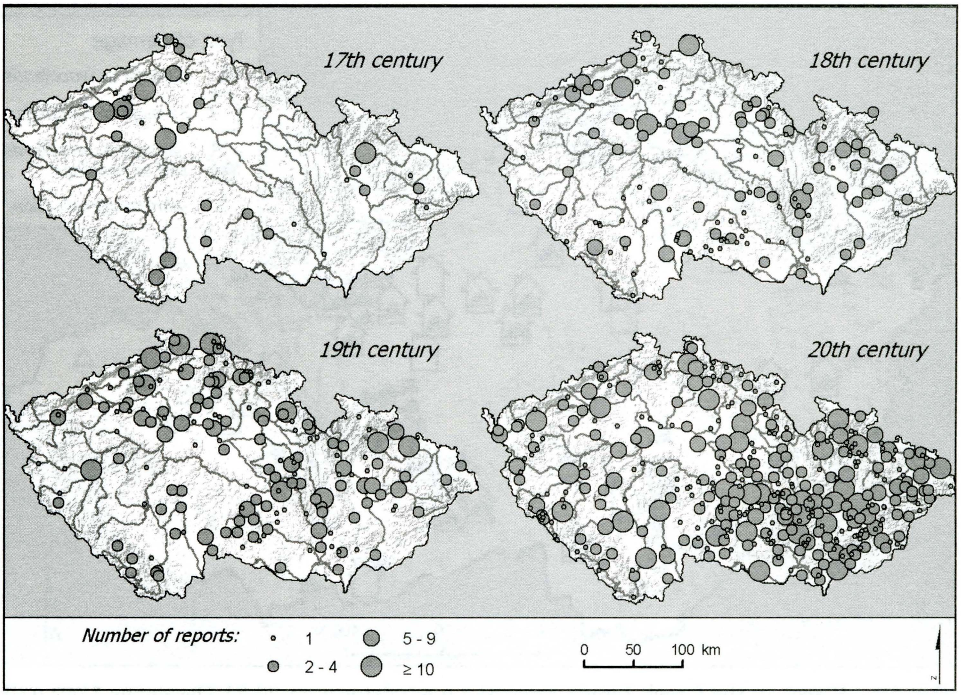

Fig. 9 – Number of reports on wind damage in forests recorded for individual places in the territory of Czechia, 17th – 20th centuries

than in borderland mountains. The lowest number of reports comes from the area of western Bohemia.

Using the database compiled, it is now possible to define the extent and character of damage done by the most significant windstorms, which may be defined as 'the windstorms of the century' (Brázdil and Dobrovolný 2001). In most cases they are winter-type windstorms affecting a great number of locations. These types of storms are often mentioned in records from surrounding countries. One example is a windstorm that affected the territory of the Czech Lands on 20-21 December 1740 (Fig. 10). With respect to both the quantity of records and the number of affected areas this is the best-recorded historical windstorm in the Czech Lands before 1900 AD. The storm was also reported in France, Austria, Germany and Spain. The records state that the windstorm came to the area of Czechia from the north-west. The first gusts were observed in south-west Bohemia in the early-evening hours. It reached central Moravia at around 8.00 pm. The storm lasted the whole night until the following day and caused considerable material damage. As far as can be ascertained, the most affected areas were north-east Bohemia, the Bohemian-Moravian Highland and the Drahanská vrchovina (Highland), but also southern Bohemia and the area of the Jeseníky (Mountains) in North Moravia. Forest areas in particular suffered considerable damage. According to the records of the Šebesta family from Klatovy (Hostaš 1895) 'hrozný vítr ... třetí díl lesů v české zemi zporážel' (i.e., a terrible wind ... uprooted a third part of the forests in the Czech Lands). Brázdil et al. (2004a) list all the affected locations and sources, mentioning the damage during this windstorm. Unfortunately, the sources enable only a small fraction of the data to be found

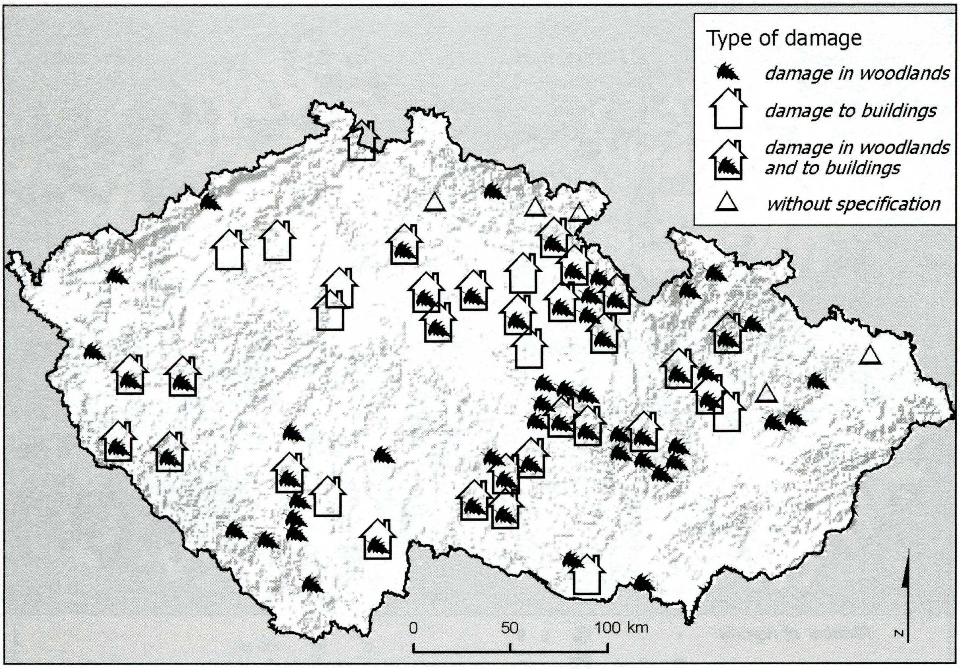

Fig. 10 – Places in the Czech Lands reporting a windstorm on 20-21 December 1740 with the main types of damage

that could help to analyse the meteorological parameters of the windstorm. Luterbacher et al. (2002) carried out a reconstruction of the mean sea level pressure (MSLP) field based on historical climatology data, but only at the monthly level. They define December 1740 as a month with an excessively expressed zonal circulation. This type of circulation is often connected with the occurrence of windstorms in the area of Central Europe (Dobrovolný and Brázdil 2003b). However, for a detailed analysis, the daily MSLP values would be far more valuable than a monthly average. The occurrence of such a gale is far more likely to be connected with a changeover of circulation patterns than with average MSLP conditions. However, a reconstruction of the daily MSLP fields and the position of the main circulation centres derived from the data of historical climatology are not available at present.

Conclusion

The effort that is being put today into the expansion and improvement of the database of historical climatology offers new opportunities for analyses and presentations. The analysis of data in their spatial context often enables, apart from their verification through cross-referencing, their more convenient interpretation. Especially in cases of remarkable extreme weather events it is possible to find data from a great number of locations. When compared with the present instrumental data, the written record sources, in particular, describe the impact of these events together with the extent and nature of the damage. The spatial analysis of wind damage enables the characterization of the most affected localities. However, in most cases, it depends on the reliability of the source material. The spatial analysis of the most significant cases of gales offers the most valuable data. These can assist as analogues for current extreme weather events, towards a better understanding of their origin and also for more effective prevention.

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Shrnutí

PROSTOROVÁ ANALÝZA ŠKOD ZPŮSOBENÝCH SILNÝM VĚTREM A VICHŘICEMI V ČESKÝCH ZEMÍCH OD ROKU 1500

Meteorologické extrémy způsobují každoročně značné materiální škody i ztráty na lidských životech. Právě zvýšený výskyt extrémních projevů počasí se uvádí jako jeden z možných důsledků globální změny klimatu (Houghton et al. 2001). Protože data o meteorologických extrémech z instrumentálního období jsou z časového hlediska omezena, je třeba hledat alternativní zdroje informací o těchto jevech. K takovýmto zdrojům pro před instrumentální období patří mimo jiné údaje z dokumentárních pramenů. Patří sem zápisy v análech, kronikách, pamětech, dále vizuální denní pozorování počasí, záznamy ekonomické povahy, zprávy v novinách, osobní korespondence apod. Sběrem, analýzou a interpretací těchto tzv. proxy–dat se zabývá historická klimatologie.

Jestliže zpočátku byl v historické klimatologii akcentován především časový aspekt zpráv a byly sestavovány různé chronologie, rostoucí množství a kvalita shromážděných údajů umožňuje v současné době analyzovat i vlastnosti prostorového rozsahu zaznamenaných zpráv.

Předložený příspěvek se zabývá prostorovou analýzou zpráv o škodách způsobených silným větrem a vichřicemi v českých zemích od r. 1500. Vstupním materiálem jsou údaje z databáze historické klimatologie Geografického ústavu přírodovědecké fakulty Masarykovy Univerzity v Brně. Zprávy o výskytu vichřic obsahují vedle vlastního popisu události také více či méně přesné údaje o době výskytu, postižených lokalitách či o charakteru způsobených škod. Podle těchto prvotních údajů byl každý záznam v databázi dále kategorizován z hlediska typu události (tab. 1), rozsahu (tab. 2) a charakteru způsobených škod (tab. 3). Při vlastní interpretaci zpráv je nutné zohledňovat jejich popisný (kvalitativní) charakter či značnou míru subjektivismu autora zprávy, který se ve většině případů věnoval více popisu následků vichřic než jevu samotnému.

Přes naznačené problémy byl sestaven rozsáhlý soubor, který umožňuje hodnotit mimo jiné prostorové rozložení postižených lokalit. K tomuto hodnocení byly využity nástroje ArcGIS, za pomoci kterých byly sestaveny kartodiagramy a kterými bylo také charakterizováno prostorové rozložení míst se škodami způsobenými vichřicemi. K tomuto účelu bylo využito dvou metod – metody nejbližšího souseda a metody výpočtu Moranova indexu prostorové autokorelace (Lee a Wong 2001). Jestliže první metoda hodnotí pouze vzdálenost bodů,

druhá metoda uvažuje v každém analyzovaném bodě i počet zjištěných událostí (případů škod větrem). Obě metody umožňují porovnat konkrétní rozložení lokalit s určitým druhem události s teoretickými typy rozložení. Tato teoretická rozložení bodů v prostoru jsou definována jako rozložení pravidelné, náhodné či shlukové.

Vlastní analýza prostorového rozložení postižených lokalit byla provedena pro jednotlivá století (obr. 3 až 7) a tabulka 4 shrnuje počty zjištěných případů vichřic. Z analýzy je patrné, že především pro starší období se v sestavených mapách odráží spíše množství a kvalita zpráv něž predispozice míst vůči škodám větrem. Lokality často odrážejí působiště autora zprávy. Proto se zvýšené počty zpráv vztahují k velkým městům a nebo k lokalitám, ze kterých byly k dispozici vizuální denní záznamy o počasí.

Prostorové rozložení lokalit postižených škodami silným větrem hodnocené Moranovým indexem je charakterizováno jako náhodné pro 16., 17. a 20. století, zbývající dvě století jsou charakterizována spíše rozložením shlukovým. Metodou nejbližšího souseda jsou rozložení pro všechna století s výjimkou 16. charakterizována jako shluková.

Ze sestavených map je patrný postupně se měnící charakter zpráv o škodách způsobených větrem. Zprávy o větrných lesních kalamitách jsou poměrně málo četné pro 16. a 17. století, výrazněji se začínají objevovat až v 18. století. To může souviset například se zlepšujícími se způsoby evidence v lesním hospodářství na jednotlivých panstvích či s vysazováním stejnověkých monokultur náchylnějších větrným kalamitám.

Především pro největší vichřice, které postihly území českých zemí v posledních 500 letech, lze nalézt v historických pramenech velké množství informací z mnoha lokalit. Dokumentární prameny tak často umožňují charakterizovat rozsah a charakter způsobených škod, ale i průběh vlastní události. Případem vichřice, která je nejhojněji popsána v historických zprávách, je ta z 20. a 21. prosince 1740 (obr. 10). Uvedená vichřice byla zaznamenána i v okolních zemích a podle některých zpráv zničila celou jednu třetinu lesů v českých zemích.

Úsilí vložené do rozšiřování a zkvalitňování databáze historicko–klimatologických údajů v současné době přináší nové možnosti analýzy i prezentace dat. Prostorová analýza míst se škodami větrem sice dovoluje charakterizovat oblasti zvýšeného výskytu, ve většině případů však souvisí s kvalitou vstupního materiálu. Velmi cenné informace přináší prostorová analýza největších případů vichřic. Ty mohou sloužit jako analogony pro současné případy extrémních projevů počasí, pro lepší porozumění příčin jejich vzniku a též k efektivnější ochraně před jejich následky.

Obr. 1 – Území České republiky s označením historických zemí
Obr. 2 – Titulní strana moralistického spisu kněze Víta Jakeše Přerovského sepsaného jako reakce na ničivou vichřici, která postihla české země 28. prosince 1612 (Brázdil et al. 2004a)
Obr. 3 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 16. století
Obr. 4 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 17. století
Obr. 5 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 18. století
Obr. 6 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 19. století
Obr. 7 – Počty případů silného větru zaznamenaných pro jednotlivá místa na území Česka v průběhu 20. století
Obr. 8 – Hlavní typy škod způsobené silnými větry a vichřicemi v průběhu 16. století. Hlavní typy: škody na budovách, lesích, ostatní, bez specifikace.
Obr. 9 – Počty zpráv zaznamenávajících škody větrem v lesích pro jednotlivé lokality v českých zemích v průběhu 17. až 20. století
Obr. 10 – Místa v Česku zaznamenávající škody větrem při vichřici z 20.–21. prosince 1740 s hlavními typy škod

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JAROMÍR KOLEJKA, JIŘÍ ŽALOUDÍK

MONITORING OF CZECH LANDSCAPE DEVELOPMENT USING GIS AND REMOTE SENSING

J. Kolejka, J. Žaloudík: *Monitoring of Czech Landscape Development Using GIS and Remote Sensing.* – Geografie–Sborník ČGS, 111, 1, pp. 70–91 (2006). – Historical studies of landscape represent a part of traditional research in Czech geography. Modern technologies allow carrying out more accurate, more detail and more extended research actions. Methodically the historical landscape studies are supported with rich territorial databases of maps and aerial/satellite imagery. Examples presented in the paper document typical ways of GIS and RS applications starting with digital multitemporal imagery analysis to the utilizing of digital landscape model as fully integrated and sophisticated database supporting landscape analysis with respect to both natural and social area features.
KEY WORDS: landscape history – digital monitoring techniques – GIS and remote sensing – digital landscape model.

1. Introduction

Landscape is a multi-dimensional geographical object. One of its dimensions harmoniously blending with the other landscape qualities is time. In terms of forming landscape, man represents a significant factor. The role of man in Czech landscape has undergone dramatic changes related to the area, character and intensity of such an impact. The contemporary landscape is always a product of a co-operation of natural and anthropogenous factors working in a wide range of mutual interactions. The final outcome is a colourful mosaic of individual forms of landscape cover and manifold types of cultural landscape covering the Czech Republic.

Historical changes in land use have always been a popular subject of geographical and landscape-ecological research. However, geoinformation technologies have enabled people to carry out the research multilaterally, efficiently, to integrate a number of differing data and to do it practically upon request. Moreover, if we have an intimate knowledge of the given area's natural features we can reveal whether the changes' motive can also be constituted by the site's .different qualities. From a time series of changes we can then deduce the types of land use changes a given type of environment has undergone. Analogically, we can expect a similar development in other areas, which is interesting for landscape planning. While remote sensing and the technologies of global positioning systems are alongside cartography important sources of data, the technologies of geographical information systems serve as a tool for their pre-processing, saving, thematic evaluation and, most importantly, for acquiring new information on the area.

2. Sources of the dynamics and development of Czech landscape

Czech cultural landscape has been undergoing changes which reflect the economic and social events while respecting the area's natural determinants. It is a generally known fact that the landscape character is influenced by a wide range of factors. Among the natural agents are the global and local climates, macro- and meso-relief (position within the general layout of the area's relief and the position on the specific relief shape, including its gradient, exposure and altitude), the geological background, soil (the presence of fertile or barren soils), humidity conditions (proximity of a water plane, lack or surplus of humidity), local sources of free or fixed energy (wind, running water, biomass or fossil fuels, dramatic soil movements, including avalanches), biota character (autochtonous plant communities, present species of beneficial or invasive plants and animals) and others.

Among other things, economic conditions are determined by the area's position in relation to the local, regional or higher authorities, the current market situation (upturn or decline), prices of land, available workforce (its numbers, qualifications, work morale), raw materials and natural resources availability, relation to technical or communication infrastructure, the division of land into lots, taxation and others.

Socio-political factors are asserted through cultural and ideological influences, such as the impact of national and local traditions, population density and organization, people's education and religion, wealth, mentality, direct and indirect influence of the state and its authorities, people's standard of living and their leisure time, lifestyle, family character and others.

Indisputably, all these factors play a role in the development of cultural landscape. Yet, the ratio of their mutual interaction can vary from site to site. In most cases natural conditions have dominant impact, predominantly the climate and relief as natural parameters which cannot be influenced by people. Therefore it is the economic and human factors which greatly vary in their effect and mutual combinations, and which can respect the influence of natural background in different ways. This plurality has lead to the great diversity of world's, Europe's and present Czech cultural landscapes.

Owing to long-term directing of landscape processes towards production and other purpose-oriented roles the landscape systems structure has adapted both in spatial and functional context. Undesirable supraliminal reactions of landscape systems can also occur (such as erosion resulting from eliminating erosion control structures of small-scale farming).

At present globalization and its outcomes confront us in different forms, have impact on the everyday life of ordinary people and are directly reflected in the cultural landscape development in Czechia.

With regard to the development of urbanized landscape, our concepts are based on the fast developing network of super- and hypermarkets mushrooming along the main access roads and their crossroads, warehouses and production halls in industrial parks and their vicinities, towns slicing off the originally agricultural landscape into colonies of family houses and mini housing estates. However, the real processes taking place in agricultural landscape are not so apparent. It is true that there is a growing number of areas abandoned by large-scale farming and some industrial and mining activities. Roads are constructed and modernized. Many country settlements are subject to building development, at least in places of positive economic impact. We have almost got used to critical opinions frequently expressed on the past and present changes of our landscape. Amateur conservationist movements often do not spare an opportunity to express their criticism and in many cases it is difficult to contradict them. There is no denying that landscapes all over the world are going through both deliberate and undesirable negative changes. One of the objectives of this study is to demonstrate the traditional methods and technologies used in Czechia in order to effectively document historical changes in land use and to evaluate them.

3. Analogue geo-spatial data on land use in the past and at present

In the course of the last four hundred years a number of cartographic works documenting the contemporary situation in land use have originated in the

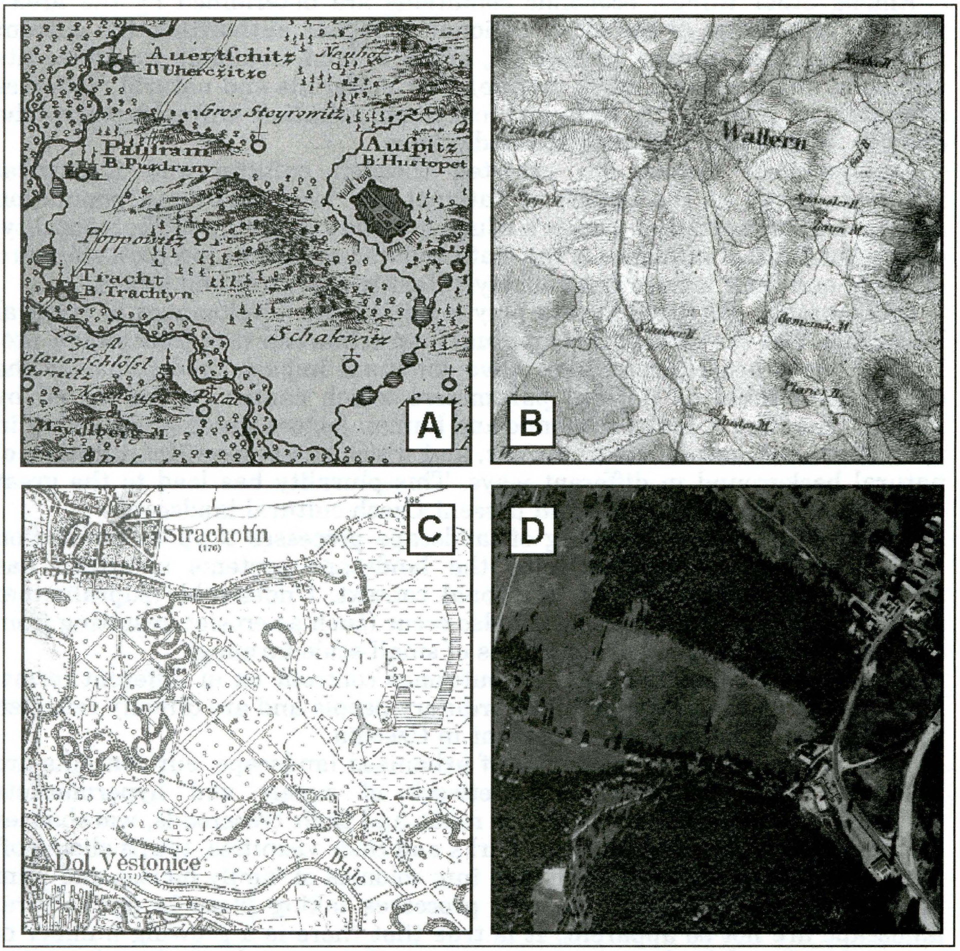

Fig.1 – Oldest detailed cover map of land use in Czechia – Müller's map (A), Example of geo-referenced map list from the Second Military Survey (B), Re-ambulated map with a detailed representation of land use in the 1920s (C), Black and white orthophotomap processed in GIS (D)

area covering today's Czechia. In contrast to the period following the end of Middle Ages, when maps of mostly small scales presented a very rough layout of main settlement, forests and water planes (objects), Baroque times introduced a relatively exact documentation of some estates or their parts, usually gardens or manors. Maps covering a state's whole area were not drawn until the 18th century. In 1720 Müller's map of Bohemia was printed in the approximate scale of 1 : 132 000, well recording the layout of forests and fishponds (Fig. 1A). In the second half of the same century (1764–83) the so-called First Military (Joseph's) Mapping was carried out in a similar scale (approximately 1 : 144 000). Very exact data of very good quality were acquired through the cadastral measurements of the so-called stabile cadastre in 1824–46 which yielded map documentation of land use in the scale of 1 : 2 880. These data were then used to complete maps of the so-called Second Military (Franciscus') Mapping (1836–52) in the scale 1 : 28 800 (Fig. 1B). In the 1870s maps of the renewed cadastre were made in the scale of 1 : 2 880. At the same time the so-called Third Military Mapping was carried out in the scale 1 : 25 000 (1876–80). From these data special topographic maps in the scale of 1 : 75 000 and general map of 1 : 200 000 were derived.

Shortly after the independent Czechoslovakia was established in 1918, re-ambulation of topographic maps in the scale of 1 : 25 000 was carried out together with complementing them with contour line hypsography (in place of shading – Fig. 1C). During World War II topographic measuring in system S–42 (Gauss-Krüger) was carried out. Starting with the 1950s, topographic maps in the scales of 1 : 10 000, 1 : 25 000, 1 : 50 000, 1 : 100 000, 1 : 200 000 and 1 : 500 000 were made in the co-ordinate system S–JTSK (Křovák). They were created for public use (with certain limitations) while reliably recording the contemporary land use. At present these maps are subject to periodical renewal and systematic digitalizing (and vectorizing). Another source of cartographic information are similar maps in the S-42 system produced by the former Czechoslovak People's Army, later Czech Army (1 : 25 000 – 1 : 500 000). Starting with the 1930s topographic maps have been renewed and complemented with the help of aerial surveying, initially black and white and as of the 1970s coloured. Since the late 1960s photographic records of the territory coming from Soviet satellites (Soyuz, KFA, KATE) have been available. Majority of analogue map and image data from the past have been recently transformed into digital raster form, the reason being more efficient archiving, protection of blueprints and most importantly to make them more accessible to users.

4. Digital geo-spatial data on land use in the past and at present

All the sheets of Müller's and the so-called military mappings from the 18th and 19th centuries have been recently scanned and rectified and are now accessible to the public on the Internet (http://oldmaps.geolab.cz). Majority of historical aerial surveys archived in Czechia are also being digitalized. Maps of the stabile cadastre from the first half of the 19th century are gradually digitalized. Czech Office for Surveying, Mapping and Cadastre is also transforming its archives of topographic maps into digital form. General public has had access to the files of ZABAGED 1 and 2. The first one contains a vectorized content of topographic maps of the whole Czechia in the S–JTSK system in the scale of 1 : 10 000, the second one presents only one colour raster layer or sectional black and white layers of the same map file. The Military Institute of Geography and Meteorology in Dobruška offers vectorized layers of topographic maps in the scales of 1 : 25 000 (DMÚ 25) and 1 : 200 000 (DMÚ 200). These maps were mostly made with the help of photogrammetry in the 1990s, in some cases their content is of a later date. In these maps one can track down some of the main categories of land use in a given time period.

In the category of satellite data we have scanner (mostly multi-spectral) data from the Landsat satellites (since the mid-1970s), SPOT (since the 1980s), Kosmos (since the early 1980s) and a number of other satellites, including the high-definition data from recent times (Ikonos, Quick Bird and others).

Standard orto-rectified digital aerial surveying data have been available since the end of the 20th century (Fig.1 D). Colour digital orto-photomaps of the entire territory of the Czech Republic have been available since 2004.

The output of digital historic database of land use in Czechia in the past is represented by cartograms depicting the structure of land use in individual cadastre areas of Czechia based on 19th and 20th century censi (Bičík, Kupková 2001). These data in different combinations have also been used by Czech scholars for history-geographic studies. These have been implementing the GIS technology since mid-1980s and as of the 1990s have been using predominantly the software produced by ESRI.

5. Orientation of the land use studies

The process of anthropogenic landscape development lacks the typical auto-regulatory processes inherent in nature where natural landscape structure becomes an integral product of interacting local, regional and global factors which respect the laws of evolution and stability.

The emergence of human society brought about new environmental evolution agents which observe some auto-regulatory trends only on certain conditions. Viewed from this perspective, human history appears to be a battle of one species with its environment (Dorst 1974). Considering the fact that through landscape "cultivation" people created their own environment suitable for living, working and relaxing, history of mankind becomes a long-term process of creating a man-made environment while requiring enormous labour, time, material, energy, financial, and intellectual costs.

As the distance between people and nature continued to grow, balance between the factors of "destruction" and "creation" had to be maintained with the help of further spending.

The degree of depth or comprehensiveness of a landscape change and its study can be classified with regard to the localization exactness of the identified change (Fig. 2):

1. Chronological localization – registered change is related to a given date or period.
2. Statistic localization – registered change is related to a standard territorial statistic unit.
3. Geometric localization – identified change is related to a point, line or area described by geographic, metric or other positional coordinates.
4. Geographic localization – each individual change, groups or classes of changes are related to an individual type of geographic environment.

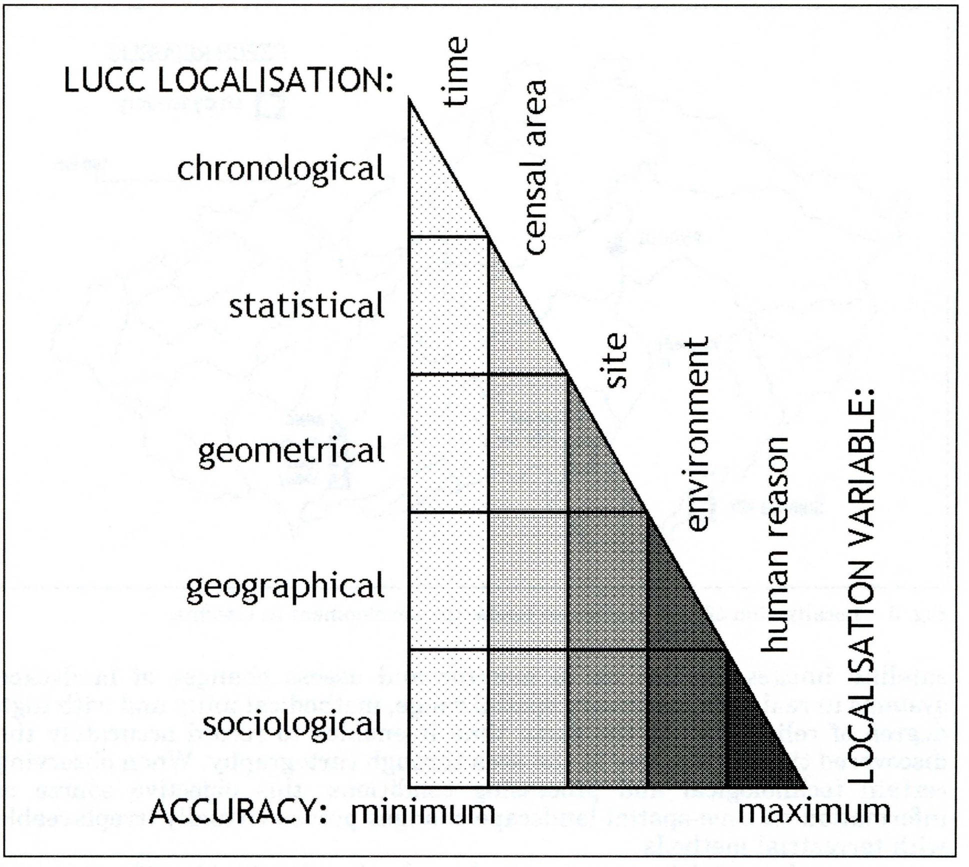

Fig. 2 – Relations between the comprehensiveness of land use and cover changes studies, the exactness of changes localization and the properties of a given change

5. Sociological localization – each individual change is localized and explained within the given social and economic context.

The most exact research brings the most reliable results and as such is the primary objective of many projects which must be completed in the shortest time possible. Such a research provides good answers to the questions of "What? When? Where and why?". If all these questions are properly answered, then development trends and regularities of landscape development are revealed. The knowledge of trends and development regularities are indispensable for forecasts of changes in landscape and its use. Selected results of studies on adequate exactness levels of landscape changes are listed below.

6. Methodical samples of remote sensing data and GIS technology uses in landscape changes monitoring

The methods of remote sensing are useful and effective precisely in the study of landscape objects and phenomena dynamics. The use of aerial and

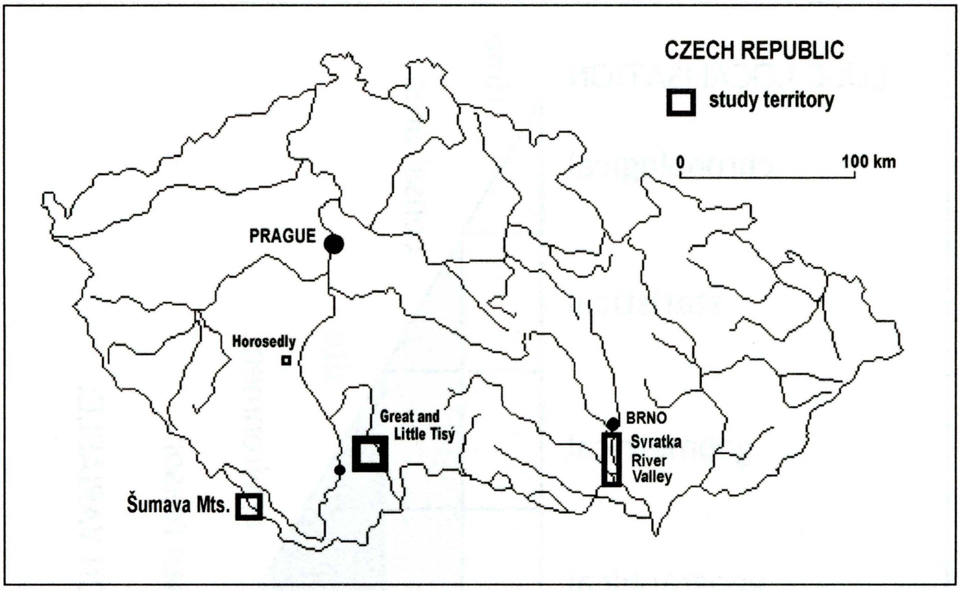

Fig. 3 – Localization of case studies on landscape development in Czechia

satellite images enables us to monitor and assess changes of landscape systems in real time, necessary spatial range, methodical unity and with high degree of reliability. At the same time it enables to record accurately the discovered time differences in the area through cartography. When observing certain technological and processing conditions, this objective source of information on time-spatial landscape changes proves virtually irreplaceable with terrestrial methods.

Large-scale aerial images are used predominantly for identification and exact localization of required object in landscape (usually through visual interpretation). However, they are equally useful in thematic categorization and quantification of spatial relations in the area. Recently they have been rivaled (in terms of technology, not prices) by satellite images of high and medium resolution. As for the implemented processing technologies, both simple optical-analogue methods of data interpretation (visual comparison and assessment of shapes, texture and location of the depicted objects) and digital methods of processing and assessment of remote sensing data (exact geometric corrections, creation of orthophotos, digitalization of objects' thematic layers and their quantitative analysis or modeling) find productive use in the work of landscape ecologists and geographers. The choice of used methods and data can be tailored to the desired purpose (needs and objectives of the project), financial limits and technical equipment of their users.

The contemporary modern technology of GIS has a virtually unlimited processing and presentation potential. It provides an expedient extension of remote sensing possibilities. The included methodical outline presenting structurally and functionally different model areas in Czechia (Fig. 3) demonstrates our experience with implementing remote sensing and GIS technologies in the detection and study of landscape changes.

6. 1 Aerial imagery – monitoring and analysis of agricultural landscape changes

The turning point in radical changes of Czech landscape in the 20th century was the time of collectivization launched in the mid-1950s. In the first stage of land consolidation plots of land were usually designed in such a way so that not to disturb hydraulic amelioration works and erosion control and so that replotting and changes in land use did not disturb the contemporary road network. After 1958 synoptic projects of land consolidation were drawn with the objective to manage the newly organized land resources with the help of enlarging tracts of land and constructing a new road and drainage network. As of 1973 all work on this type of synoptic land consolidation in Czechoslovakia was halted. Focus shifted to the processing of plans concerning the development, concentration and specialization of agricultural production.

Selected methods of monitoring and assessment of the condition and changes of landscape diversity (or biodiversity – eco-stabilization elements and components of landscape) with the help of remote sensing and GIS are illustrated on the case of an agricultural area subject to intensive farming in the vicinity of Horosedly (reference area covering 7.3 sq km – Písek region, South Bohemia). The detected changes were analyzed in the periods before collectivization and shortly before the comeback of market economy in the last century (Žaloudík, Hanousková, Kolejka 2003).

Methods of landscape ecological research were implemented in the following areas:

- collecting and inventory of basic data and information on the area
- field reconnaissance and mapping
- assessment of landscape diversity (its forms, structure and changes).

The digital image processing was done with the help of EASI/PACE software from PCI Canada, the editing and statistical analysis of GIS data was processed in ArcView produced by ESRI. The data analysis drew on panchromatic aerial photographs from August 29, 1952 and June 14, 1988 (obtained in the form of positive contact photocopies in the scale of 1 : 23 000) and on a number of thematic maps. The processing itself encompassed a wide range of different methodic procedures of remote sensing and GIS (e.g. digitalization and geometric correction of photographs, image slicing, visual and semi-automated interpretation, multi-temporal synthesis, editing of linear and polygonal layers, post-classification comparison, identification of the area's invariants, multi-criteria analysis and verification of the expert assessment). In the course of the final identification and assessment of the studied landscape changes the method of superposition of developed component thematic masks (vegetation, roads, differentiation of agricultural areas) was implemented to determine the temporary-spatial differences or concord of the studied objects (comparison was done with the help of logical operations with bitmaps – their difference and intersection).

The implemented methodic procedures identified and assessed the following categories of interest objects: plots of agricultural land and the means of their differentiation (plot arrangement), vegetation cover (forests and scattered vegetation), road network (roads, field or forest trails), interaction elements and significant landscape ecosystems (from the perspective of territorial systems of ecological stability). The discovered facts can be summarized in the following categories:

6. 1. 1 Assessment of changes in land allotment

The average differentiation ratio of the studied area was approximately 12 times higher in analysed period (the total ratio of plots being 800:65), which means that viewed from this perspective the diversity of contemporary landscape has diminished. The average size of historical plots in the given area was approximately 0.74 ha, at present it is approximately 9.14 ha. Exception to the rule can be traced only in the urban areas (crofts, gardens and orchards) or in areas of the hardly accessible river Skalice floodplain which in the period of 1952-1988 did not significantly change in terms of size, shape or location (approx. 40 very small sectional plots).

Historical layout and land/plot orientation in landscape respected the terrain and soil conditions of the area (compare the elongation of tillage routes along the contour line), humidity conditions (connection to the

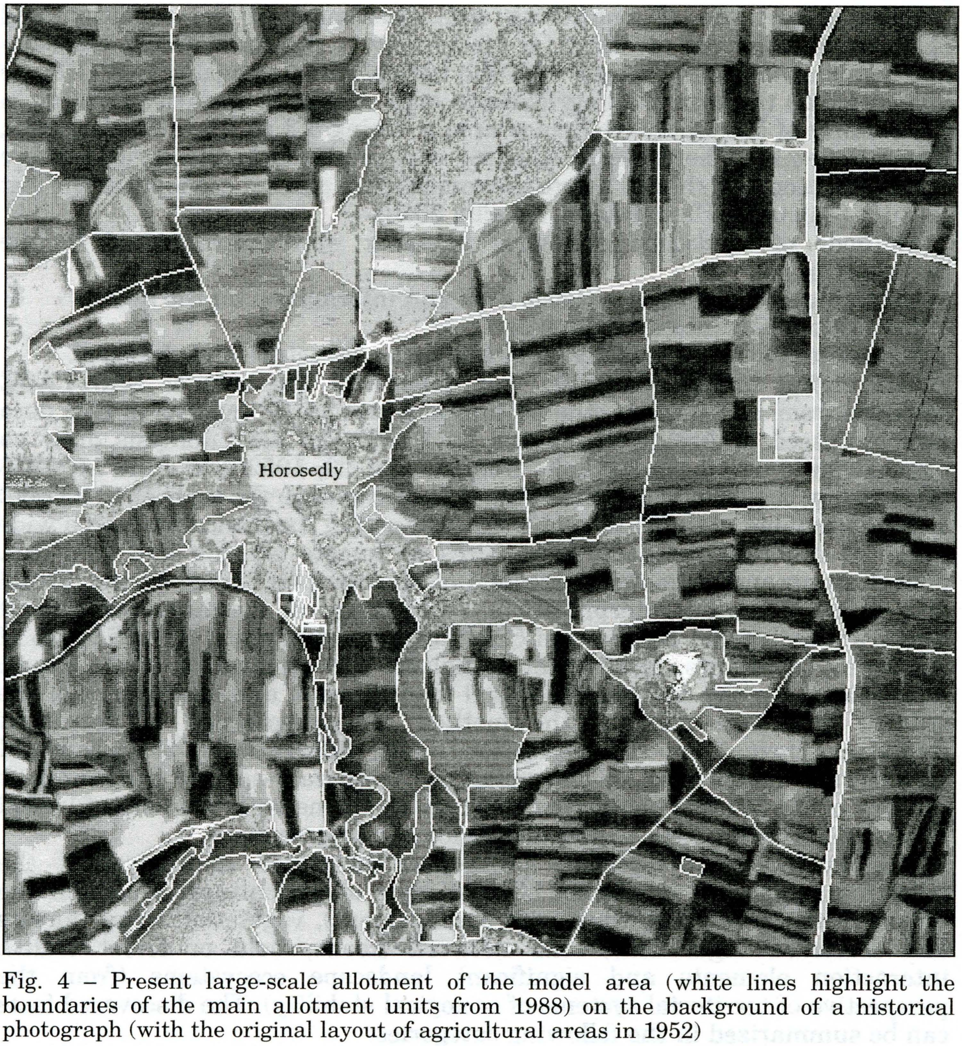

Fig. 4 – Present large-scale allotment of the model area (white lines highlight the boundaries of the main allotment units from 1988) on the background of a historical photograph (with the original layout of agricultural areas in 1952)

amelioration channels - old irrigation and drainage systems) and socio-economic conditions of the area (settlement conditions, types of transport and small-scale agricultural production – with the need to bring plots as close as possible to the places of processing and storage).

In contrast, the modern landscape structure of the 1980s and its large-scale allotment virtually lack any sense of adhering to the general principles of practical differentiation of plots from the perspective of land resources protection (erosion, humidity conditions), the conservation of landscape stability (fields and ecosystems), biodiversity development, area's barrier-free accessibility or the diversity of the landscape mosaic (including the perception of the landscape character). Today the measures aimed at rectification of this situation are generally exerted secondarily via supplementary and restoration measures in landscape (Fig. 4).

6. 1. 2 Assessment of vegetation cover changes

The executed analysis focused mainly on the presence of continuous forests, scattered vegetation both in open landscape (hedgerows, solitary trees, bank vegetation, alleys along roads and others) and in settlements (intravillan wood species vegetation in parks or public gardens).

The analysis of total differences of forests and scattered vegetation in the model area (increase and decrease in the period of 1952–1988) via implementing synoptic and partial masks of the tree-shrub vegetation revealed that the total vegetation area and the occurrence frequency of its functional eco-stabilization forms has significantly increased in the agricultural area.

In 1988 the area of wood species vegetation exceeded the incipient situation in 1952 by 17 per cent (11.4 ha), while in open agricultural landscape the increase was significantly higher (by up to 53 per cent, i.e. 9.4 ha). This situation can be explained by forest restoration of certain areas not suitable for agricultural use (forestation) or by natural succession development in unused or inaccessible parts of the area (waterlogged areas, forest edges, hedgerows and ditches, deserted quarries) which encompassed even forests (development of unbroken young growth or natural seeding). Plots of land which became marginal in terms of large-scale agricultural production reached a higher stage of structural differentiation and more advanced succession stages of development in many places. They developed both shrub and tree layers, which gives evidence of a long-term biota stabilization in the area.

A slight decrease in tree vegetation can be traced only in the case of local occurrence of settlement greenery (parks and gardens) and due to artificial intervention of people in some forest stands (exploitable forest management, higher ratio of clear felling). A leap (decrease) in tree vegetation are then apparent along road network (as a result of alley felling in the course of widening or construction of roads, as a result of eliminating old roads or others).

From the ecological and landscape perspective it is interesting to assess the condition and development of those landscape ecosystems which enable to conserve biodiversity and the positive development of vegetation structures stabilizing the landscape even in the generally unfavourable conditions of an area subject to intensive farming. The ratio between ecosystems with good auto-regulatory abilities and the less stable vegetation components of landscape is 4.5:1 (in 1988), respectively 3.55:1 (in 1952). The mutual ratio between the present and historical extent of such ecosystem areas is 1.23:1, which constitutes a slightly positive increase.

6. 1. 3 Assessment of changes in the area's accessibility

The area's accessibility was analyzed in terms of the existing (former or present) network of identifiable spatial lines which can be used for transport or pedestrian traffic in the landscape (roads, railroads, field and forest trails, dried-up amelioration channels or ditches).

In order to compare the level of the area's overall accessibility, the total length and density or these lines and their spatial layout must be taken into account (type and regularity of the network, its prevailing orientation), possibly the existence of important spatial barriers. In 1952 roads create a relatively dense regular network (without basic directional restrictions of accessibility and barriers). In 1952 the length of road network in the area was 59.7 km (density 8.2 km/sq km). In 1988 it was 32.2 km (4.4 km/sq km), which is approximately 46 per cent less in comparison to the initial situation.

A complex assessment and synthesis of data acquired from aerial photograph and map analysis enabled us to analyze the general condition and development of the studied agricultural area's landscape structure (its diversity and stability). It became apparent that exact qualitative-quantitative data from remote sensing contribute greatly not only to correct purpose-driven interpretation of landscape structures (the character and layout of their elements and components), but also facilitate a better formulation of optimization proposals for ecological landscape management (when assessing relevant interactions and changes in landscape). Introduction of geo-information methods into the traditional exploration of landscape objects and phenomena, and the use of multi-temporal image data in particular, not only considerably enhance the informative value of a data collection but also conveniently widen the overall information scope, objectivity and realization possibilities of a given landscape changes research.

6. 2 Satellite images – monitoring of changes in protected nature areas

The main objective of the case study of National Nature Reserve (NNR) Velký and Malý Tisý (Žaloudík, Šíma, Kolejka, 2005) was to detect changes in the structure and condition of pond ecosystems and to outline ways of land use by using the method of digital processing and remote sensing data interpretation. The reference area for localizing the identified landscape changes was the reserve's vicinity, defined as the catchment area of the studied pond system covering 19.1 sq km.

As digital data sources were used satellite records from Landsat 5 – Thematic Mapper from October 26, 1988 and July 10, 1995 (the terrestrial pixel resolution 30x30 m). The records came as identical sections of the image scene so that the wider interest area of NNR was covered by qualitatively homogenous satellite information from all the seven spectral channels.

Apart from distinct local changes in the development of the protected pond system (long-term changes in the extent and distribution of the water bodies and littoral areas were discovered on 13 per cent of the reserve's area with the help of aerial photographs from 1949, 1967 and 1995) significant recent

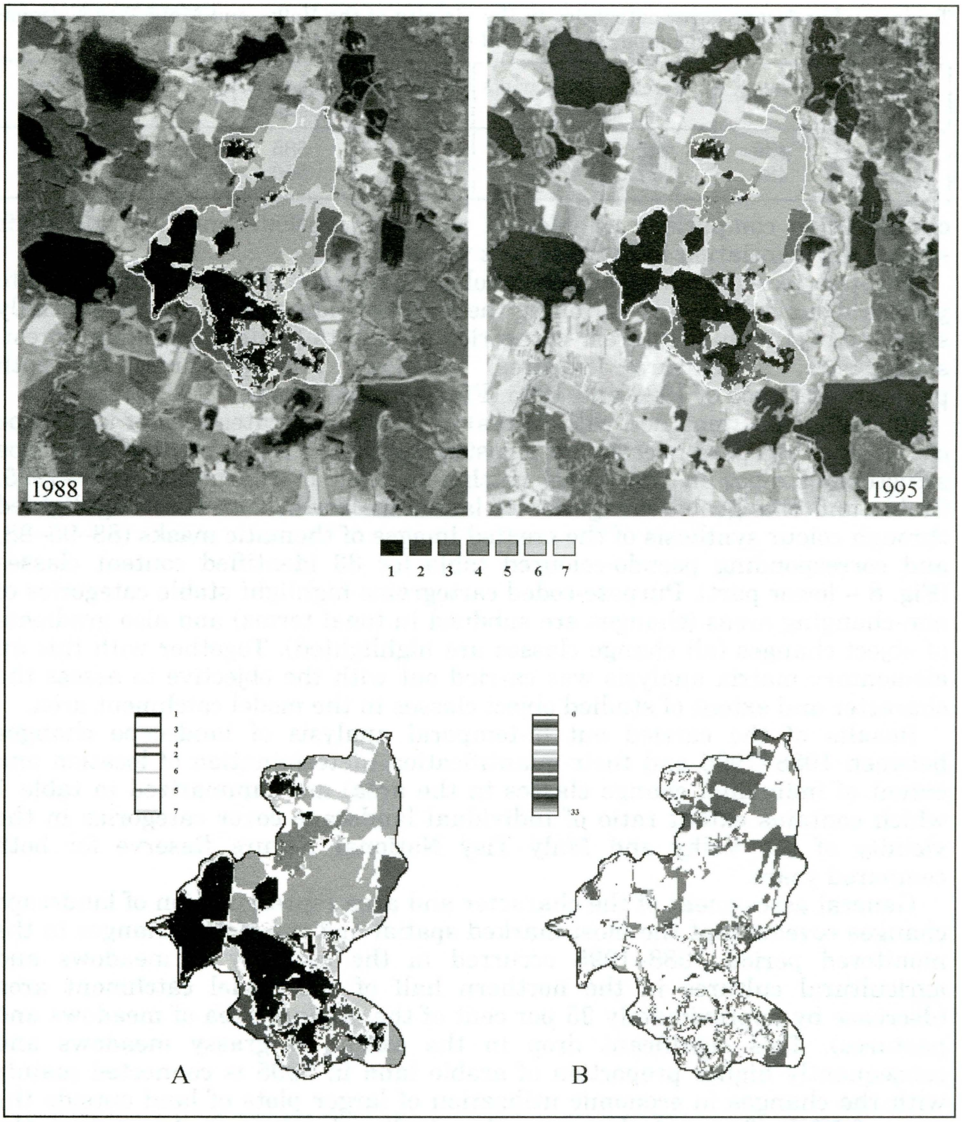

Fig. 5 – Condition and changes of land cover in the protected area and vicinity of the NNR Velký and Malý Tisý on satellite images from 1988 and 1995. Upper part: Differentiation of land cover of the distant surroundings of the National Nature Reserve Velký and Malý Tisý on satellite images from 1988 and 1995, Legend: 1 – water, 2 – wetlands, 3 – forest, 4 – settlements, 5 – fields, 6 – meadows and pastures, 7 – others; lower part: Post-classification assessment of land cover changes between 1988–1995, A – coding of stable object categories, B – coding of the change gradient.

changes affected also the vicinity of the NNR of Velký and Malý Tisý. This can be documented by analysing available satellite images from 1998 and 1995 in all the catchment area of interest (Fig. 5).

The analysis of time changes of the model area's structure (landscape cover and land use) encompassed a two-stage process of detection and post-

Table 1 – Landscape cover categories in the vicinity of the Velký and Malý Tisý National Nature Reserve for both compared years (all entries are in hectares)

Year	Water	Forest	Settlements	Wetlands	Meadows, pastures	Fields	Other
1998 1995	439 487	242 227	74 74	49 52	385 250	548 692	173 128

classification comparison of selected object categories' condition and their spatial differentiation in the reserve's vicinity.

Through transforming optimized colour syntheses of satellite images into pseudocolour tables and through their thresholding we at first partially separated individual interest categories of objects (water, wetlands, forest, settlements, agricultural cultures, meadows and pastures) for both photograph terms of 1988 and 1995 (Fig. 8 – upper part).

Raster masks (modified with filters) for individual categories of landscape cover were then used to carry out a post-classification assessment of landscape structure changes in the model catchment area in the period 1988–1995. Stable and changeable categories of landscape cover were then highlighted through colour synthesis of the created images of thematic masks (88–95–88) and corresponding pseudo-coloured table for 33 identified content classes (Fig. 8 – lower part). Purpose-coded cartograms highlight stable categories of non-changing areas (changes are subdued in tonal terms) and also gradients of object changes (all change classes are highlighted). Together with this an elementary matrix analysis was carried out with the objective to assess the character and extent of studied object classes in the model catchment area.

Results of the carried out bi-temporal analysis of landscape changes between 1988–1995 and their quantification (determination of location and extent of individual change classes in the area) are summarized in table 1 which contains extent ratio of individual landscape cover categories in the vicinity of the Velký and Malý Tisý National Nature Reserve for both compared years.

General assessment of the character and area representation of landscape changes reveals that the most marked spatial and functional changes in the monitored period 1988–1995 occurred in the category of meadows and agricultural cultures in the northern half of the model catchment area (decrease by approximately 35 per cent of the original area of meadows and pastures). This significant drop in the extent of grassy meadows and consequently higher proportion of arable land in 1995 is connected mainly with the changes in economic utilization of larger plots of land outside the area of NNR (frequent changing of agricultural cultures). Apart from the "settlements" category, also wetland zones remained virtually unchanged (despite their drying-up and overgrowing with shrubs). Small local changes can also be detected in object categories "forest" and "scattered vegetation" (slight decrease in trees in favour of other objects) and also in "water objects" where overall areal increase was detected while the original layout of water planes remained the same (the difference can be accounted for water discharge or higher water level in reservoirs, rather than real changes in hydrographic conditions). The remaining identified changes in the model area do not bear great importance in terms of the overall differentiation of landscape cover nor in relation to the studied pond ecosystems. Moreover, part of the changes is directly related to partial interpretation interferences (e.g. to the problem of transitional mixels on the edges of homogenous areas).

The applied methods of processing and analyzing digital satellite images facilitated not only the correct location and exact analysis of the most significant changes in the model area of NNR Velký and Malý Tisý in terms of area and importance. The methods also enabled us to quantify, appropriately cartographically represent and archive them in a special database for prospective comparative studies or further use. The demonstrated method of digital image analysis and territorial changes documentation is practically irreplaceable with the traditional terrestrial inventory methods.

It transpired that marked spatial changes of landscape elements and components cannot be avoided even in strictly protected areas. The aforementioned NNR displays both spontaneous evolutionary changes of nature and changes connected directly or indirectly with human activities in landscape (changing intensity and ways of farmland use, nutrients brought in from the catchment area, water pollution, fish management and others). Taking into consideration the significant changes taking place in the vicinity of the NNR, we can presume certain connection between them and the area of the NNR itself.

6. 3 Old and contemporary maps in GIS – Changes of the floodplain landscape in the impact zones of nearby towns and villages

An experimental method was employed for mutual spatial and chronological comparison of the eco-stabilization effect of land use in the floodplain of the Svratka river south of Brno up to the confluence with the Dyje. The total of 39 conventional territorial units in three categories was defined in the floodplain with the objective to statistically localize identified changes. The first category encompasses the “closer surroundings” of a settlement represented by a circle with 500 m radius. In this space everyday and intensive human activities are expected. Centres of settlements localized on the floodplain’s perimeter were taken for the centres of individual circles, resp. bridges across the river in the settlements’ immediate surrounding which overcome the river’s barrier effect. “Distant surroundings” of a settlement with their commonplace yet not everyday economic utilization make up a circle in the floodplain with 1 000 m radius. The remaining area between the circles was termed “free floodplain” with anticipated lower intensity of utilization owing to its distance from settlements. In places of two main historical fords across the river near Židlochovice and Vranovice the floodplain was divided into three sections.

In the four studied periods of 1824–46 (stable cadastre), 1876–80 (Third Military Mapping), 1953–60 (topographic mapping in the S-JTSK system) and 1992 (aerial surveying) we determined area representation of individual forms of land use in component study sites within the listed categories. Each form of land use was numerically evaluated by the so-called ecological stability level (ESL) based on its eco-stabilization effect. Generally speaking, it is expected that the closer a given form of land use is to the natural form, i.e. forest (reading 7), the deeper its eco-stabilization effect in the environment will be (built-up area has reading 1). For each study site in each period a so-called coefficient of ecological stability (CES) was calculated as an integrated manifestation of all the represented forms of land use on its

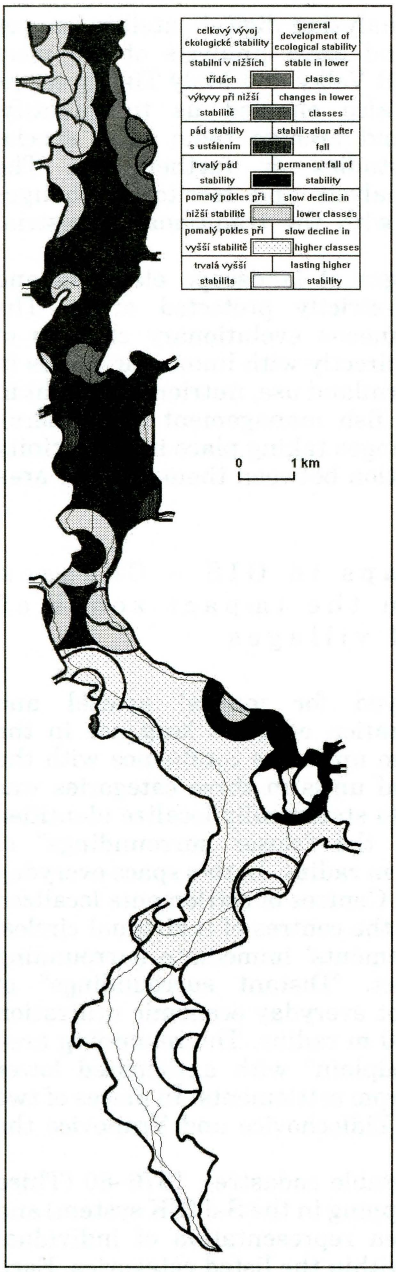

Fig. 6 – Development trends of ecological stability of landscape between the years 1825–1992 in relation to the changes in land use in the Svratka river floodplain near Brno (in closer and distant surroundings of settlements and in free floodplain)

ecological stability (ES). This resulted in a survey of the Svratka floodplain's spatial diversification which reflected the growing ES levels south of Brno in every studied period.

The next stage involved calculating the differences in CES values between individual periods in every study site. From the time series of these differences a development ES trend for each site was inferred (Jurnečková, Kolejka 1999). Based on the degree and character of the changing CES levels a number of types of development ES trends were distinguished (Fig. 6). While sites closer to Brno were characterized by their constant gradual ES decline, southern edges of the Svratka floodplain show an opposite trend even though they are situated in the same natural environment. The growing polarity of the floodplain can be attributed to Brno's limited economic impact on the Svratka floodplain. This relatively inconspicuous phenomenon has not so far met any response in terms of remedial measures in the area and remains outside the focus of conservationist activities.

6. 4 Old maps and orthophotos in GIS – Identification of development trends of land use in given natural conditions

The Czech-Bavarian border running through the Šumava mountains is one of the oldest and most stable borders between European states. Yet its vast forests have never presented an insurmountable obstacle and innovation always travelled in both directions. More accurate and detailed data on the real appearance of its cultural landscape date back to the 18th and in particular to the 19th century when landscape survey along either side of the border was carried out. First mutually comparable data come from the first half of the 19th century. Since then a number of quite detailed and reliable cartographic data have been collected on both sides of the border. These data document land use in the course of the past two centuries and the landscape's natural conditions.

The comparison focused on the cadastre of Strážný on the Czech side with attached cadastre of the former settlement Silnice (the area's conventional designation being "Strážný"). German side is represented by the settlement Philipsreuth with attached villages of Vorder-, Mittel- and Hinterfirmiansreuth (the area's conventional designation being "Philipsreuth"). Both monitored areas are immediate neighbours on the Czech-German frontier. The basic principle of our choice was their location on the Šumava planes and their similar natural conditions which were at the basis of their human utilizing. The total area of Strážný is 13.1 sq km and Philipsreuth covers 10.2 sq km. Comprehensive and varied information on both areas of interest was collected and it facilitated the creation of a digital landscape model (a multi-laterally integrated database) of entirely analogous content for both monitored areas. This model included a digital map of natural background (with homogenous typological natural landscape units described by their climatic, geological, humidity, soil and other characteristics) and maps of land use from the first half of the 19th century, the time before WW2 with predominantly German inhabitants settled on either side of the border and from 2002, shortly after the fall of the iron curtain. Homogenous natural landscape units were used as reference sites for geographical localization of identified changes in the landscape. A related sociological localization focusing on a number of aspects of population structure and local economy is in the process of completion.

The identification of development trends of land use draws on the analysis of area representation of individual forms of land use in individual types of natural landscape units. Basic spatial analyses were conducted with the help of ArcView GIS software and its extension Spatial Analyst. The acquired data were statistically processed in Microsoft Excel and classification procedures drew on Excel's programme Unistat 5.5.

The geo-statistic data analysis yielded a great number of comparative tables, graphs and development curves. A glimpse at the histogram of changes in area distribution of forests, meadows, arable land and built-up area in analysed periods based on individual types of natural environment in Strážný and Philipsreuth (Fig. 7, see groups 13 – humid units and 14 –podsolic units which are both abundant on either side of the border) suggests that despite similar natural properties the point of departure in terms of land use in the first half of the 19th century was different for each area, owing to the different economic orientation and different economic specialization of the border settlement population. Twists of fate of pre-war years did not facilitate any approximation of land use in the different national parts, in spite of the fact that there were few ethnic differences in their respective populations (the percentage of Czechs among the inhabitants of Strážný and Silnice was negligible). It transpires that the main reason was a different economic climate on either side of the border. Majority of population on the Czech side found work in forests, which was not sufficient to support families and as a result other (predominantly farming) activities were a bare necessity. On the German side field farming probably played only a minor role and its importance continued to diminish. Following the Munich Treaty both areas on either side of the border were united in a higher administrative unit but the areas remained different in economic terms. This difference was manifested in a different structure of land use which was conditioned by differentiated pressure on land reflecting different standards of living. In

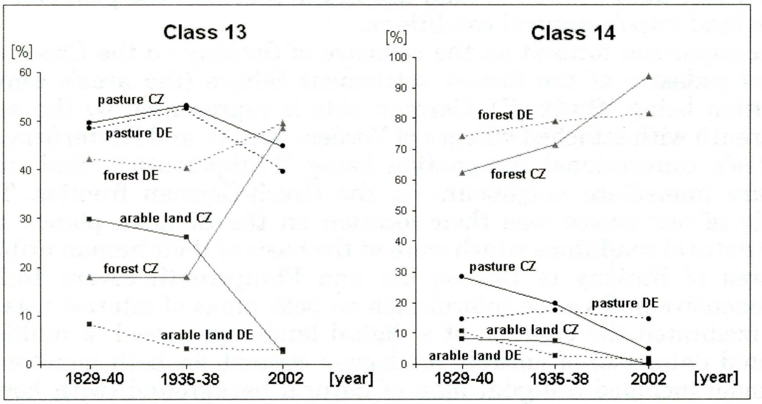

Fig. 7 – An example of convergent land use between 1825 and 2002 in natural landscape units characteristic for both border areas

post-war years it was predominantly the Czech side which saw a radical change of politico-economic situation. After majority of the German population had been resettled a border zone was established which considerably limited the area's economic use and consequently its settlement. The municipality Silnice practically disappeared. Old farmhouses scattered along the border were deserted and only customs office buildings and the border crossing remained from the original village. Even these buildings were used occasionally when needed for the guarding of state border. Similarly, in Strážný a number of farmhouses were deserted. Population decrease and political obstacles resulted in a drop in land pressure, which in turn facilitated gradual natural succession and eventual forests planting on the deserted farmland (both arable land and meadows). The German side experienced a less obvious population reflux into inland and also the decrease in land pressure was less pronounced, among other things owing to a formerly weaker orientation towards farming production. Restructuralization of employment highlighted the recreational function of all the settlements, Mittelfirmiansreuth in particular, which developed into a winter sports resort with relevant facilities and infrastructure. A similar development, in particular after 1989, can be detected in Strážný where a network of tourist and entertainment services has been built, including extensive "stall trade" activities. The area of arable land in the interest area is negligible on both sides of the border today. Apart from the intravilan of Strážný the entire area on the Czech side is protected as a part of the Šumava National Park and the area east of the international road connecting Passau and Vimperk as a part of the Šumava Protected Landscape Area. The German side does not have a similar status of land protection.

Remarkably, the development on one side was distinctly different from and virtually independent of the development in its counterpart across the border. The area has seen a physiognomic (visual) land convergence, particularly in terms of the distribution of forest units, meadows and pastures on either side of the border within the analogical types of natural environment and location. It has also seen the development of a similar structure of land use in a number of natural landscape unit types represented in both national areas.

Should then large parts of both areas show identical or similar natural conditions, their structure of use concurs as well. On the other hand, specific types of natural environment without a corresponding equivalent abroad tend to have different structures of use. A hypothesis presents itself to explain these facts: along both sides of the border a "generally rational" structure of land use is formed which respects (today and in the recent past) the marginalization of the area, its gradual depopulation, extensification of agriculture, and also strengthens its recreational role regardless the prevalent socio-economic system and standard of living.

ArcView GIS software tools enable us to create applicable statistical background documentation for more detailed analyses and data syntheses. Each type of a natural landscape unit, separately for the Czech and the German parts of the area, was described by an appropriate percentage of the represented forms of land use in all three analyzed periods. Owing to the fact that a decisive share of all the units was always constituted by forests, meadows and possibly by arable land, these dominant physiognomic units (defining the character) of cultural landscape were selected for further assessment. Each group of types of natural landscape units both in the Czech and German parts was described by a nine-digit vector whose co-ordinates represented the percentage of forests, meadows and arable land in the years 1829–1840, 1935–1938 and 2002. These vectors representing every homogenous natural landscape unit in both border areas were classified with the help of cluster analysis implementing the method of "Furthest Neighbour". The resulting outcome represents development trends of land use in different types of natural environment. (Marek 2004).

Five groups of landscape units with similar development were identified: A, B, C, D and E. The fifth one, group E, exists in Germany but does not have analogy on the Czech side. However, its size is negligible and as such was not subject to further analyses. For pairs of natural landscape unit groups subject to similar development representative histograms and maps of land use changes were drawn, as they are indispensable for interpreting the classified development (Fig. 8 – parts a, b).

It became apparent that in order to achieve a similar target effect, i.e. highly similar present use, individual groups of natural landscape units separately in the Czech and German parts "chose" either entirely different or on the contrary identical strategies.

The group of natural landscape units of type A, which includes predominantly areas of valley bottoms and stony hillsides on both sides of the border, is characterized by an antithetic development connected with a dramatic loss of arable land and increase of forest on the Czech side, while on the German side the changes of land use are negligible. Despite this the structures of land use on both sides of the border converge. Group B with similar representation of units which considerably differ in humidity conditions is characterized by a gradual development on the German side and a similar but faster development on the Czech side. However, the structure of land use in these units remains radically different. The German side is predominantly forested, the Czech side shows a balance between forests and meadows. Units of type C include extreme stony (or wet) units and demonstrate an identical development over the entire period of time on both sides of the border, showing a slight fluctuation in the percentage of monitored forms of land use. Dramatic and entirely different changes characterize the group of units D on both sides of the border. However, these

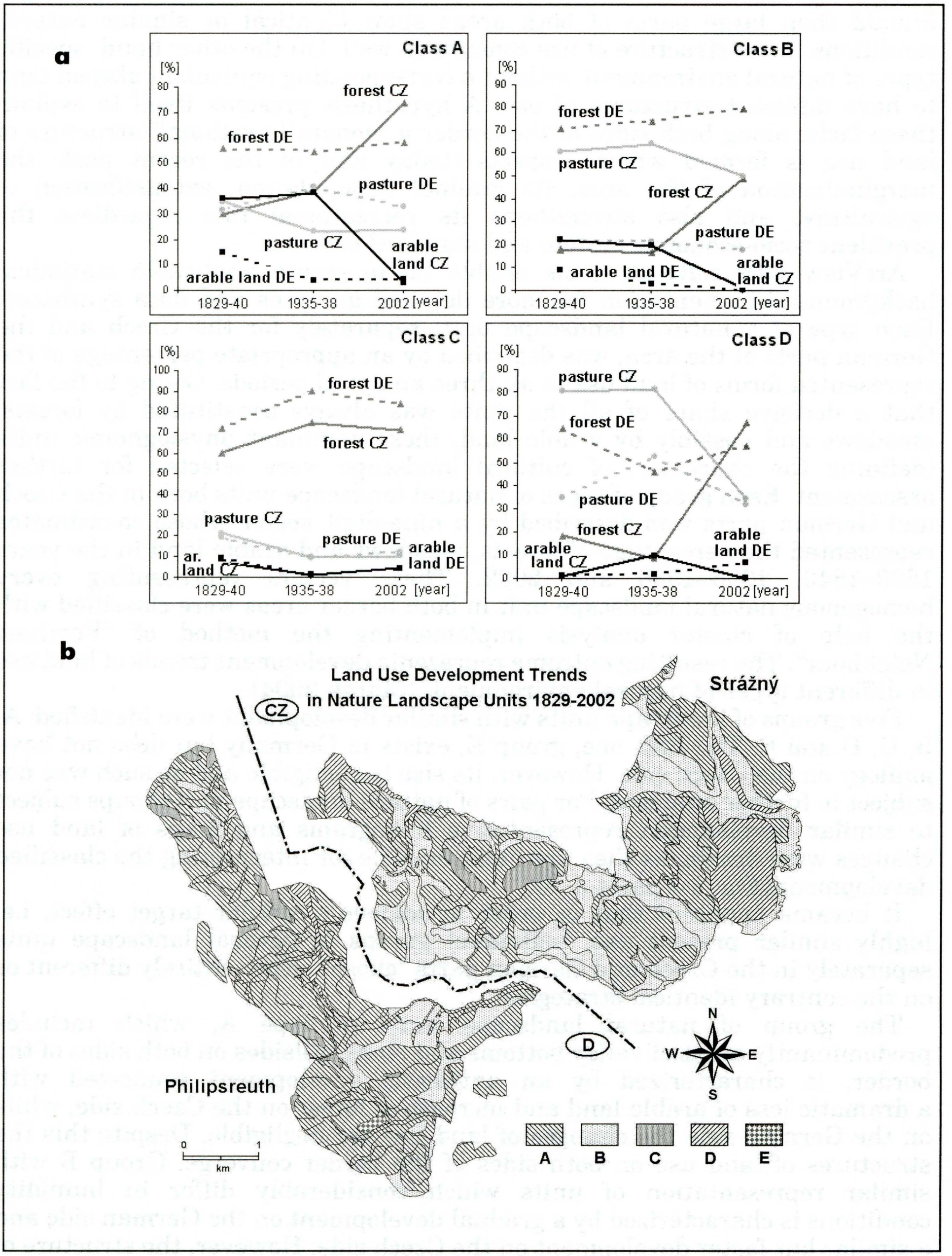

Fig. 8 – Groups of natural landscape units based on the identified development trends of land use (8a) and their projection in the map (8b)

lead to an almost perfect convergence of the present land use with forests slightly prevailing over meadows. Group E exists only on the German side and shows a loss of forests which remain scarce, while dominant meadows gain dominance and arable land is eliminated.

Generally speaking, both the entire area and its individual types of natural landscape units (except group B) are characterized by land use convergence (Fig. 8a). However, strategies for achieving this convergence differ: from highly chaotic changes in the past (D) to a more extreme concept of trends on the German side (A) or a completely analogical development (C). The data obtained from the interest area prove that the tendency towards a "rational" organization of a functional landscape mosaic is generally consistent regardless the ruling political or economic systems. It also proves that population density and partially people's standard of living, or "economic climate", play a dominant role. Relating to the general trend of European Union to secure the same standard of living for all population communities, the creation of a homogenous economic climate could prove counterproductive to the efforts to maintain a high diversity of cultures and cultural landscapes.

7. Conclusion

The objective of this paper is not to provide a comprehensive survey of methods used in Czech geography to identify landscape changes. It can be viewed as an effort to document the principal groups of methods in individual case studies. The study of this phenomenon in Czech geography encompasses a wide range of projects of varying localization specifications – ranging from a simple time line of recorded changes, to statistic localization in the interest area as a whole (cadastre areas or another type of defined space, e.g. a map sheet or its sector), geometric localization in a given place with given topological coordinates, geographic localization in an area with given natural or environmental characteristics to relating the obtained results to the area's given social and economic parameters. The more demanding and complicated the need for a temporary-spatial coincidence of reality, the more important modern geo-information technologies become, should it be in terms of collecting , processing and analyzing data or in the presentation of one's results. Needless to say that these technologies have substantially helped us progress in the study of landscape changes and that they have facilitated the acquisition of data which are new both quantitatively and qualitatively and which have moved our knowledge substantially forward. Experts studying landscape changes in Czechia closely follow technological development and are already considering employing new, more advanced technologies to detect and localize landscape changes (e.g. laser imaging), this time in 3D geographical space. Furthermore, new geo-information technologies facilitate animations of detected changes and optimize the ways of sharing research results with specialists and general public (Svatoňová 2005). A better understanding of landscape changes, their causes and impact form a suitable basis for optimizing landscape management.

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Shrnutí

MONITOROVÁNÍ VÝVOJE ČESKÉ KRAJINY S UŽITÍM GIS A DPZ

Různé studie věnované využití půdy jsou pro český geografický výzkum krajiny typické. Digitální geoinformační technologie, které se objevily na počátku 80. let 20. století, výrazně změnily možnosti dlouhodobého sledování krajiny. Česko disponuje značným množstvím různých kartografických údajů o minulosti území, které sahají až do 18. století. Po digitalizaci těchto analogových údajů mohl úspěšně začít historický výzkum krajiny. Dvacáté století vylepšilo kartografické databáze leteckými snímky (od 30. let 20. století) a satelitními snímky (od 70. let 20. století).

Článek ukazuje různé aplikace GIS a dálkového průzkumu Země ve výzkumu změn krajiny. Využití leteckých snímků při monitorování a analýze změn zemědělské krajiny se týká poměrně krátkého časového úseku od roku 1952 do dneška a je ukázáno na příkladě jižních Čech. Metody digitálního zpracování snímků umožnily identifikovat změny zemědělských pozemků, rozmanitosti krajiny a přístupnosti. Satelitní obrázky byly použity pro sledování změn v chráněných přírodních oblastech v krajině jihočeských rybníků. Za použití metod třídění snímků a maskovacích operací byly zjištěny a utříděny změny rozlohy vodních ploch a břehové vegetace.

Byla vypracována sada historických map o využití půdy na základě starých map údolí řeky Svratky jižně od Brna ve východní části země. V povodí bylo vymezeno celkem 39 obvyklých územních jednotek ve třech kategoriích (blízké okolí sídla, vzdálené okolí sídla a volná říční niva podle intensity lidské činnosti). Ekologické vyhodnocení tříd využití půdy a statistické metody umožnily stanovit rozvojové trendy ekologické stability ve všech úsecích nivy řeky Svratky. Digitální model krajiny s plně (logicky) integrovanou databází sestávající ze souboru více parametrových vrstev údajů (přírodní pozadí, lidský vliv a rozvojové limity) s digitálním elevačním modelem byl použit v oblasti česko-německého pohraničí pro stanovení trendů vývoje krajiny v jednotlivých třídách přírodních krajinných jednotek. Byla zjištěna obecná tendence ke konvergenci využití půdy v podobných přírodních podmínkách (ale v odlišných politických a sociálních podmínkách). Takový jev může v budoucnu ohrozit stávající vysokou rozmanitost kulturní krajiny v Evropě, pokud globalizační a evropeizační proces bude pokračovat bez ohledu na krajinné bohatství.

Obr. 1 – Nejstarší podrobná mapa využití půdy v Česku – Müllerova mapa (A), příklad georeferenční mapy z druhého vojenského mapování (B), reambulovaná mapa s podrobným vyznačením využití půdy ve 20. letech 20. století (C), černobílá ortomapa zpracovaná GIS (D).

Obr. 2 – Vztahy mezi souhrnnými studiemi o využití půdy a jeho změnami, přesností lokalizace změn a vlastnostmi dané změny. Vlevo odshora dolů: umístění LUCC, chronologické, statistické, geometrické, geografické, sociologické, přesnost:minimální – maximální. Vpravo sestupně zleva doprava: čas, zkoumané území, lokalita, okolí, lidské důvody, lokalizační proměnná.

Obr. 3 – Lokalizace jednotlivých studií o vývoji krajiny v Česku. Modelová území: Horosedly, Šumava, Velký a Malý Tisý, údolí řeky Svratky

Obr. 4 – Stávající velkoplošné rozložení parcel modelového území (bílé čáry označují hranice hlavních parcelních jednotek z roku 1988) na pozadí historické fotografie (s původním rozložením zemědělských území v roce 1952).

Obr. 5 – Podmínky a změny povrchu v chráněné oblasti a v blízkosti národní přírodní rezervace Velký a Malý Tisý na satelitních snímcích z let 1988 a 1995. Nahoře: rozlišení povrchu v širším okolí národní přírodní rezervace Velký a Malý Tisý na satelitních snímcích z let 1988 a 1995. Legenda: 1 – voda, 2 – mokřiny, 3 – les, 4 – sídla, 5 – pole, 6 – louky a pastviny, 7 – ostatní; dole – poklasifikační vyhodnocení změn povrchu mezi lety 1988 a 1995, A – kód kategorií stabilních objektů, B – kód gradientu změny.

Obr. 6 – Vývojové trendy ekologické stability krajiny mezi lety 1825 a 1992 ve vztahu ke změnám ve využití půdy v povodí Svratky u Brna (v blízkém a vzdálenějším sousedství sídel a ve volné nivě).

Obr. 7 – Příklad konvergentního využití půdy mezi lety 1825 a 2002 v přírodních krajinných jednotkách charakteristických pro obě pohraniční oblasti. Vlevo odshora dolů: třída 13, pastviny CZ, pastviny DE, lesy DE, orná půda CZ, lesy CZ, orná půda DE, rok. Vpravo odshora dolů: třída 14, lesy DE, lesy CZ, pastviny CZ, pastviny DE, orná půda CZ, orná půda DE, rok.

Obr. 8 – Skupiny přírodních krajinných jednotek na základě zjištěných rozvojových trendů využití půdy (a) a jejich projekce v mapě (b – rozvojové trendy využití půdy v přírodních krajinných jednotkách 1829–2002)

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CHANGES OF LAND USE IN PRAGUE URBAN REGION

I. Bičík, L. Kupková: *Changes of land use in Prague urban region.* – Geografie–Sborník ČGS, 111, 1, pp. 92–114 (2006). – Land use changes in Prague urban region (the capitol - Prague, the Prague-East and the Prague-West districts) are evaluated in the article in the time period of 1845-2000 and that is done on the data basis of the land use structure in the years 1845, 1948, 1990 and 2000. The evaluated time horizons are historical milestones in social development of Czechia, the stress is put on the last ten-year period of transformation. The LUCC Prague methodology was used for the evaluation of land use development. The intensity of occurred changes is analysed through the index of change, the typology of main landscape processes in individual partial phases of the evaluated period is analysed further. The cadastral territory of Čestlice was selected as a case study, in which the comparison of land use structure in the years 1845 (reconstruction from cadastral maps) and 2003 (field mapping itself) was carried out in details.
KEY WORDS: land use – landscape processes – interaction nature and society – Prague urban region – Czechia.

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1. Introduction

Geography studies landscape as a complex of mutual relations between nature and human activities on different levels – from the local to the global one. These relations and their consequences are changing with time and therefore also the landscape changes in its character, structures and its space arrangement.

For a long time, geographic research into landscape developed especially in its individual components, i.e. according to the division of geography into disciplines studying individual components of the landscape. Only little attention was paid to studying of mutual relations of these components and of their impact on the whole, i.e. the landscape in a particular place and at a particular time, as far as it was ever done, it was with little scientific erudition and strong pragmatically (ex. territorial planning) or it had a strongly descriptive character and mainly instructive and informative goals. Haggett (1975) states that geography is situated at the boundary of natural and social sciences, that it is the only science interested to the same extent in natural sphere and living conditions of man, regional contrasts and unequal distribution of living assets and values among people. Geography therefore deals with the structure and interaction of two main systems: ecological connecting man with the environment and spatial connecting one area with other ones through a complicated exchange of flows. At the beginning of the 1970s when new themes of the state of living/nature environment and of its protection were opened in the scientific and decision-making spheres, geography had a unique opportunity to respond to the newly forming "social order" and to substantially help to its solution. But as in geography at that time a narrow specialization according to individual disciplines clearly prevailed over studying of the whole complex, i.e. landscape, geography remained aside of this new research sphere characteristic for the last quarter of the 20th century. This was the case not only in our country but also in the world and, beside the belated development of geography as a science due to the complexity of its research object (i.e. landscape as a complex and not in its individual components), a significant role was played also by feeble managing background (in Czechia also political one) necessary to go through in this new direction of scientific research.

Johnston (1998, p. 141) divides geographical studies according to four main approaches, the first of which we consider as principal for our research: according to the interest specified by the orientation of individual disciplines studying components in two main semi-complexes – physical and human. Their mutual interconnection is feeble and there are only few themes in which they meet – one of them being environmental problems in a large context of the interaction nature – society. This can be studied on different order levels. Because of very heterogeneous detailed information necessary for such studying, studies in local and microregional character prevail and studies dealing with mezzo- or macroregional levels or even global studies dealing with a large complex of relations nature – society are less frequent (Johnston et al. 2001 ; Haberl et al. 2001, 2002a, 2002b; Douglas, Huggett, Robinson 1999 etc.). More frequent are mainly those aimed at individual components or elements of the landscape system.

During the last 30 years, the interest in studying development and territorial differentiation of the interaction nature – society has increased. It is undoubtedly due to a substantial increase of negative impacts of social-economic sphere development on the landscape not only on local and microregional level, but also on higher order ones. Therefore we consider the evaluation of the interaction nature – society as one of present key problems to which science must respond.

Studying of the above-mentioned interactions must include looking for driving forces involved in individual period of the last two centuries in changes of landscape functions and influencing land use. Land use as reflection of the interaction nature – society is in individual parts of the world in different development stages and a corresponding reaction in "delayed" regions can help to understand processes of interaction development in more advanced regions.

During the last 50 years, land use has been more and more influenced by progressive differentiation of functions of the core and the periphery. Transfer of many activities to centres of higher order level and emergence of new functions of these cores cause greater differences in area structure between cores, their background and other territories. The largest centres, as for instance Prague, have been progressively increasing their territorial framework, in which they influence emergence of new functions. The consequence is a different development of area structure of large cities and of their background in comparison with the other territories of the state. Specific conditions of land use structure development of Prague urban region enable to analyse trends which are progressively emerging or which will emerge in future in other agglomerations. They are mainly a significant increase of built-up and the other areas in the suburban zone, a decrease of arable and agricultural land both in evidence and sensibly higher in field, formation of specific functions (service areas, suburban family housing, recreation forests, waste sites, etc.) significantly differentiating the land use structure development of core regions from the peripheral ones. Because of the development capacities of Prague the obtained results can be used also as a basis for reflections on land use development in other post-totalitarian countries.

2. Theoretical issues for evaluation the interaction nature – society in the territory of Czechia

Similar land use structures of pre-industrial period (dependent above all on natural conditions) have been changing since the beginning of industrialization under the influence of the modernization of the society. Territorial differentiation has been progressing due to the growing impact of economic, social, political and location factors in industrial and post-industrial society. We presume that the present land use in Czechia corresponds to location in core or peripheral territorial position and to natural conditions of the analysed locality.

Land use has been developing to a deeper territorial differentiation of area structure state and development both in individual localities and in greater territorial units in dependence of functions given to them by the society in a certain period of its development. Self-supplier economy of the pre-industrial society is characterized by a larger extent of agricultural land resources (the maximum was reached in the 1880s, see Jeleček 1985), by the intensity and use of its individual categories, by a strong pressure on forest areas as a source of a further increase of agricultural land resources, by a small extend of built-up and the other areas. The production-market function of landscape in industrial society causes regional differentiation of agricultural effectiveness and therefore also regional differences in specialization and intensity of land use structure development. Multifunctionality and steadily increasing conflicts of functions in the landscape of the post-industrial society with an increasing importance of non-productive functions (water management, ecological, protective, recreation, residential, etc.) are accompanied by an extraordinary increase of built-up and the other areas, but also of areas with different degree of protection with limited possibilities of economic use, or with specific functions with impact on land use structure.

In the case of post-socialist European countries, the effort to reach a high intensity of farming and a maximal self-sufficiency on the state level lead to undesirable impacts on the quality of environment. After the turn of political situation there occurred rapid changes in volume, structure and intensity mainly of farming and naturally also substantial and relatively quick changes in area structure as well as a progressive slowing down of landscape degradation (Bičík, Götz 1998; Bičík, Jančák 2001; Bičík, Jančák 2005). Together with progressive globalization influencing more and more also Czechia, an imbalanced space land use development will be influenced by importations of agricultural products, by promotion of subsidized, i.e. cheaper, EU products at the Czech market with impact on inland producers, but also by more general processes of urbanization and suburbanization, by restructuring of town agglomerations, etc. which influence, directly or indirectly, also the area structure. Land use development can largely depend on these processes both on global and continental level, but also on the level of state or region. This is due mainly to the fact that in more developed countries rural areas are conceived as "space dimension of collective consumption" (Cater, Jones 1989, p. 219), where the production function is one of many and in many fields it is today a quite insignificant one. It is due to the fact that the prevailing urban population requires in this stage of society development from rural areas many functions needed mainly by urban population (recreation areas, water resources protection, nature protection, military areas and training grounds, dumping grounds, etc.). For the two last centuries, land use in Czechia has been significantly changing both vertically, i.e. with altitude, where especially nature factors prevail in land use structure, and horizontally, where position, i.e. mainly social economical, factors prevail. There occurs a deep regional differentiation of territorial functions and thus land use structure changes. These changes were characterized in many publications as well as in Czech and foreign scientific journals (Bičík et al. 2001; Bičík, Jeleček 2005; Bičík, Kupková 2001 and others); therefore we will concentrate in this paper on trends in land use changes and on their causes in Prague urban region.

3. Aims and methods

Land use represents one of the ways of studying landscape and landscape changes. With regard to the structure of the observed categories of use, land use is a more suitable term. Under our conditions, individual categories of land use represent a different degree of transformation of the original natural environment. On the one hand we differentiate categories (classes) of rather natural character (forest or water areas, permanent grassland), although used to a certain intensity, then categories with a more pronounced degree of transformation of the original natural environment (arable land, permanent cultures: gardens, orchards, vineyards, hop fields) and categories of areas, where the original environment has been totally changed and where it is an artificial or devastated landscape (built-up, the other areas). Certain inaccuracy and generalization are evident. Evident is also a shift of classification of individual areas during the more then 160 years of keeping evidence in Czechia. Other possible imprecise evaluations may be due to the fact that this evidence is based on balance evaluation of decrease and increase of individual categories per partial territory (cadastral territory, municipality, district, region, state) and it does not record a possible change of location within the given territory without a change of its extent. Territorial units are from this perspective a black box and data on land use structure in our evidence do not allow observing this aspect.

Essential is also the fact that we deal with the extent of individual plots according to the evidence kept by geodetical service per cadastral territory and not with the real state in field which is always rather "ahead" the records. While in the past this difference used to be quite small, in the transformation period (after 1990 land was restituted to 3.5 million of owners) differences between records and the real state in field reach, in arable land, about 10 %, differences in other categories are sensibly smaller.

In spite of certain limitations and inaccuracies given by the used statistical evidence of area structure, the similarly aimed research based on area structure database in comparable territorial units is well founded because of three facts:

Data of land use structure represent a certain generalized image of the interaction nature – society on the level of cadastral territory.

The possibility to compose data of individual cadastre, or of comparable territorial units formed out of them, to greater territorial units enables, in a necessary degree of generalization, to evaluate the state and development of the landscape and the driving forces existing on individual regional levels.

This possibility to compose data enables to interconnect the knowledge of the interaction nature – society on all levels from the local to the state or the above-state one, although in a certain generalized form. So oriented research is a link of the research into long-term development of the interaction nature – society from the local to the state and higher regional level.

It follows that research into the dynamics of the interaction nature – society based above all on data on land structure offers the possibility of evaluation applied mostly in regional and above-regional comparisons. It is not suitable for observation of the dynamism of the interaction nature – society on the lowest (i.e. local) level, here is better to use methods using mostly geoecological approaches and detailed map data from different time horizons. They enable to study territorial details and represent an important feedback for our research based on statistical evidence of land use.

In research into land use development we use database established by mapping of the Franciscan cadastre in the years 1826–1843 (dated 1845 when data on the former districts were published) and on land use evidence from the years 1948, 1990 and 2000. It was being compiled in the years 1994–1998 and its concrete output is the database at the Faculty of Science, Charles University (LUCC UK Prague) and several dozens of published articles. The methods are described in detail in many publications (Bičík, Štěpánek 1994; Bičík et al. 1996; Bičík, Jeleček 2005) and it is not the aim of this paper to list them here in detail. We would only like to stress that out of about 13 000 data for cadastral territory some 9 000 basic territorial units (BTUs) were formed, the total area of which is comparable in all four time horizons (the differences do not exceed 1 % of the BTU´s area), which enables to compare both changes in area of individual categories and changes in structure of eight basic and three summary comparable categories. Arable land, permanent cultures, meadows and pastures form together agricultural land; forest areas; built-up, water and the remaining areas form together other areas.

Among the most important published papers resulting from these projects are those which closed a certain stage of work and enabled to evaluate the obtained results (Bičík et al. 1996, 2001), or those of methodical character (Bičík 1994, 2005), or contributing to knowledge of certain relationships between area use development in Czechia and selected indices (as altitude, official price of agricultural land, position, etc. – Bičík, Štěpánek 1995; Bičík 2001; Bičík, Kupková 2003; Mareš, Štych 2005 and others). In our geographical literature these methods are based on similar studies on land use structure development of the former North Bohemia region (Pokorný 1970, 1972; Bičík 1988), on historical-geographical analyses of dynamism of agricultural land use by Jeleček (ex. 1985, 1987) and on two papers by Häufler (1955, 1960). It is interesting that a greater attention was paid in Czechia to using of the original database under the form of land use evidence than to classical land use prepared by field mapping (Stamp 1945, 1950;

Kostrowicki 1962, 1965 and others), which was influencing geographical studies in Europe for at least twenty years (also in neighbouring Poland and Slovakia, see Biegajło, Paulov 1966; Biegajło 1972). As the land use structure concerns, we paid attention to Prague and to its background by using statistical data of land use (Bičík 1993, 1994) and data from Earth remote sensing according to the distance and individual segments from the agglomeration core (Kupková 2003). Recently a study combining analyses of area structure development in Prague urban region both based on statistical data and by comparison of detailed land use structure development in three model territories in Prague background (Bičík, Kupková 2006) was published.

The aim of this paper is to show, with the help of GIS instruments, land use structure development according to comparable BTUs in Prague urban region (for simplification we use administrative delimitation: Prague and districts Prague-East and Prague-West) in the years 1845-1948-1990-2000 and to try to explain principal trends and microregional differentiation of landscape changes which occurred in this period.

4. Land use structure development according to BTUs

Situation in land use structure development is documented with the help of the LUCC UK database Prague compiled from data on cadastral territories partly linked to basic territorial units (BTUs) comparable, by their territory, in all observed time horizons. It is evident that in the territory of Prague as well as in other regions of a significant concentration of social-economic activities, it was necessary, to ensure comparability, to link together original cadastres, because territories of an unknown land use structure used to be exchanged among them. Therefore we analyse in Prague urban region on the territory of Prague only 30 BTUs and on the territory of Prague-East and Prague-West districts in total 174 BTUs representing territorially

Table 1 – Land use changes in Prague

	1845		1948		1990		2000	
Area category	ha	%	ha	%	ha	%	ha	%
Arable land	47 251.7	72.4	42 798.7	65.6	26 795.2	41.1	26 360.1	40.4
Permanent cultures	1 802.4	2.8	5 878.9	9.0	5 873.7	9.0	5 867.7	9.0
Meadows	2 787.1	4.3	1 787.7	2.7	716.8	1.1	683.7	1.0
Pastures	4 774.8	7.3	1 646.4	2.5	426.9	0.7	404.1	0.6
Agricultural land	**56 616.0**	**86.8**	**52 111.7**	**79.8**	**33 812.6**	**51.8**	**33 315.6**	**51.1**
Forest areas	**4 554.1**	**7.0**	**4 919.2**	**7.5**	**5 889.8**	**9.0**	**5 856.3**	**9.0**
Water areas	1 104.9	1.7	889.0	1.4	1 316.6	2.0	1 313.3	2.0
Built-up areas	731.5	1.1	2 924.0	4.5	4 666.1	7.1	5 265.0	8.1
Remaining areas	2 232.2	3.4	4 426.1	6.8	19 576.2	30.0	19 476.6	29.9
Other areas	4 068.6	6.2	8 239.1	12.6	25 558.9	39.2	26 054.9	39.9
Total	**65 238.7**	**100.0**	**65 270.0**	**100.0**	**65 261.3**	**100.0**	**65 226.8**	**100.0**

Source: LUCC UK Prague
Note: Delimitation of Prague as in 2000 is based on data from cadastral territories transformed, to ensure comparability, into BTUs. Therefore our database does not always follow frontiers between districts and regions. There is thus a certain difference between the database delimited according to LUCC UK Prague and the evidence of cadastral bureaus.

comparable units, the total area of which differentiated in time by less than 1 %. Because of methods of the database compilation, it was necessary in some cases to link together, when forming BTUs, sometimes even cadastres belonging to different districts. These differences from the course of external limits of Prague-East and Prague West districts and of Prague itself, by which we delimit the territory of Prague urban region, are visible on cartograms. In our analysis also the limits of Prague and both rural districts slightly differ from official limits of these three territories (as in 2000). Therefore our data rather differ from those given by the Cadastral Office, be it in the total area or in the area of individual categories. Table shows the area structure development in so delimited territory in the years 1845–2000 (bold data represent summary data of summary categories: agricultural land resources, forest, other and total areas), Tab. 1, Fig. 1.

Our database enables to analyse eight basic categories and for all of them it is possible to compile cartograms of the part of the category on the area of the territorial unit or cartograms of development of the category between two of the four observed time horizons. For the whole Czechia, samples of these outputs are given in publications Bičík et al. 2001; Bičík, Kupková 2003 and elsewhere. Here we want to use more complex indices we have already used previously to evaluate land use structure changes.

Index of change is evaluating by one figure the share of areas, on which a change of area of 8 basic categories within the given BTU occurred between two time horizons. Formula for calculation of the index of change is

$$IC = \frac{\sum_{i=1}^{n} \left| A_{1i} - A_{2i} \right|}{2 \times E}$$

The next three cartograms (Fig. 2, 3, 4) evaluate the set of BTUs in the territory of urban region in the periods 1845–1948, 1948–1990 and 1990–2000, which enables to compare the area dynamics of the transformation period with the previous stages of social economic development.

Index of change is in the first more than one hundred year period the highest in the proper core of agglomeration (Fig. 2). In the other part of Prague urban region, the index of change oscillates in the majority of BTUs up to 5, i.e. the level in which the category of use was changed in 5 % (and less) of the area of the given territory. Exceptionally there are BTUs with index of change up to 15. The most important changes in area use are registered in those parts of Prague which used to be freely linked to the historical core and which have undergone a significant transformation because of building of new industrial and storage structures and new residential houses mainly for lower social layers concentrating, in the period 1870-1930, in several waves new immigrants to Prague (Vysočany, Libeň, Holešovice, Žižkov, Vinohrady and others). The maximal index of change, i.e. 55.4, was registered during the more than one hundred year period in the cadastral territory of Bubeneč, where mainly building of more-storied houses in combination of villas with fenced gardens for higher social layers concentrated. These parts of urban region were manifesting a rapid population growth and progressively became administrative parts of Great Prague. A quickly developing transport infrastructure network was

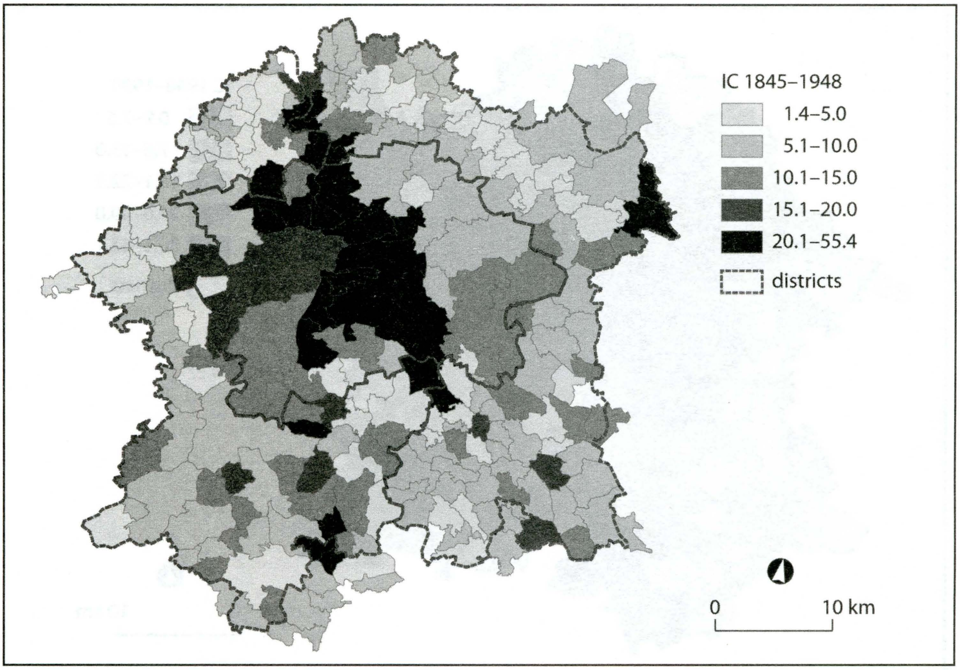

Fig. 2 – Development of index of change in the years 1845–1948 in the territory of Prague urban area (PUA; Prague + districts Prague East, Prague West). Source: LUCC UK Prague.

contributing to intensive changes in area structure. All this was occurring on the detriment of the up to then intensively used agricultural areas which remained in many places of "Great Prague" at least to the World War II.

In the period 1948–1990 (Fig. 3), there is an evident high level of index of change exceeding 22 in the majority of Prague BTUs (maximum: Veleslavín 62.1; minimum: Stránka near Brandýs nad Labem in Prague-East district: 0.94). Because of the length of the period (42 years), which is about 2.5 times shorter than the more than centenary previous period, we can say that the intensity of land use changes in this period (calculated for ten-year period) is about four times higher. It is characteristic that in this period the highest levels of index of change are concentrated in Prague itself. It is undoubtedly due also to the fact that we consider the town limit as in 2000 and therefore such delimited Prague include all territories administratively annexed to the town since 1948. The main reason of high values of index of change in this period is an intensive housing development mainly on greenfield sites, building of new industrial areas and transport infrastructure (D1 highway, addition of a double track on main railways, interconnection of newly built housing estates with town centre, etc.). A significant decrease in area is characteristic for agricultural land resources and mainly for arable land. It can be said that in this period structural changes in land use corresponding to departure from traditional forms of land use to new metropolitan functions of Prague urban region were going on or completed.

In Prague background there are evident significantly higher values of index of change in comparison with the previous period, which is clearly visible in the cartogram. This state results from a more intensive economic use of the background, mainly from a decrease of agriculture land resources

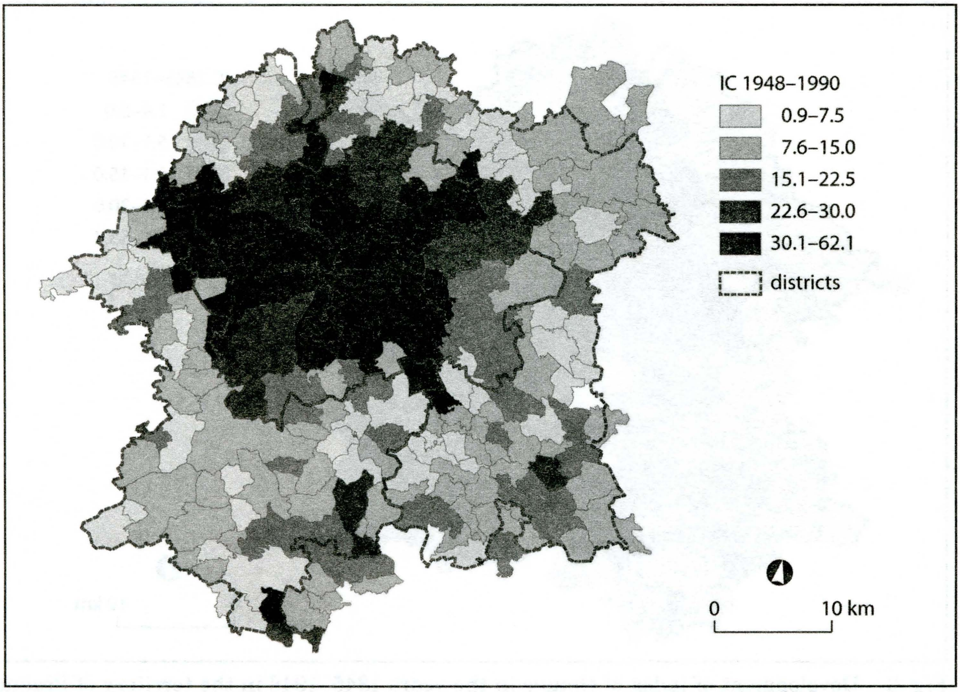

Fig. 3 – Development of index of change in PUA in the years 1948–1990. Source: LUCC UK Prague.

in favour of built-up and remaining areas (development of communication networks, development of industrial, storage and residential functions of some from the transport viewpoint well located settlements). In some BTUs southwards from Prague, there was a rapid increase of second residences which resulted in changes in land use connected with an increase of built-up areas and permanent cultures areas (gardens) on the detriment of forest areas or little fertile and mostly worse accessible agricultural land areas.

The last period 1990–2000 (Fig. 4) is only ten years long and its cartogram manifests the lowest level of changes. The table documents registered levels of index of change in unequally long periods and their standardization for a ten-year period. According to data from selected territorial units, in BTUs localized closer to the centre a high intensity of change was registered mainly in the years 1948–1990, somewhere even in the previous period. On the contrary, "rural" BTUs manifest the highest standardized index of change in the last decade of transformation 1990–2000 (max.: Krňany: 32.0, min.: 0.12: Holubice v Čechách), or in the totalitarian period (1948–1990). The total move in land resources structure in Prague background is higher during the last fifty or ten years. In spite of an increasing difference of evidence and real state of individual categories of land use in the field (mainly in the last period), it is a more general trend of an increasing index of change in Prague urban region.

More significant changes in land use in the years 1990–2000 are characteristic mainly for Prague background. It is undoubtedly both a consequence of suburbanization tendencies with an important building of residential houses of family type (Jesenice, Dolní Břežany, Kolovraty and

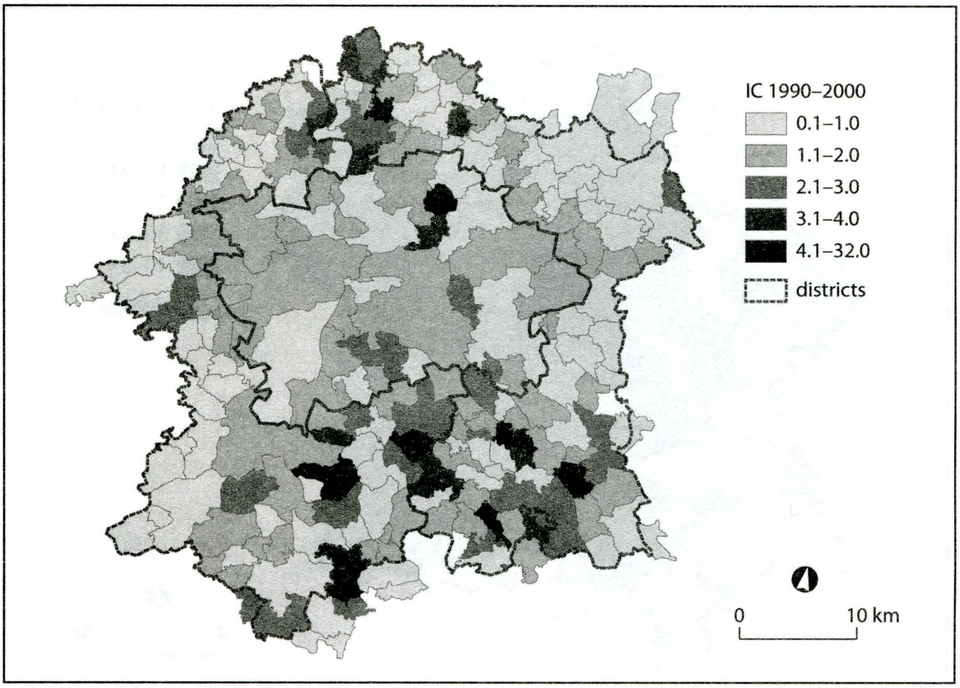

Fig. 4 – Development of index of change in the years 1990–2000 in PUA. Source: LUCC UK Prague.

elsewhere) and a result of construction of service and storage structures in the near proximity of Prague along highways (ex. Čestlice, Nupaky, Rudná and elsewhere). It is also an impact of some other phenomena caused by a significant lowering of the intensity of agricultural use of landscape due to cutting off of subsidies and to bad natural conditions of some BTUs in the southern background of Prague. In the territory of Prague, the move in the total structure of areas is very low. It is probably a consequence of a limitation of larger housing development but also of the fact that in this period the quality of evidence was not maintained and some changes in categories were not reported (mainly arable land transformed into meadows, pastures or laying fallow for more than four years), partly because of higher expectations of owners concerning compensations for confiscated arable land for non-agricultural purposes. There are many similar lands in the territory of Prague (ex. Radotín, Lahovice, Slivenec, Řeporyje or some areas in the northern margin of Prague).

The index of change in the three observed periods is further evaluated with the help of typology of these changes. Figure 5 depicts whether the given territorial unit was, by the size of its index, below (0) or above (1) the average value of Prague urban region. Position in the group of three digits characterizes in the first position the oldest period, in the second position the totalitarian period (1948–1990) and in the third position the transformation period (1990–2000). The picture documents the southeastern sector of Prague as the territory with most significant changes from the viewpoint of land use structure (intensity of landscape change) in the whole monitored period of about 155 years. Besides this territory, there are other three lines in which

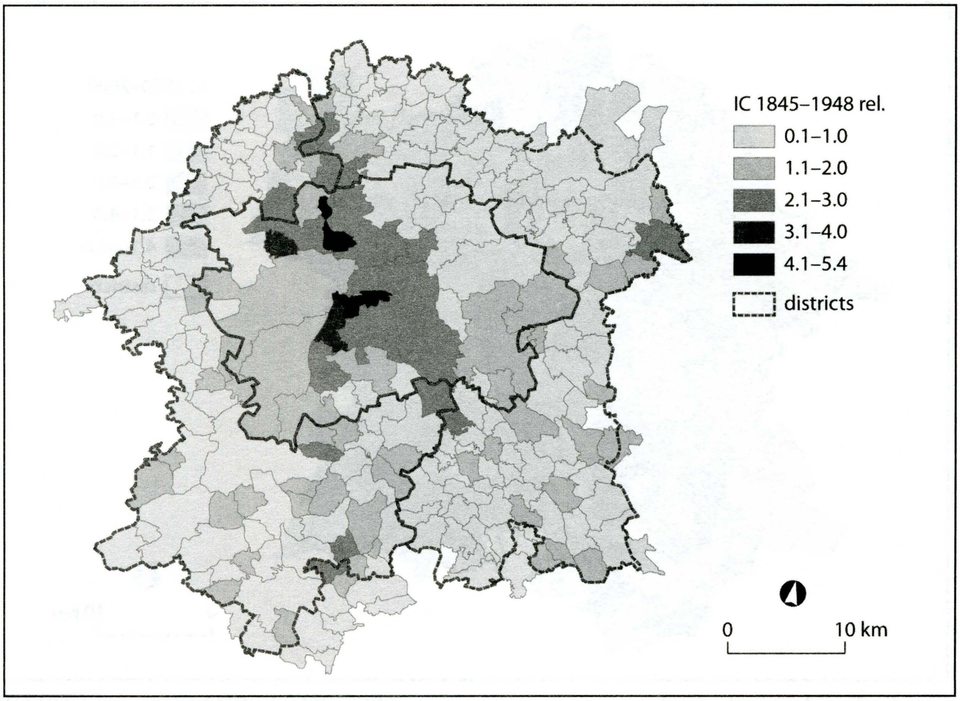

Fig. 6 – Standardized index of change on 10 years in PUA (1845–1948). Source: LUCC UK Prague.

there are always several BTUs with a high intensity of landscape changes. The first ones could be characterized as territories bound to the Vltava course southwards from Prague, the second as areas immediately without Prague border on the north-west along the Vltava course, the third line is south-eastwards from Prague and follows the D1 highway and the road Prague-Říčany. On the contrary, nearly a half of BTUs in rural districts manifest a state where in none period the intensity of area structure changes was above the average of Prague urban region. From this viewpoint, they are territories where urbanization, or suburbanization pressures were not so strong and had not a more significant impact on area structure changes.

Because of different lengths of individual analysed periods, index of change was standardized for ten-year period (although such simplification may be imprecise, especially for the period 1845–1948 (as it withholds various trends) depicted by the following series of cartograms (Fig. 6, 7, 8) with the same scale classification. These cartograms clearly depict the first period as that where only a small part of historical Prague itself clearly linked to the Vltava course reaches the three highest value of land use structure change. The second, totalitarian period manifests substantially higher standardized values of index of change for a ten-year period, when the proper territory of "Great Prague" reaches in the majority of BTUs two highest values of index of change of the unified scale. Also Prague background manifests substantially higher changes in land use structure than in the previous period, although they are territorially differentiated. A similar image, i.e. more intensive changes in the period 1948–1990, is

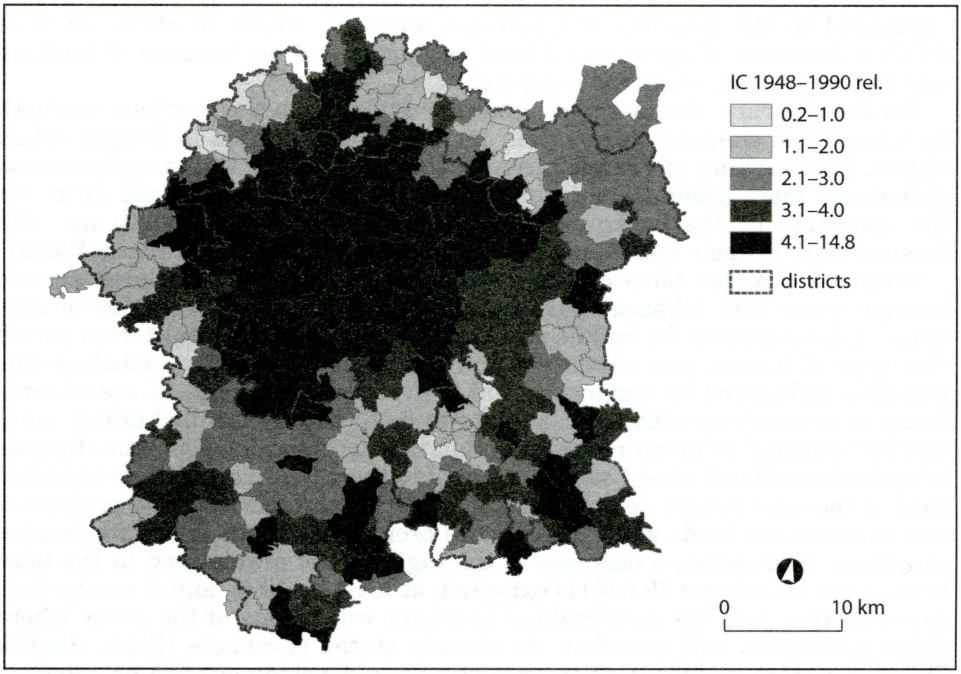

Fig. 7 – Standardized index of change on 10 years in PUA (1948–1990). Source: LUCC UK Prague.

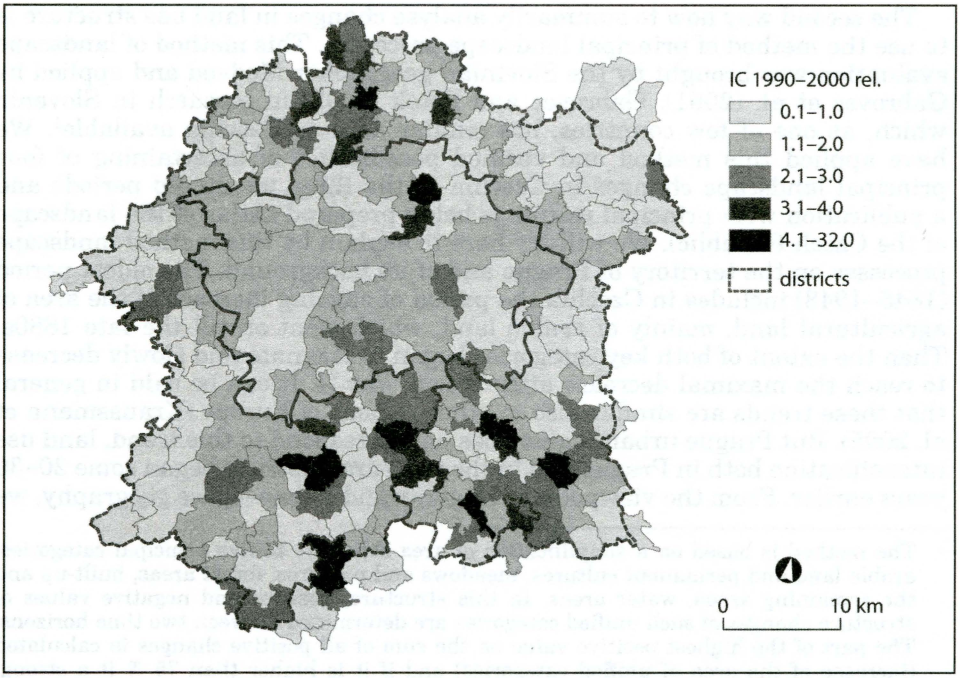

Fig. 8 – Standardized index of change on 10 years in PUA (1990–2000). Source: LUCC UK Prague.

registered in the majority of Czechia's territory, where in about 95 % of BTUs a decrease of agricultural land resources and an increase of built-up and the remaining areas were registered.

On the contrary, the last period largely differs from the previous one both by intensity of changes and by their territorial distribution in Prague urban region. The territory of Prague has not registered during this transformation period any more pronounced intensity of changes in standardized form. On the contrary, in the background, both along the Vltava course up- and downstream Prague and along D1 highway and the road Prague-Říčany, substantial changes have occurred. There have concentrated large service storage areas and adjacent parking areas and intensive processes of new housing development for middle and higher class, as in the totalitarian period this type of houses was expensive and scarce in Prague. Nevertheless this period is influenced by lagging behind of evidence of changes in use of some areas in comparison with the real state in field (mainly untilled arable land) and by "waiting" of many restituents (land owners) for development of prices of agricultural land after Czechia' s entry to the EU. It can be thus expected that in the near future not reported changes in land use and new projects of use of restituted lands will cause a more pronounced move in the whole area structure. In Czechia, a decrease of the high part of arable land in the total area of the state (now 39.8 %) is expected, at least by 10 %, and it can be thus expected that just the metropolitan territory will be one of the areas where these tendencies will manifest. As already stated elsewhere (Bičík, Jančák 2004), a certain stabilization in area structure development can be expected only after foreigners will be allowed to purchase land in Czechia which should be in 2012.

The second way how to summarily analyse changes in land use structure is to use the method of principal landscape processes. This method of landscape evaluation was brought by the Slovinian geographer Medved and applied by Gabrovec et al. (2001), Gabrovec and Petek (2002) in research in Slovenia which, as one of few countries, has similar data as Czechia available[1]. We have applied this method and verified possibilities of ascertaining of four principal landscape changes in Czechia in the three monitored periods and a publication with principal results is being prepared (Atlas of the landscape of the Czech Republic). We will try here to explain by this method landscape processes on the territory of Prague and of its background. The oldest period (1845–1948) includes in Czechia the period of ongoing increase of the area of agricultural land, mainly of arable land, which went on till the late 1880s. Then the extent of both key categories began to stagnate and slowly decrease to reach the maximal decrease after World War II. It can be said in general that these trends are similar also in other regions of Europe (Kraussmann et al. 2005). But Prague urban region does not correspond to this trend, land use intensification both in Prague and in the two rural districts began some 20–30 years earlier. From the viewpoint of Hägerstrand's time–space geography, we

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[1] The method is based on a simplification of area structure to five principal categories: arable land and permanent cultures, meadows and pastures, forest areas, built-up and the remaining areas, water areas. In this structure, positive and negative values of structure changes of such unified categories are determined between two time horizons. The part of the highest positive value on the sum of all positive changes in calculated (increase of the area of unified categories) and if it is higher than 75 % it a strong, 50–74.9 % a mean and 25–49.9 % feeble process of intensification of farming, grassing down, forestation or urbanization.

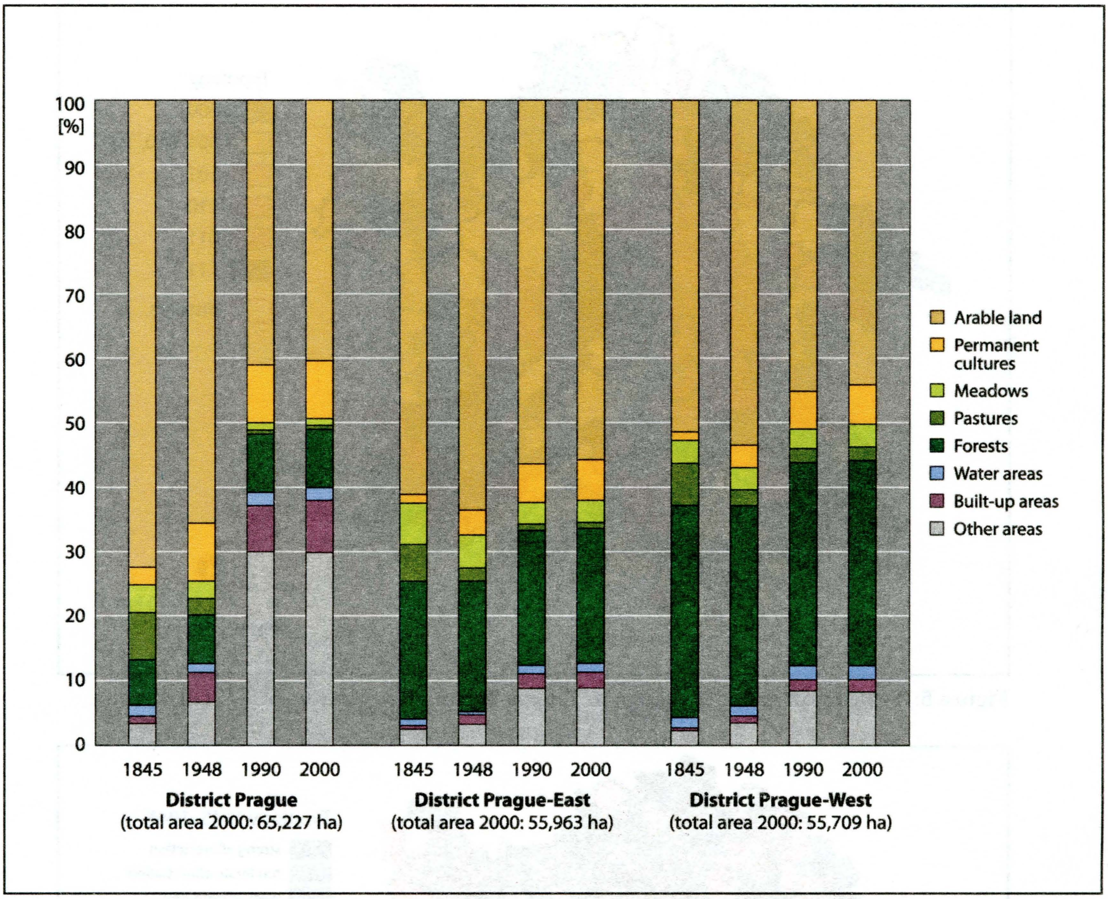

Fig. 1 – State and development of land use structure in Prague and in Prague-East and Prague-West districts in the years 1845 – 1948 – 1990 – 2000. Source: LUCC UK Prague.

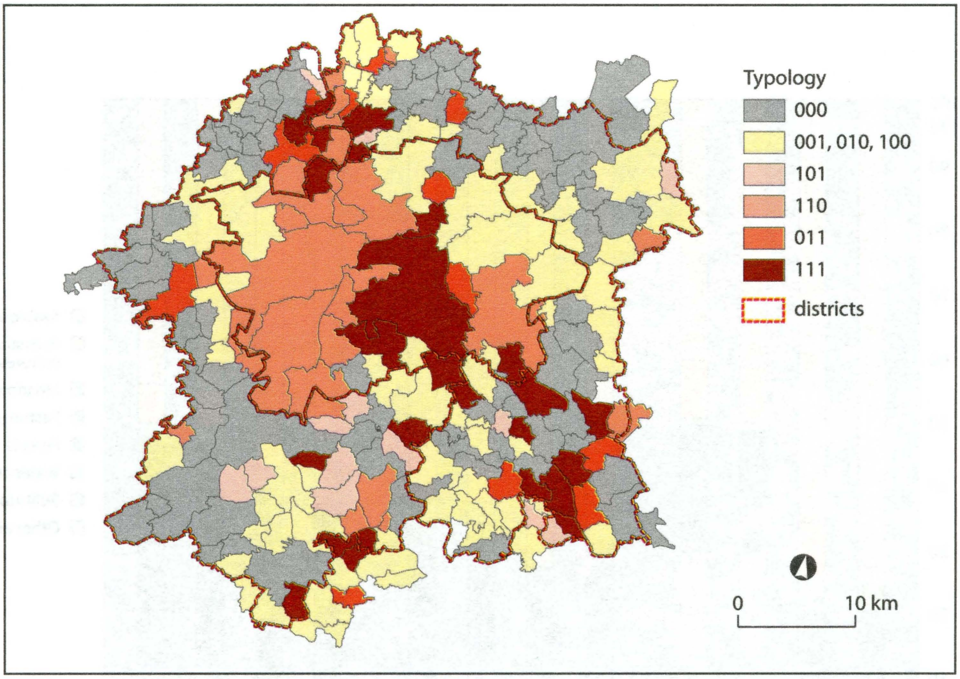

Figure 5: Typology of index of change in Prague urban area. Source: LUCC UK Prague.

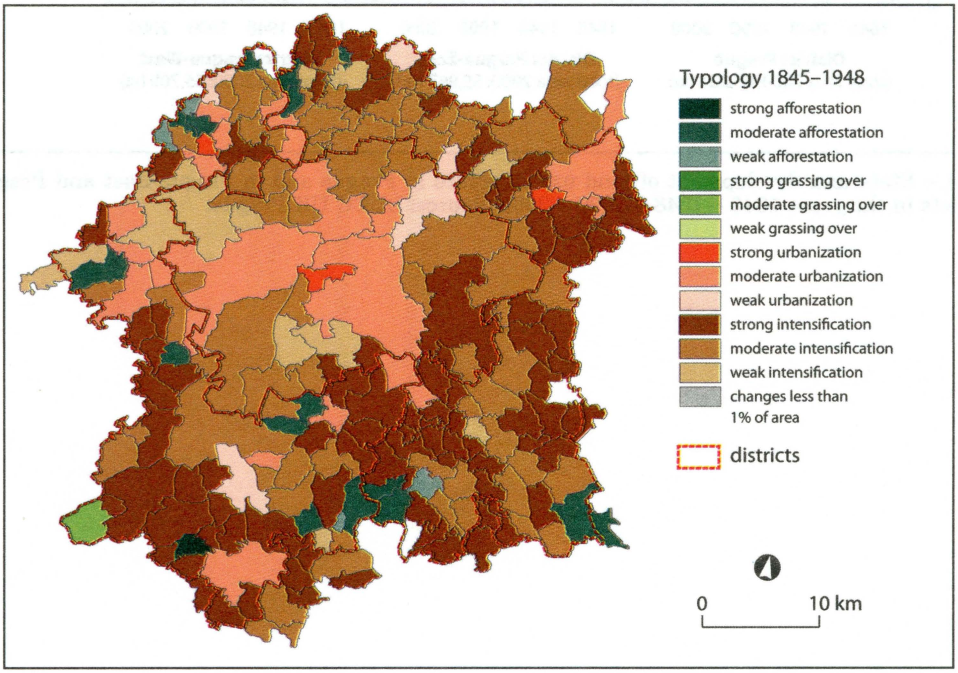

Fig. 9 – Typology of main landscape processes in the years 1845–1948. Source: LUCC UK Prague.

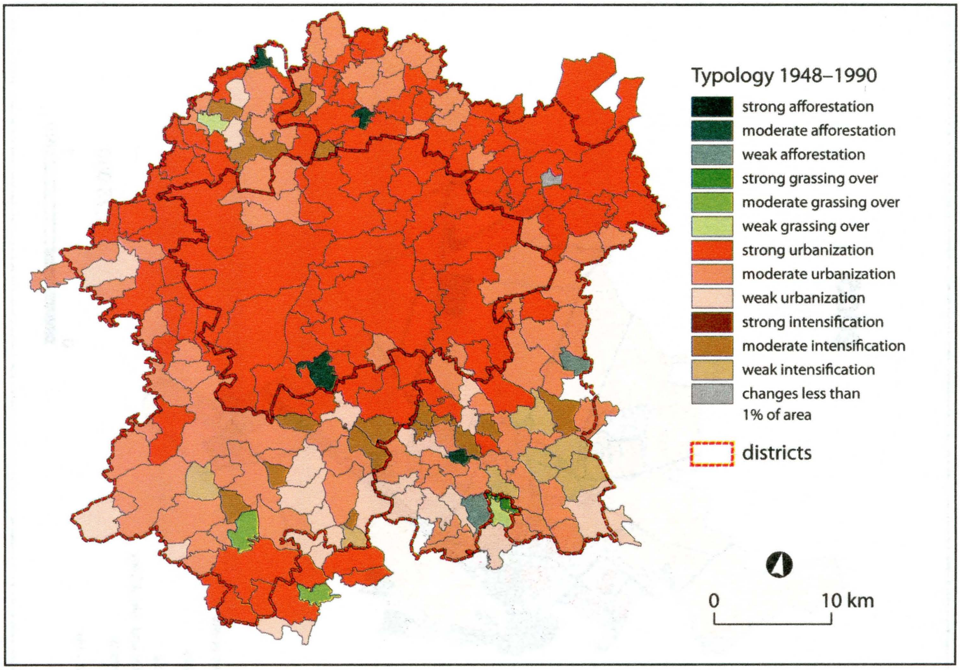

Fig. 10 – Typology of main landscape processes in the years 1948–1990. Source: LUCC UK Prague.

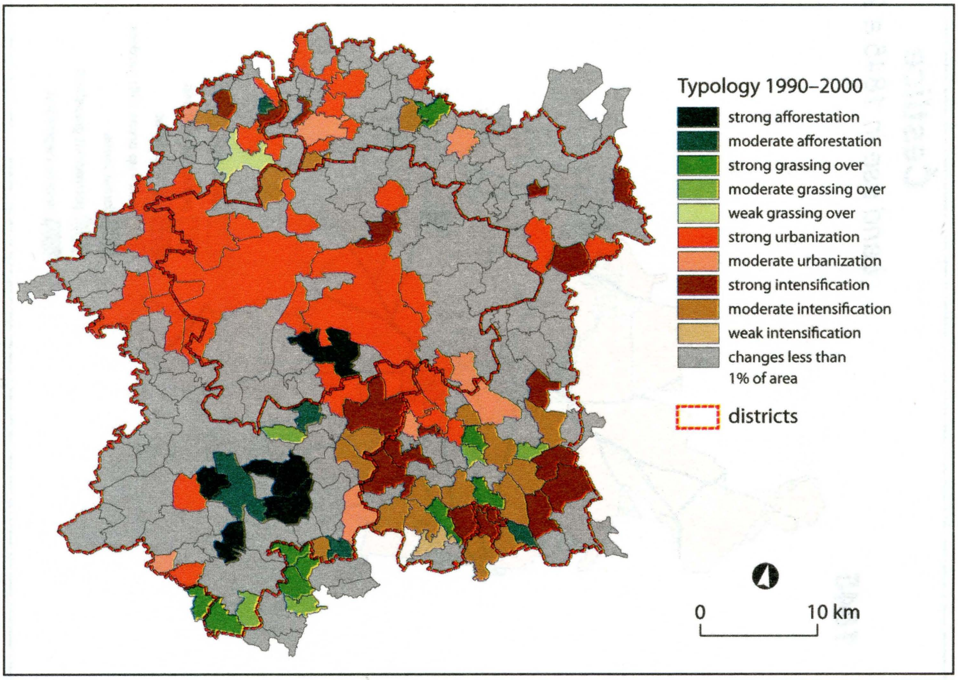

Fig. 11 – Typology of main landscape processes in the years 1990–2000. Source: LUCC UK Prague.

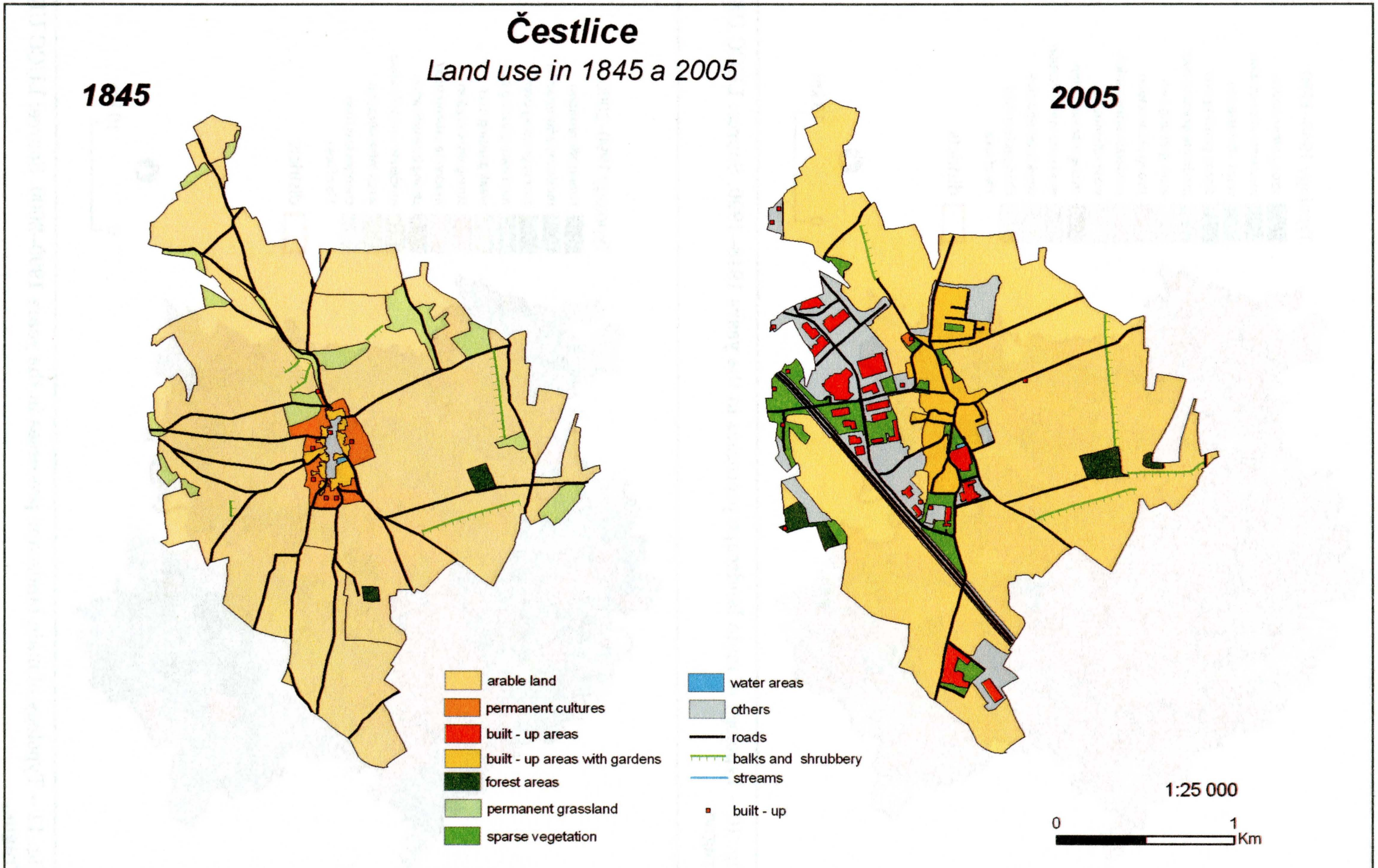

Fig. 12 – Lnad use structure in Čestlice in 1845 and 2005. Source: LUCC UK Prague.

should evaluate the analysed territory as a core, from which the given innovation (intensification of land use and changes) spread to other regions.

The figure 9 documents this period and shows quite clearly that it is a period of a significant intensification of agricultural land use. In fact, out of the 204 BTUs of Prague urban area only a small part (44) manifests other dominating processes than a strong and mean intensification of farming. This defines the role of background of the proper core of the town in this period as strong production-supply functions of a large consumer centre, Prague. It is interesting that even in this period, there are, within Prague urban region, several BTUs with a mean and feeble development of forested areas.

The second, totalitarian period (1948–1990, see fig. 10) is characterized by a generally clear trend corresponding to what has been ascertained for the territory of the Czech Republic, i.e. dominance of urbanization processes. It is only logical that in the territory of Prague urban region these processes of increase of built-up and the other areas are probably the most intensive; in various intensity, they characterize the move in area structure in more than 85 % of BTUs of Prague agglomeration. We could probably generalize the thesis that in that period the increase of built-up and remaining areas is as dominating as in the first period of intensification of agricultural use of the landscape of Prague agglomeration.

The transformation period (1990–2000, see fig. 11), contrary to both precedent ones, is characterized rather by a variety of main processes of different intensity. Because this period is sensibly shorter, it is not surprising that the general dissimilarity of principal landscape changes is much smaller than in both previous periods. The town core itself manifests rather an urbanization process, i.e. a prevailing increase of built-up and remaining areas. In the background of both rural districts in the NW and SE axes, cartograms display even some rather unexpected trends, undoubtedly influenced by different ideas on restituted land use by their owners in comparison with land users in the totalitarian period. We have in mind rather surprisingly dominant processes of grassing, forestation or intensification of farming in some BTUs. As the process of restitution of land resulted in a substantial fragmentation of land tenants and landowners, use of restituted lands in this period is quite diversified. We suppose that general pressures of development requirements of the town and of its agglomeration will manifest, in the following period, rather by a weakening of surprising tendencies in land use in Prague background from the years 1990–2000.

5. Conclusions

GIS application enabled in this paper to analyse, with the help of the LUCC UK Prague database, long-term trends in land use in Prague and its background. It is a pity we cannot form further time horizons to study still more in detail the trends connected with increasing development and loss of traditional agricultural functions in this exposed areas of Czechia. But still the existing data from these four time horizons can very well document the trend of area changes parting from the core of an agglomeration to its margins. This trend was documented also by analyses of detailed maps of selected model territories (Bičík, Kupková 2006). In general, there is on the one hand an increase of built-up and the other areas in the direction from the centre to progressively more distant margins of agglomeration and on the other hand other changes in land use structure corresponding to new functions of an agglomeration at the end of the 20th century. It is rather surprising to ascertain that even in the proper core of agglomeration the forest areas have increased by more than one fourth (up to 9 % in Prague today). The same is true for remaing areas which are now more than nine times larger than in 1845. A similar increase area of permanent cultures is connected above all with a more than triple increase of the area of gardens, which however have substantially changed their function during the observed period from productive to recreational and representative one. It is thus logical that spreading of land use structure changes on the outer margin of Prague agglomeration is more than significant. Originally clearly agricultural functions of this area have during 160 years changed to numerous other functions (living mostly in family houses, recreation, storage, productive, ecological and protective functions, etc.) which, together with growing requirements on living, change the original rural landscape and the structure of its areas.

Land use structure development in the observed territory differs, because of its functions, from the majority of the territory of Czechia. This is characterized by a substantial differentiation of area structure development up to the middle of the 20th century. Under worse natural conditions of Czechia, the area of agricultural, and mainly arable land has decreased, under better natural conditions agricultural land resources have stagnated or even increased. In the totalitarian period (1948–1990), there was practically everywhere in Czechia a decrease in agricultural land resources and mainly in arable land and a sensible increase of built-up and remainig areas. This corresponded also to the development in Prague territory. The recent period of transformation is characterized in Czechia mainly by a substantial increase of permanent grassland on the detriment of arable land, to which the area structure development in Prague background corresponded only partially. The development in Prague urban region only in older periods partly corresponded to the area structure development in other parts of Czechia, recently, mainly after 1980, not only the core itself but also the outer territory of the PUA have becoming more and more different. There, especially during the last ten years, a very strong suburbanization process has been going on with an exceptional impact on area structure. Although it is dominated mainly by building of family houses (very reduced during the totalitarian period), impacts on landscape and area structure are extraordinary especially in places of concentrated service/storage development. An example of such territory is for instance Čestlice on the southeastern margin of Prague, where the present state is the result of the development of last ca 12 years (fig. 12).

General trends in area structure indicate that during the monitored 160 years, there occurred in Prague agglomeration a differentiation of the core area of Czechia from the area structure development in other territories as well as territorially differentiated changes within the PUA. Main transport axes of railway and road transports influence intensive changes in land use structure by stronger impacts of suburbanization. This manifests also by a different land use structure development in northern and southern background of Prague. The southern background has better natural conditions both for building of new family houses and for recreation and its changes in area structure are influenced also by changes in agricultural policy. In the past, agricultural enterprises under worse natural conditions were largely subsidized. This maintained a higher part of arable land in territories, where it is now substituted by permanent grassland and that both officially (with change of category in area evidence) and unofficially (arable land laying fallow for more than four years). Especially the southern margin of Prague agglomeration manifests recently rather surprising changes in area structure as forestation or grassing as dominant landscape processes. Exactly in this territory the possible problems are connected with transformation of many recreation houses to permanent residences, especially in localities near main communications to Prague (as a rule up to 40–50 minutes to the centre). This causes and in future will cause problems in these localities with regard to territorial planning and new residential functions influencing traditional recreation localities (noise, dust, increased traffic, problems with water, wastes, etc.).

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Shrnutí

ZMĚNY VYUŽITÍ PLOCH V PRAŽSKÉ AGLOMERACI

Aplikace GIS umožnila v tomto příspěvku hodnotit pomocí databáze LUCC UK Prague dlouhodobé trendy využití země v Praze a zázemí. Je škoda, že není možné vytvořit další časové horizonty jimiž by mohly být studovány ještě podrobněji trendy spojené s narůstající zástavbou a ztrátou tradičních zemědělských funkcí v tomto exponovaném prostoru Česka. Přesto i na uvedených datech z těchto čtyř časových horizontů je velmi dobře dokumentován trend přeměny ploch z jádra aglomerace směrem k jejím okrajům. Tento trend jsme dokumentovali i analýzami podrobných map vybraných modelových území (Bičík, Kupková 2006, v tisku) a jde v podstatě jednak o nárůst zastavěných a ostatních ploch směrem od centra ke stále vzdálenějším okrajům aglomerace a jednak o další změny struktury ploch odpovídající novým funkcím aglomerace na v konci 20. století. Poněkud překvapivé je zjištění, že i ve vlastním jádru aglomerace vzrostl rozsah lesních ploch o více než čtvrtinu (na dnešních 9 % výměry Prahy), stejně jako nárůst ostatních ploch na více než devítinásobek proti roku 1845. Podobné zvětšení ploch trvalých kultur je spojen především s více než trojnásobným nárůstem ploch zahrad, které ovšem za sledované období podstatným způsobem změnily svoji někdejší funkci produkční na dnešní funkce rekreačně reprezentační. Je proto do značné míry logické, že šíření změny struktury ploch se na vnějším okraji pražské aglomerace jeví jako velmi výrazné. Z někdejší jednoznačně zemědělské funkce se totiž tomuto území po 160 letech přisuzují četné další funkce (bydlení převážně v rodinných domech, rekreační, skladové a výrobní, ekologicko- ochranné atd.), které spolu s rostoucími nároky na bydlení mění původní venkovskou krajinu a její strukturu ploch.

Vývoj struktury ploch se ve zkoumaném území vzhledem k funkcím odlišuje od většiny území Česka. To je charakterizováno značnou diferenciací vývoje struktury ploch až do poloviny 20. století. V horších přírodních podmínkách Česka ubylo zemědělské a zvláště orné půdy, v lepších přírodních oblastech zemědělského půdního fondu stagnuje či se dokonce rozšiřoval. V období totality (1948–1990) prakticky všude v Česku ubylo zemědělského půdního fondu a zvláště orné půdy, a výrazně narostly plochy zastavěné a ostatní. Tomu odpovídal i vývoj na území Prahy. Poslední období transformace charakterizuje v Česku především výrazný nárůst trvalých travních porostů na úkor orné půdy, čemuž jen zčásti odpovídal vývoj struktury ploch v zázemí Prahy. Vývoj v pražském městském regionu tedy jen ve starších obdobích zčásti odpovídá vývoji struktury ploch na ostatním území Česka, v novější době, především po roce 1980 se stále výrazněji odlišuje nejen vlastní jádro, ale i vnější území aglomerace. V něm se především v posledním desetiletí realizuje silný suburbanizační proces s mimořádnými dopady na strukturu ploch. I když mu dominuje především výstavba rodinných domů (za totality silně potlačená) dopady na krajinu a strukturu ploch jsou mimořádné především v místech koncentrované obslužně skladové zástavby. Takovým územím jsou např. na jihovýchodním okraji Čestlice, kde současný stav je výsledkem vývoje posledních 10–12 let.

Celkové trendy ve struktuře ploch naznačují, že v průběhu sledovaných 160 let v pražské aglomeraci dochází jak k odlišení jádrového prostoru Česka od vývoje struktury ploch v ostatním území, tak k územně diferencovaným změnám v rámci aglomerace. Hlavní dopravní osy železniční či silniční dopravy ovlivňují intenzivnější změny využití země silnějšími procesy dopadů suburbanizace. To se projevuje i v odlišném vývoji struktury ploch v severním a jižním zázemí Prahy. Jižní zázemí má lepší přírodní podmínky jak pro výstavbu nových rodinných domků, tak i tradice rekreačních funkcí a jeho změny ve struktuře ploch jsou ovlivněny i změnami zemědělské politiky. V minulosti byly zemědělské podniky v horších přírodních podmínkách výrazně dotovány. To udržovalo vyšší podíl orné půdy v území, která je dnes nahrazována trvalými travními porosty, a to jak oficiálně (se změnou kategorie v evidenci ploch), tak neoficiálně (orná půda ležící ladem déle než čtyři roky). Právě již-

ní okraj aglomerace Prahy vykazuje v posledním období změny ve struktuře ploch poněkud překvapivé, jako je zalesňování či zatravňování jako dominantní krajinné procesy. Právě v tomto území jsou i potenciální problémy spojené s přeměnou četných rekreačních chat na objekty trvalého bydlení a to zvláště v lokalitách s dobrou dostupností hlavních komunikačních tahů na Prahu (zpravidla do 40–50 minut do centra). To vyvolává a v budoucnu spíše ještě více vyvolá problémy v těchto lokalitách jak z hlediska požadavků územního plánu, tak z hlediska nových obytných funkcí rušících tradiční rekreační lokality (hluk, prašnost, zvýšená doprava, problémy s vodou a odpady atd.).

Obr. 1 – Stav a vývoj struktury ploch v Praze a okresech Praha–východ a Praha–západ v letech 1845–1948–1990–2000. Pramen: LUCC UK Prague.
Obr. 2 – Vývoj indexu změny v letech 1845–1948 na území pražského městského regionu (PMR). Pramen: LUCC UK Prague.
Obr. 3 – Vývoj indexu změny v PMR mezi lety 1948–1990. Pramen: LUCC UK Prague.
Obr. 4 – Vývoj indexu změny v PMR mezi lety 1990–2000. Pramen: LUCC UK Prague.
Obr. 5 – Typologie indexu změny v PMR. Pramen: LUCC UK Prague.
Obr. 6 – Standardizovaný index změny na 10 let v PMR mezi lety 1845–1948. Pramen: LUCC UK Prague.
Obr. 7 – Standardizovaný index změny na 10 let v PMR mezi lety 1948–1990. Pramen: LUCC UK Prague.
Obr. 8 – Standardizovaný index změny na 10 let v PMR mezi lety 1990–2000. Pramen: LUCC UK Prague.
Obr. 9 – Typologie hlavních krajinných procesů v letech 1845–1948. Pramen: LUCC UK Prague.
Obr. 10 – Typologie hlavních krajinných procesů v letech 1948–1990. Pramen: LUCC UK Prague.
Obr. 11 – Typologie hlavních krajinných procesů v letech 1990–2000. Pramen: LUCC UK Prague.
Obr. 12 – Struktura ploch v Čestlicích v roce 1845 a 2005. Pramen: LUCC UK Prague.

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JIŘÍ HORÁK

TRANSPORT ACCESSIBILITY EVALUATION

J. Horák: *Transport accessibility evaluation.* – Geografie–Sborník ČGS, 111, 1, pp. 115–132 (2006). – Theoretical means of accessibility measures are applied mainly for transport accessibility evaluation. Analyses of transport accessibility are usually based on data collected during census. Nevertheless its results for commuting are published with remarkable delays. Monitoring campaigns organised by specialised companies represents another possibility, but the cost of such a statistical campaign is relatively high. The other possibility is the application of network analysis in the environment of geographic information systems for the evaluation of non-public individual transport. For evaluation of transport accessibility using public transport means, the analysis of time schedules can be applied. It is possible to evaluate existing public transport connections, analyse selected conditions, evaluate real costs of commuting, conditions of commuting like number and waiting time for changing and apply a Monte Carlo simulation approach to evaluate not only average conditions but also the range of commuting conditions (which can be next utilized with a probabilistic approach). The selected presented methods were applied and tested for Bruntál district in Czechia. The transport accessibility was studied from the point of view of commuting to work and a comparison with the situation in the labour market was undertaken.
KEY WORDS: transport accessibility – GIS – network analyses – public transport – commuting.

1. Introduction

The description and analysis of transport accessibility have both a significant impact in decision making for new investments where the placement of a new facility depends on the relative advantageousness of the location as well as in the personal choices of migrating people. The transport accessibility of basic services (job, education, health, culture, administration) has to be assured to a satisfactory level and the local/central governments should support public transport in an appropriate way that is connected with non-neglected requests to their budgets. An insufficient level of transport accessibility of employers could be accompanied by a higher level of unemployment, notably in certain professions with low incomes. Special attention has been paid to the analysis of transport accessibility for the location of emergency services.

2. Measures of accessibility

The concept of accessibility of geographical objects has been studied since the 1950's. The accessibility is measured by specific indicators, which describe the position of a relevant object in the frame of spatial structure on the basis of connectivity and distance of this object to other objects. Thus, the accessibility is a geographical feature of the object. Its evaluation utilises distance measures inside a point or line pattern.

Measures of accessibility can be divided according applied metrics to: distance-based, time-based, topological, cost, others. The accessibility can be evaluated in relation to other criteria, e.g. proposed travel means. From this point of view the most significant variants to be studied are non-public individual transport and public collective transport.

The most frequent indicator of accessibility utilises the length calculation of the path in the graph (indicator of travel accessibility). The graph represents a model of a transport network; where accuracy depends on the scale and the level of generalisation. Thus, the result is certainly highly influenced by the model abstraction level and its quality. Usually network analyses for searching shortest path in GIS environment are applied.

The best travel accessibility has the location with the smallest value of indicator:

$$D_i^C = \sum_j d_{ij}^c$$

D_i^C indicator of travel accessibility in location i
d_{ij}^c length of the shortest path from the location i to j
i index of the source
j index of the target

Other variants of accessibility indicators can be obtained by substitution of usual metric distance by time evaluation of the path or by application of topological measures (number of connections etc.). Number of connections was used e.g. by Rölc (2001) for an evaluation of transport accessibility of regional centers. Some accessibility measures can also include human well-being indicators which trend to incorporate human properties and behaviour into the model (e.g. physiological index of weariness with respect to commuting described by Hůrský 1969).

Simple measures of accessibility (presented above) suppose all geographical objects (sources and targets) are equal and evaluated with the same weight in the model. The more advanced models applied different weights to targets (especially different attractiveness of the targets). Typical measures of attractiveness are based on population (resp. segment of population). The application of the attractiveness represents the first step in the change to apply a general gravitation model (models which maximise the entropy). The gravitation model is used for various purposes. The description of theoretical relationships among urban centres in Czechoslovakia based on such a model was provided by Řehák (1992). An adjusted gravity model was applied to test an influence of urban spatial structures to commuting patterns in Seoul Metropolitan Region (Sohn 2005).

3. The transport accessibility analyses

One of the many references to the practical application of accessibility analysis shows Bracken (1994), who describes the results of studying of general practitioners accessibility. Burrough et al. (1998) similarly documented the analysis of car ambulance accessibility (applied limit is 9 minutes), but also the working positions accessibility in the western part of the Netherlands expressed in transport time by means of individual automobile and also by public transport.

The comparison of public and individual transport accessibility associated with the critical assessment of the gravity model and the exploitation of a GIS environment was shown by Hansen (1996). The continuous need for theoretical and empirical research on relationships between accessibility, option values and non-user benefits, and the measurement of different components of accessibility was emphasised by Geurs and Wee (2004).

The role of public services in the transport model differs between countries. The relatively high level of bus transport density in countries of previous communist block was documented by Jordan (1995). Czechia can be characterised as one of the countries where the extent of public transport is still relatively high in spite of continuous increases in the use of individual transport. Thus, the evaluation of public transport accessibility cannot be neglected. Additionally, these analyses allow for the possibility to evaluate the geographical conditions of the territory.

The following main methods appropriate for transport accessibility studies can be applied:

- analysis of census results
- survey, territorial monitoring
- analysis of data collected by transport providers
- network analysis
- analysis of time schedule of public transport
- socio-economic models (e.g. gravity model, regression model).

Selected methods as well as their advantages and disadvantages are described in more detailed.

3. 1. Analysis of census results

The census represents an important source of information essential for various analyses and evaluations. Also analyses of transport accessibility usually benefit from the census results. The statistics are organised according gender, age, main economical sectors, frequency of commuting and time spent by commuting (in categories).

Nevertheless, censuses are organised with 10 year intervals and the results for commuting are published with substantial delays – e.g. in Czechia usually more than 2 years. If the evaluation of the current situation represents the objective, such postponing of data supply is evidently unsatisfactory. The data cannot reflect the changes of employment structure and commuting destinations in connection with the change of employers, whether it concerns their location change or orientation or even their existence. Such changes have been recorded quite often in the last decade and the constantly changing situation in the labour market typical for all market economies will always be responsible for a disparity between historical data from census and the actual situation.

The second issue of census utilisation is connected with the aggregation level of the published results. The results are processed usually to quite a rough form, the documented time of commuting are classified by 15–30 minutes steps and, in particular, this time does not distinguish between the walk time and transport time, commuting to work and commuting to education etc. Even more, persons with alternative accommodation fill in the questionnaire with the time of commuting from the alternative location instead of their residence (Horák et al. 2004). This fact complicates the evaluation of data processing. We cannot be sure that the stated time corresponds to the commuting from the present residence location (that is known) or from the alternative accommodation the location of which is unknown.

3. 2. Surveys and analysis of data collected by transport providers

Another possibility is represented by surveys organised by specialised companies, which can provide detailed results in one time slice. Generally, the frequency of customers in the personal public transport has been monitored (the number of transported persons, the number of persons getting on board at the individual pickup points etc.). Unfortunately, the cost of such a statistical campaign is relatively high and cannot cover large areas with full details. It is not possible to infer the share of commuting to work. Organizationally less demanding would be the theoretical possibility of ticket-sale data exploitation but the personal public transport companies do not want to provide such a data because of their competitors. There also remains the disadvantage of impossibility to distinguish the reason of travelling.

Also, it is possible to insert into this group of instruments, the experts' opinion on the situation in a certain location or alternatively to exploit the database of transport providers, generally available by non-private subjects providing the emergency services, e.g. fire brigade and ambulance. This information can be exploited not only for evaluation and improvement of a special transportation but also wider for evaluation of the local transport situation.

3. 3. Network analysis

The transport situation can be transformed into a topologically correct network (graph). It represents a model where every segment can be evaluated in an appropriate way (time, velocity, conditions, etc.) and utilised in network algorithms based on graph theory. Network analysis can be applied to find the best route between two nodes, to solve the "salesman problem", for location and allocation of facilities etc. Due to automation of processes in GIS it is able to calculate all transport combinations for commuting between nodes which cover all settlement and all destination locations in the area (application e.g. in Cometti et al. 1996). The resolution of node locations should be satisfactory in respect to acceptable walking distance. Then the evaluation of all routes and analysis of the transport accessibility for any location by individual transport means follows.

Usually, the algorithm for searching the shortest path (e.g. Dijkstr algorithm) is applied. The algorithm finds the shortest connection between 2 locations in the network (nodes), records the path and calculates the time needed to travel along this path. It is assumed that a person, who regularly commutes, selects the shortest path from all possible ones.

It is evident that the results of the analysis are not influenced by the algorithm type selection but above all by the adequacy of prepared network model. All of the significant transport flow lines have to be included in the model. It is not simple to designate which flow lines may have significant influence on the model above all in the case of towns and agglomerations. There it is necessary to define the connection restrictions (e.g. one way streets) and to set up the impedance of individual network segments properly (generally the time needed to go through the segment). The impedance is usually determined on the basis of time allocation according to the speed, assigned to the whole class of given type of communication. More advanced models also enable one to apply impedance of nodes, which can represent an average delaying at the crossing. The greatest deviation from reality happens here. It is possible to achieve better results by individual segments calibration according to the real travel time between 2 places. For calibration the analysis of time schedule or census results can be used. Of course there also remain certain model limits, given by the applied assumptions such as the constant speed of the given road segment, convenient meteorological conditions and stable traffic density.

4. Analysis of time schedule of public transport

For evaluation of transport accessibility using public transport means the analysis of time schedules can be applied. Due to the required extent of processing it is needed to find out an appropriate way to process and evaluate thousands of requests for commuting. Clearly, a digital form of time schedules and a special programme application have to be used here.

We utilised a DOK programme, which is tailored for searching in time schedule IDOS (application for travel connection searching). The programme operates in two time-separated steps. In the first step it opens the database, where the user inserts the input parameters of the searched connections. DOK reads the database and as soon as it reaches the demand that has not been searched yet it reads its input parameters that than inserts into users' interface of the IDOS application and starts the connection searching. As soon as the IDOS finds the connection, DOK lets the found connection to be saved into the text file. In the second step the DOK searches through the text file and identifies the parameters of found connection. It saves the results of this processing into the database. Results stored in the database can then be easily processed and evaluated.

The main advantages of automated processing can be seen in:

- evaluation of existing (or planned) public transport connections
- extended processing of thousands of commuting requests with automation of result evaluation
- analysis for selected conditions (e.g. commuting in the specific time)
- evaluation of real costs of commuting
- evaluation of conditions of commuting like number and waiting time for changing
- possibility to apply a Monte Carlo simulation approach to evaluate not only average conditions but also the range of commuting conditions (which can be next utilised with probabilistic approach or bulk service approach)
- low cost of analysis
- reiteration in any time.

The weakness of this method can be found in the need for an appropriate parameters setting (parameters for commuting like requested time of departure or arrival which can, however, be overcome by the mentioned simulation approach), appropriate evaluation of results (evaluation of different parameters of found connections), selection of probable commuting destinations (decreasing uncertainty connected with decision taking about commuting from a studied residential area).

4. Case study

The main objective was to evaluate transport accessibility in the pilot area with application of different methods, verify these methods, document their advantages and disadvantages, and compare results from different processing procedures. The second objective was the comparison of the level of accessibility with indicators of the unemployment situation. The initial assumption was the level of unemployment depends in an indirect way upon transport accessibility, thus the locations with good transport accessibility should show significantly lower levels of unemployment.

Also the motivation to commute was studied on the basis of calculation of real labour costs including travel costs.

The transport accessibility was evaluated for each part of the municipalities. The transport destinations were selected according to the main application, which is the evaluation of transport accessibility for commuting. In our case study, the assumption of the strongest influence of important employers was accepted. Thus, the locations of important employers represent the possible targets. This selection was verified by census results.

The transport accessibility was evaluated using network analysis and analysis of time schedule. The first method evaluates the situation for individual means of transport, while the second one provides the evaluation of public transport situation.

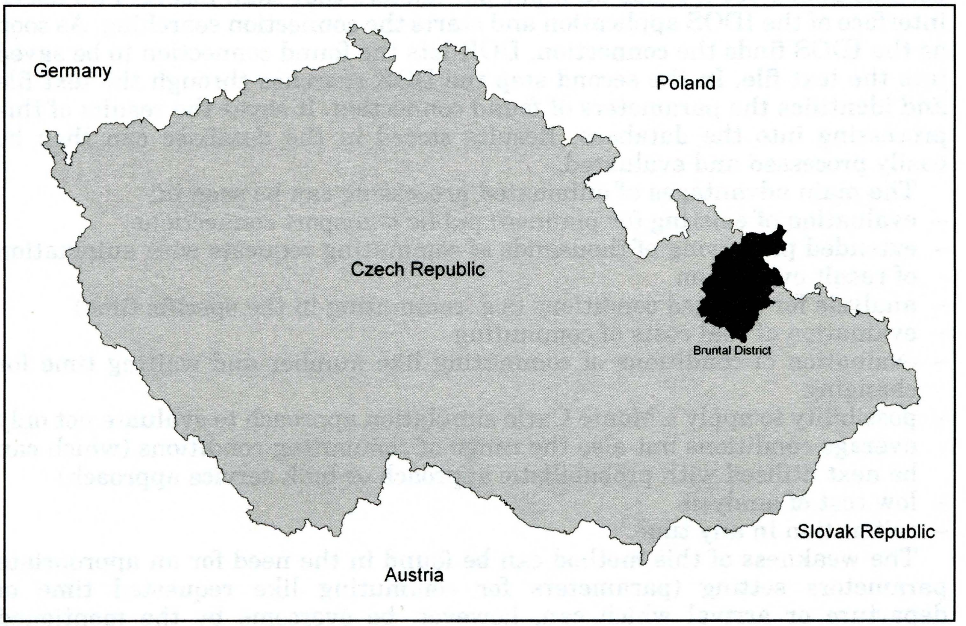

Fig. 1 – Location of the pilot area

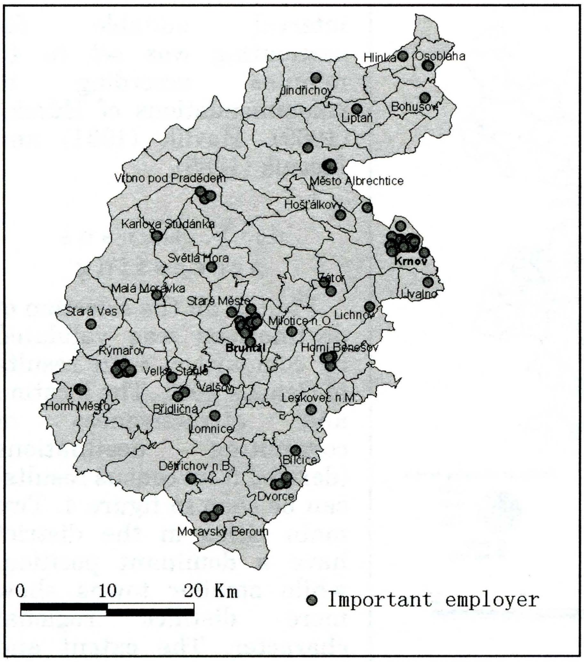

Fig. 2 – Distribution of important employers in Bruntál district (according to the Labour office)

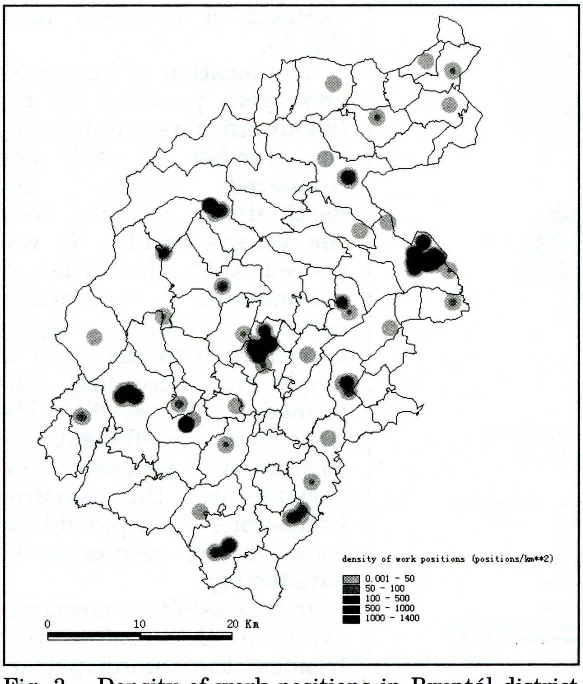

Fig. 3 – Density of work positions in Bruntál district (kernel estimation with a 1000 m wide band)

The study was applied to the territory of Bruntal district in Czechia (fig. 1). This area can be characterised as a problem region with tough geographical conditions (mountainous relief, larger distances and excentricity of transport network, more severe weather conditions, a peripheral position in the country, etc.). The geographical conditions are accompanied. with the high level of unemployment. The seriousness of the labour market situation, indicated relations to the transport accessibility and high interest of local labour offices were the main reasons for the selection.

Important employers were identified in collaboration with the local labour office. There the employers employing of 50 and more employees were chosen. The employers of the neighbouring regions were not included into the processing in this stage according to a recommendation of experts from the local labour office. The peripheral and mountainous character of the studied area are likely to decrease a possible bias.

The location of important employers can be seen in figure 2. A better image of distribution of work positions is obtained after kernel processing of employer's capacity (fig. 3). The resulting pattern indicates probable destinations of commuting and their attractiveness. Other parameters used for analysis can be found e.g. in Horak et al. (2005). The time

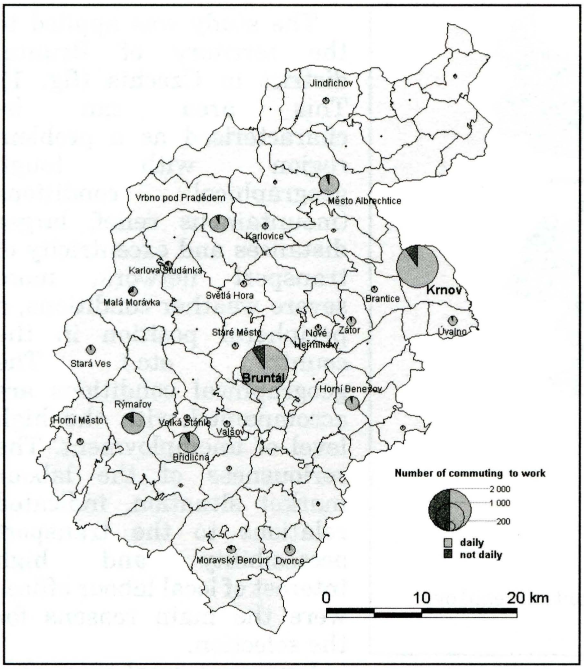

Fig. 4 – Number of persons commuting to work inside the Bruntál district (according to the Census 2001)

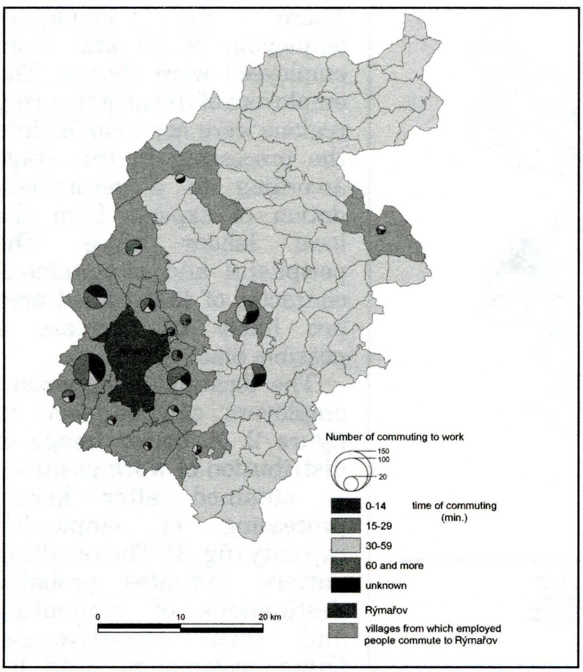

Fig. 5 – Commuting to work in Rýmařov town (according to the Census 2001)

interval suitable for commuting was set to 45 minutes according to recommendations of Hůrský (1969), Havlík (1981) and Líčeník (1985).

4. 1. Census processing

First of all the selection of destinations was validated by comparison with results of Census 2001. The location and attractiveness of commuting destinations (derived from census results) can be seen in figure 4. Two main cities in the district have a dominant position, while smaller towns show more distinct regional character. The extent and local character of the commuting catchment can be demonstrated on the example of Rymarov town (fig. 5).

The location of important employers provided by the labour office were ordered by the number of staff and compared with the destinations obtained from the census results. It was proved that the order of destinations according census results highly correlates with the order of employers according the number of staff. The Spearman coefficient of correlation reached 0.7. Considering the existing limitations, it is possible to consider the results to be satisfactory.

It is possible to positively evaluate the reality that besides the municipalities scheduled in the last and next to last place, all of the municipalities with the significant destination of the commuting to work from the evidences of the labour offices were identified.

We can conclude that the comparison of destinations approves the satisfactory utilisation of important employer's locations (from 50 and more employee) from the monitoring of labour offices. The determination of order for destination appears to be less valid.

4. 2. Network analysis

To evaluate the individual transport accessibility, network analysis of the studied territory was provided. The transport serviceability of the significant employers has been evaluated by means of number of municipalities from which it is possible to commute to the employers. This indicator controls the catchment area of the individual employers and documents their advantage in view of their accessibility for potential employees.

The road network model was constructed from the digital topographical map (based on a map with scale 1 : 25 000). Each line segment of the model was classified according to the communication category and then evaluated on the basis of recommended travel velocity for a common car. Next year, a more detailed subdivision of the last categories was undertaken (connected with appropriate travel velocity) and it resulted in improved behaviour of the model.

Next, the analysis of the shortest path between start and destination goal of the commuting, has to be processed as an automatic subroutine due to the extent of processing. The program searched the path between each part of the municipalities in the Bruntal district (165 locations). Together, 13 530 shortest paths were determined. The locations were read from the database and parameters of found paths (from, to, time, length) were also recorded to the database. Finally, results were summarised, visualised and evaluated (Peňáz 2005).

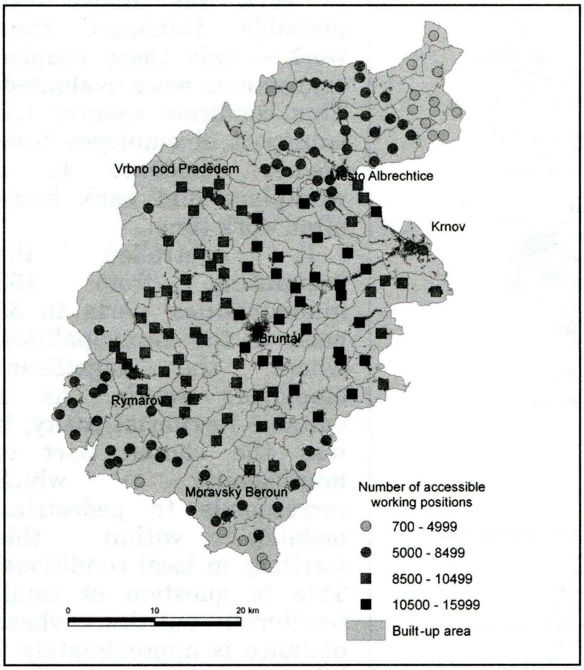

Fig. 6 – The number of working positions provided by the significant employers accessible by individual transport to 45 minutes

The analysis of available working positions did not bring us some new and unexpected results, due to relatively good connectivity (fig. 6).

The analyses were undertaken with the support of ArcGIS 8.2 Workstation, modules ARC, ARCPLOT, ARCEDIT a NETWORK, and partially ArcView GIS 3.2 for operative control and processing (tab. 1).

Table 1 – Average velocity for drive on these segments

Category of communication use	Parameters in 2003	Parameters in 2004
	Average velocity (km.hour^{-1})	Average velocity (km.hour^{-1})
Highway	85	85
Road 1st category	75	75
Road 2nd category	55	55
Main passage	40	40
Street	35	35
Purpose-built communication (including road 3rd category)		40
Consolidated path	30	20
Bridging of railways		30
Others		20

4. 3. Analysis of time schedule

The public transport in this region uses both the train and bus traffic. Both of the types of transport including the eventuality of transport means changes have been considered while searching the connections.

The analyses of time schedules were provided for various parameter settings and results were compared. Commuting for 3 work shifts were tested (1st work shift with 3 possible starting times). In all cases 15 minutes before the beginning of working time was the latest time of arrival. A similar appropriate time interval after finishing working time was set. Any transport to work was linked with probable transport from work – only these coupled connections were evaluated. This condition assures the transport of employee from his/her residence to a workplace and back home after work time.

It controlled the commuting from 153 municipalities' parts to 35 parts of the municipalities, where the significant employers reside. As a suitable territorial entity, it was the chosen part of municipality which corresponds to pedestrian mobility within this territory in local conditions. This is question of small territorial entities, whose distance is approximately 2 kilometres from each other. This decision appears as a suitable compromise among

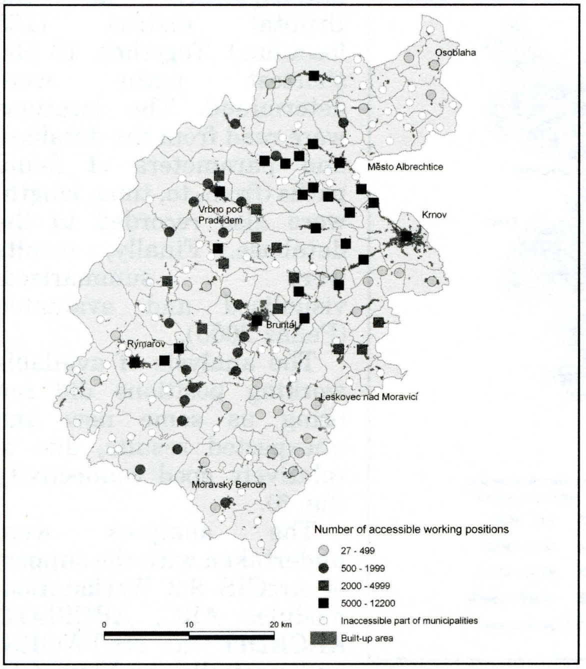

Fig. 7. – The number of work positions accessible the suitable way by public transport to the working hours beginning at 8:00 a.m.

the municipality level and individual transport pick-up points. By each part of the municipality there has been chosen the representative public transport pick-up point from which is the public transport brought into effect.

The commuting has been controlled at two levels – as suitable commuting and theoretical commuting. In the case of theoretical commuting, there it is possible to apply a longer travel time and a sooner departure than in the case of suitable commuting. The result for suitable commuting at 8 a.m. is demonstrated in figure 7.

The following measures of accessibility were tested – the number of accessible municipal parts, the number of accessible important employers and the number of accessible work positions. Also the situations in different years were investigated to verify changes in the model between years.

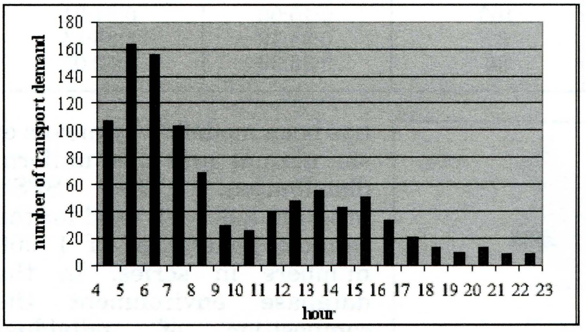

Fig. 8 – The simulated transport demands

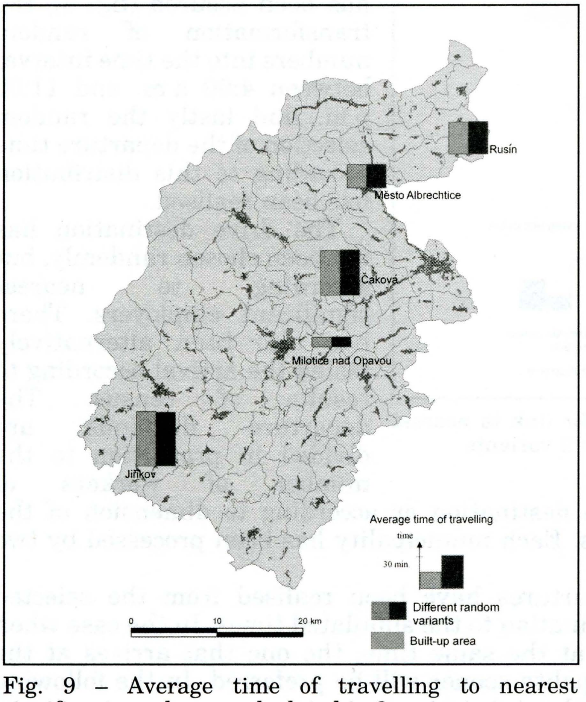

Fig. 9 – Average time of travelling to nearest significant employers calculated in 2 variants

4. 4. Simulation approach to improve analysis of time schedule

By the analysis of time schedules, there appears to be a problem with appropriate parameter settings, e.g. time of departure, arrival, and selected connection limitations. Such issues can be overcome by the simulation access applied for the connection selection.

The main goal of this evaluation was to evaluate the transport service of given municipal parts by means of public transport. The simulation of departure times from 5 selected municipal parts to the 5 nearest parts of municipalities, where the significant employers reside, was undertaken.

The transport demands distribution has been simulated according to the expert assessment of transport demands frequency. The histogram clearly shows the main morning rush hour and a secondary rush hour in the afternoon. The distribution

Table 2 – The selected municipal parts and corresponding number of successful links to given alternatives

Municipality name	No. of variant	Count of successful connection	Average travelling time	Average waiting time for the link
Čaková	11	98	0:48:07	0:54:39
Čaková	12	99	0:47:22	0:55:59
Jiříkov	9	93	0:57:06	3:50:50
Jiříkov	10	95	0:57:56	4:06:01
Město Albrechtice	1	100	0:24:50	0:21:44
Město Albrechtice	2	100	0:24:40	0:22:13
Město Albrechtice	3	100	0:20:41	0:19:55
Město Albrechtice	4	100	0:21:16	0:17:09
Milotice nad Opavou	7	100	0:10:47	0:27:02
Milotice nad Opavou	8	100	0:10:06	0:31:21
Rusín	5	87	0:34:12	1:35:14
Rusín	6	86	0:33:36	1:42:03

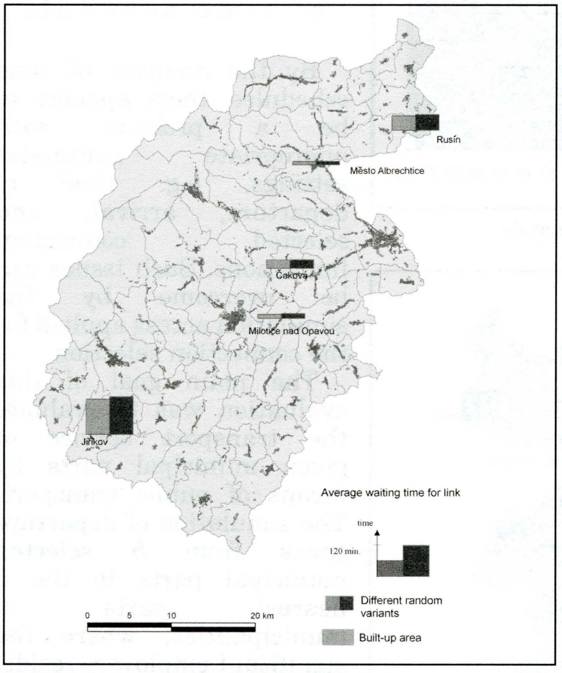

Fig. 10 – Average waiting time for link to nearest significant employers calculated in 2 variants

has been modelled by means of six normal and one uniform distribution. The SPSS program has been used for the random generation of 1 000 numbers in series. In the database environment the composition of individual distribution into the final one has been assured (fig. 8), the transformation of random numbers into the time interval between 4:00 a.m. and 11:00 p.m. and lastly the random selection of the departure time according to this distribution has been realised.

The drive destination has not been chosen randomly, but according to nearest significant employers. There has also been alternatively tested the arrival according to results of census. The departure demands are divided in proportion to the number of workers of significant employers in the destination or according to dimension of the arrival flow in case of census. Each municipality has been processed by two alternatives.

Nearby train or bus departures have been realised from the selected municipality to the final destination to the simulated times. In the case when two traffic channels depart at the same time, the one that arrives at the employer part of the municipality sooner will be preferred. In the following there were preferred links with minimum price.

The results have been simply evaluated. The number of successful found links, average travelling time (fig. 9) and average waiting time for the proper link (tab. 2, fig. 10) are the most interesting indicators.

5. Comparison to the labour market situation

The analyses of transport accessibility play an important role in the evaluation of social conditions. One of the main application areas of transport accessibility is the evaluation of the labour market situation.

An important question for the study of the labour market represents its spatial demarcation, especially for the regional labour market. According to Schubert et al. (1987) the regional labour market can be distinguished on the basis of administrative or functional limits. The administrative determination appears to be more advantageous from the point of view of available data sources. On the contrary, the main disadvantage is artificial way of regional subdivision.

The functional determination of the regional labour market mainly uses the level of commuting into the region core. E.g. according to Fischer and Nijkamp (1987) is the regional labour market defined as spatially delimited area whose borders fulfil the following demands:

- The daily commute to work across this border is inconsiderable
- The cost of commuting and the cost of migration within the region is strongly lower, than between this and another region
- The companies are situated so, that they gain more workforce within the region
- The price of searching a job within the region is much lower than searching in another region.

The concept of horizontal labour market segmentation leads to an assesment of accessibility impact to the employment structure and level. Recently, the study of relationships between accessibility and employment in developing countries was undertaken (Srinivasana S. and Rogersb P.), where the results indicate that differences in accessibility strongly affect travel behaviour.

The importance of commuting to the labour market situation was also emphasized in Czechia (e.g. Hůrský 1969 or with impact to land use planning e.g. Havlík 1981). It has been traditionally asserted that a dependency exists between unemployment situation and transport accessibility. That is why this relationship evaluation in the studied territory was done.

Spearman's correlation coefficient was used to test the relationship between the unemployment indicators and the number of work positions accessible by a suitable connection. 5 indicators of unemployment were used on the basis of previous factor and multiple criteria analysis to the labour market situation characteristics (Horak et al. 2004):

- The unemployment rate
- The proportion of long-term applicants (registered more than 12 months) from the total number of applicants
- The proportion of applicants with the primary education degree from the total number of applicants
- The proportion of applicants primarily demanding the less qualified job
- The proportion of 50 year olds and older- age group from the total number of applicants.

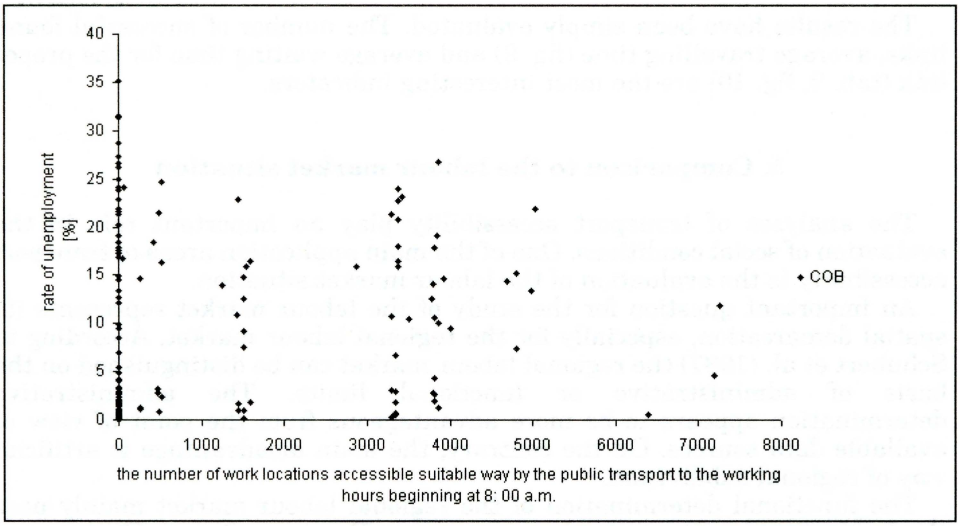

Fig. 11 – Relationship between unemployment rate (31.12.2002–30.9.2003) and number of suitable accessible work positions (important employers, work shift starts at 8 a.m.)

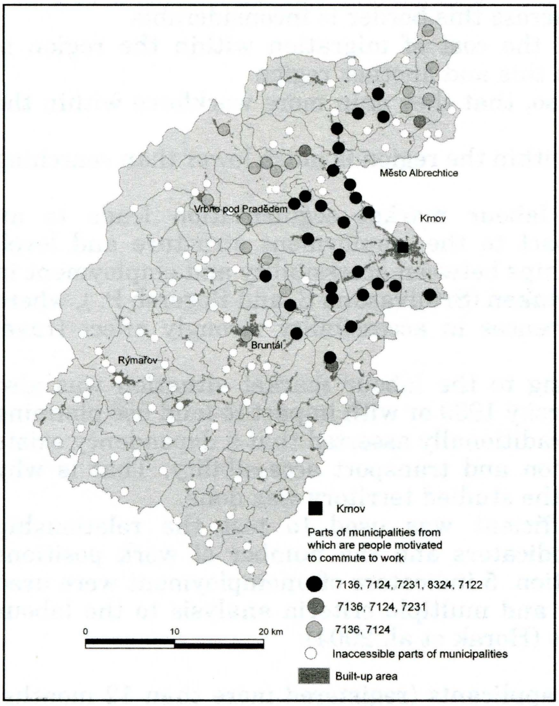

Fig. 12 – The accessibility of the Krnov town to the selected low-income professions. Explanation of professions' codes: 7 136 means fitters, locksmiths, plumbers; 7 124 means carpenters and joiners; 7 231 mechanists and car repair servicemen; 8 324 lorry and power unit drivers; 7 122 bricklayers, stonemasons, plasterers.

The value of correlation coefficient varies from 0.01 to -0.18 according to the indicator and time of commuting. Also the scatter plots did not show any dependency (fig. 11). All results of transport accessibility comparison of both the individual transport and public transport with the unemployment level show that there are no significant relationships to the situation on labour market in the existing transport situation of this area.

The analysis of wage levels provided by Trexima and information about job applicants from the labour office allow us to apply real labour costs in our analysis. Real possibilities of commuting to work in relation to labour cost including the costs connected with commuting were also evaluated. The connections searched from the analysis of timetables have been converted by using the discount information of each transport provider into the real prices of commuting per month.

Average levels of monthly wages were assigned to the individual professions, the gross wage has been by means of 2 alternatives (self-providers and the member of three-member family with the partner with average earnings and the six-year old child) converted into corresponding monthly disposable income. These professions have been further classified from the view of motivation to commute to work into selected locations (fig. 12). The results show the costs of commuting (using public transport) should have no significant effect to the behaviour of workers. It appeared, that limiting is above all the level of remuneration for work and conditions of commuting (in particular the existence of proper connection) (Horak and Sedenkova 2005).

6. Conclusion

The results show that it is possible to use the mentioned variants of employers' transport accessibility evaluation. Over the course of processing a whole range of recommendations to perform such analyses has been proposed.

After evaluation of many variants (various indicators, time schedules for 2 years, conditions for individual lower income professions etc.) following recommendations for parameters setting were proposed:

1. We do not recommend evaluating the theoretical commuting (that with the free conditions of arrival), but the suitable commuting, limited by certain settings (recommended parameters, see the tab. 3).
2. It is not needed to repeat the analysis for any possible starting time. It is enough to use only 1 or 2 times. As suitable we consider the testing of commuting to 6:00 a.m. and to 8:00 a.m. in our conditions, in relevant cases (shift operations demand) also to 2:00 p.m. and 10:00 p.m. (see the tab. 3)
3. We recommend as the most suitable indicator of controlling the accessibility of municipality from the view of commuting to work "the number of accessible work positions at significant employers by commuting to 6:00 a.m.". The important employers can be delimited as employers with average numbers of 50 employees or more. When the details of employee numbers are not available, we advise using "the number of significant employers by commuting to 6:00 a.m."
4. It is not advised to control the commuting price in individual locations and professions in detail, it is sufficient to divide the professions according to their incomes to the groups with no motivation, average and high motivation to commute. Probably, the commuting prices only influence persons' behaviour by choosing locations of their occupation slightly.
5. The inter-annual changes in public transport (PT) do not influence created model in principal that is why it is not evidently important to do the

Table 3 – Recommended parameters of suitable commuting between 2003 and 2004

Work shift starts at	6:00 a.m.	8:00 a.m.	2:00 p.m.	10:00 p.m.
Arrival	5:15 – 5:45a.m.	7:15 – 7:45a.m.	1:15 – 1:45p.m.	9:15 – 9:45p.m.
Departure	2:45 – 3:15p.m	4:45 – 5:15p.m.	10:15 – 10:45p.m.	6:15 – 6:45a.m.
Travelling time	max. 60 minutes			

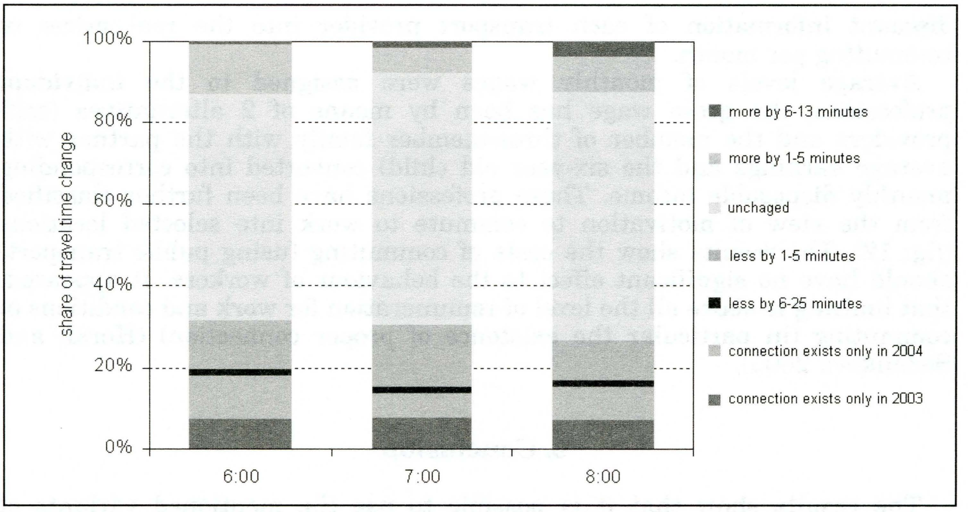

Fig. 13 – The change of travel time in selected departure time

analysis of accessibility of significant employers by means of PT repeatedly in case of slight changes of timetables (fig. 13).

We advise calibrating the models of individual connections (personal transport) by exploitation of relationships of available data from the census (if it is not too obsolete and the situation has not changed obviously) and data of public transport and connections.

The accessibility in the pilot area derived from the public transport differs from those obtained from the individual transport analysis. According to the public transport accessibility results, the part of the central region appears as inaccessible, serious difficulties can be distinguished also in the SW part of the district (differs to individual transport) and N part (similar to individual transport analysis, but strongly expressed). It appeared that the territory accessible by individual transport is larger - as it has been expected. If we would not count in the vehicle amortisation, the individual transport would be more suitable from the view of shorter distances travelling cost (app. 10 km). Of course the travelling time is in most of cases shorter (the exemption is e.g. train transport on a more suitable corridor).

The simulation approach to the link selection (on the basis of transport demands distribution) can be used to remove the problems with setting the parameters of searched connections (time of arrival/departure, limitation of selected connection by abnormal length or price).

The testing of transport accessibility with the unemployment level (described by 5 indicators) did not approve any significant relationship. The results may be used at labour offices by the assessment of commuting conditions and decision making of financial support of commuting to the employer, than by evaluating the level of transport service provision in individual municipalities with the consequences on decision making of support and transport service provision.

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Shrnutí

VYHODNOCENÍ DOPRAVNÍ DOSTUPNOSTI

Teoretická opatření týkající se dostupnosti se používají zejména k vyhodnocení dopravní dostupnosti. Analýzy dopravní dostupnosti jsou obvykle založeny na údajích shromážděných při sčítání lidu. Ovšem výsledky týkají se dojíždění za prací jsou zveřejňovány se značným zpožděním. Monitorovací kampaně pořádané specializovanými společnostmi jsou dalším možným řešením, ale náklady na takovou statistickou kampaň jsou relativně vysoké. Další možností je použití síťové analýzy v prostředí geografických informačních systémů pro vyhodnocení neveřejné individuální dopravy. Pro vyhodnocení dopravní dostupnosti pomo-

cí veřejných dopravních prostředků lze použít analýzu jízdních řádů. Je možné vyhodnotit stávající spoje veřejné dopravy, analyzovat vybrané podmínky, vyhodnotit skutečné náklady na dojíždění do práce, vyhodnotit podmínky dojíždění do práce jako počet a čekací dobu při přesedání a využít simulační přístup Monte Carlo k vyhodnocení nejen průměrných podmínek, ale také škály podmínek dojíždění do práce (což může být dále využito s pravděpodobnostním přístupem či hromadným přístupem).

Vybrané uváděné metody byly použity a vyzkoušeny v okrese Bruntál v Česku. Dopravní dostupnost byla studována z pohledu dojíždění do práce a bylo provedeno srovnání se situací na pracovním trhu.

Doporučujeme kalibrování modelů spojení v individuální dopravě využitím vztahů dostupných údajů ze sčítání lidu (pokud nejsou příliš zastaralé a pokud se stav viditelně nezměnil) a údajů o veřejné dopravě a spojích.

V případě porovnání skutečných nákladů na dopravu a nákladů na pracovní sílu jsme dospěli k závěru, že dojíždění do práce je především limitováno úrovní výdělků, dále časovými ztrátami a problémy, které dojíždění do práce působí (doba cestování, čekání na spoje), daleko více než náklady na dojíždění do práce.

Simulační přístup k výběru spojení (na základě rozložení požadavků na dopravu) může být použit k odstranění potíží se stanovením parametrů vyhledávaných spojů (čas příjezdu/odjezdu, omezení vybraného spojení vzhledem k nadměrné délce či ceně).

Výsledky mohou být využity úřady práce při vyhodnocování podmínek dojíždění do práce a při rozhodování o finanční podpoře zaměstnavatelům zajišťujícím takovou dopravu, dále při vyhodnocování úrovně poskytování dopravních služeb v jednotlivých obcích s dopady na rozhodování o podpoře a poskytování dopravních služeb.

Obr. 1 – Lokalizace modelového území
Obr. 2 – Rozmístění důležitých zaměstnavatelů v okrese Bruntál (podle úřadu práce)
Obr. 3 – Hustota pracovních míst v okrese Bruntál (jádrový odhad s šířkou pásma 1 000 m)
Obr. 4 – Počty osob dojíždějících do zaměstnání v okrese Bruntál (podle Sčítání lidu z roku 2001)
Obr. 5 – Dojížďka do zaměstnání v Rýmařově (podle Sčítání lidu z roku 2001). Počet osob dojíždějících do zaměstnání. Doba dojíždění v minutách: 60 a více; není známo; vesnice, z nichž zaměstnanci dojíždějí do Rýmařova.
Obr. 6 – Počet pracovních míst poskytovaných důležitými zaměstnavateli dostupných individuální dopravou v době kratší než 45 minut. V legendě: počet dostupných pracovních míst, zastavěná oblast.
Obr. 7 – Počet pracovních míst vhodně dostupných veřejnou dopravou v případě pracovní doby začínající v 8,00 hod. V legendě: počet dostupných pracovních míst, nedostupné části obcí, zastavěná oblast.
Obr. 8 – Simulovaná poptávka po dopravě. Osa x – hodina, osy y – poptávka po dopravě
Obr. 9 – Průměrná doba cesty k nejbližším důležitým zaměstnavatelům kalkulovaná ve dvou variantách. V legendě: průměrná doba cestování, čas, různé náhodné varianty, zastavěná plocha.
Obr. 10 – Průměrná čekací doba na spoj k nejbližším důležitým zaměstnavatelům kalkulovaná ve dvou variantách. V legendě: průměrná čekací doba na spoj, různé náhodné varianty, zastavěná plocha.
Obr. 11 – Vztah mezi mírou nezaměstnanosti (31.12.2002 –30.9.2003, osa y) a počtem vhodně dostupných pracovních míst (důležití zaměstnavatelé, pracovní doba začínající v 8,00 hod; osa x)
Obr. 12 – Dostupnost města Krnova pro vybrané profese s nízkými příjmy (části obcí, ve kterých jsou lidé motivováni k dojíždění do zaměstnání). V legendě: nedostupné části obcí, zastavěné plochy.
Obr. 13 – Změna cestovní doby ve vybraných dobách odjezdu. Osa x – podíl změny doby cestování. Vpravo seshora dolů: o 6 –13 minut déle, o 1–5 minut déle, nezměněno, o 1–5 minut méně, o 6–25 minut méně, spojení existovalo pouze v roce 2004, spojení existovalo pouze v roce 2003.

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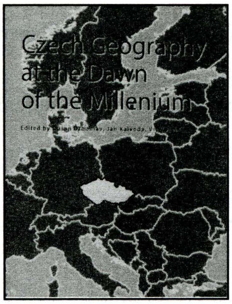

Drbohlav, D., Kalvoda, J., Voženílek, V. (eds.) (2004): Czech Geography at the Dawn of the Millenium. Palacky University, Olomouc, 428 s. ISBN 80-244-0858-9

The former Czechoslovakia was divided in 1993 into two independent states - the Czech Republic and the Slovak Republic. After a long period of common development and co-operation with Slovak geographers, a new history of Czech geography started to be written. Compared to the previous period, Czech Geography could develop in the new democratic society of the Czech Republic and be open to the new world research trends and international co-operation.

The Czech National Geographic Committee, representing Czech geographers in the International Geographical Union, in a memorandum to Czech geographers, decided from 2000 to strengthen the position of Czech geography on the international scale. It was decided to prepare an overview of Czech geography for the international community and to show its state at the beginning of the 21st century. The result of this activity is the recent book which was prepared for the occasion of the 24th International Geographical Congress in Glasgow, 2004. The book not only gives information about the history of Czech geography but presents mainly recent research results from different fields of physical geography, human geography, cartography and geoinformatics. It should reflect its recent state and show the direction of Czech geography between 1993 and 2003 - where we are and where we should go. There is a hope for further promotion of international contacts of Czech geographers as well as their inclusion in international projects and broader international co-operation.

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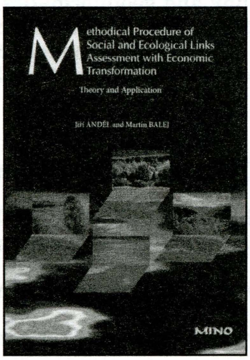
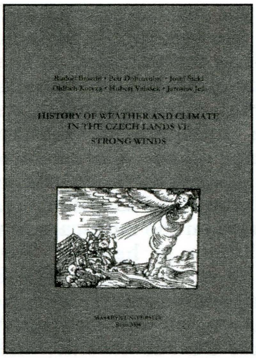
KOLEJKA, J.: Multidimensional Digital Modelling in Present Czech Geography
VOŽENÍLEK, V.: Towards to Digital Geomorphological Mapping
HORÁK, J., HORÁKOVÁ, B. ŠIMEK, M.: Using Geoinformation Technology in Labour Market Analyses



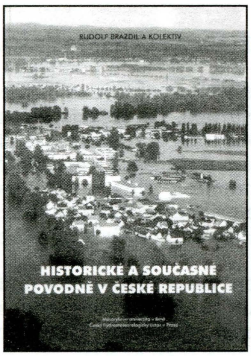
J. Anděl, M. Balej: Methodical Procedure of Social and Ecological Links Assessment with Economic Transformation: Theory and Application. MINO, Ústí nad Labem 2005, 116 p. ISBN 80-239-3893-2

The book presents input information from the Ministry of Labour and Social Affairs' project (MLSA) research project entitled "Methodical Procedure of Social and Ecological Links Assessment with Economic Transformation: Theory and Application". The framework of the research programme is quite broad with regard to the integral character of economic (or – if understood as a broader concept – socio-economic) transformation, and the interconnectedness and interdependency of social, environmental or economic changes. When being monitored, especially when it is necessary to collect data, dynamic changes in the post-totalitarian system transformation process and their historically unique character create pressure at the empirical studies level. From the point of view of the needs of the land user, decision makers and stakeholders, this task was important. The primary task was the process itself, used to evaluate the social and environmental context, search for space differentiation and development, identify conflict areas and determine the limits to socio-economic development. The structure of this introductory book to the conceptual objectives of the project. It is oriented partly from general to specific, partly towards goal setting, from measures to their implementation, and ends with the characteristics of model areas of the research. The first two chapters cover theoretical issues and focus on the methodology used for evaluation of the environmental context in which the economic transformation developed as well as on the basic solution trends. An important part of the introduction is the bibliography and the outline of a geographical approach towards evaluation of the landscape. The following two chapters describe the capacity (the research team and its structure) and the institutional background to the resolution of the project. The model areas are differentiated hierarchically by levels of the following order of magnitude: the macro-regional level represents the Region of Ústí nad Labem (where the transformational changes are probably most sweeping within Czechia), the meso-regional level represents the so-called Eastern Ore Mountains Region (very problematic mountain area in the districts of Most, Teplice and Ústí n. L.). The micro-regional level is represented by four specific landscapes, which are significant representatives of very differentiated types characteristic of the meso-regional and macro-regional level.



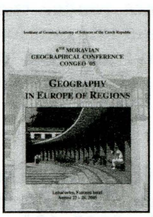
R. Brázdil, P. Dobrovolný, J. Štekl, O. Kotyza, H. Valášek, J. Jež: History of Weather and Climate in the Czech Lands VI: Strong winds. Masaryk University, Brno 2004, 378 p.

Strong winds related to convective storms and to windstorms caused by large horizontal pressure gradients in the Czech Republic for the last millennium are studied based on instrumental data and documentary evidence (chronicles, diaries, newspapers etc.). Higher frequency of strong winds is typical for the turn of the 16th and 17th centuries and mainly between the years 1770-1830. An increasing number of strong winds with a various kind of damage to nature and society can be seen from compiled series. The most severe "windstorms of the century" are described based on documentary evidence. Catalogue of tornadoes is created with analysis of their spatial distribution, annual variation and intensity. Instrumental data about strong winds are significantly and positively correlated with winter values of NAOI and CEZI and with winter mean temperatures in Prague.



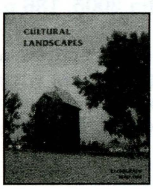
R. Brázdil et al.: Historical and recent floods in the Czech Republic. Masarykova univerzita, Český hydrometeorologický ústav v Praze. Brno a Praha 2005, 369 p. (in Czech with extended English summary)

Floods of the past millennium in the Czech Republic are analysed for five main rivers – the Vltava, Ohře, Elbe, Odra and Morava. An analysis of synoptic causes of floods and their climatological evaluation is given along with impacts to nature and society. A noticeable decline in the number of floods as well as their intensity (expressed by peak discharges with return period of N years) is detectable in the instrumental period from the second half of the 19th century to the end of the 20th century. This is due to significant reduction of winter flooding due to the overall warming of Central European winters. The relatively flood-free period of the 20th century came to an abrupt end with the two recent catastrophic floods of July 1997 and of August 2002. Chronology of the most disastrous flood events for the past millennium is developed showing important change in seasonality from floods related to snow melt / ice jam (up to 1862) to heavy rains (since 1872). Documentary evidence of floods for the pre-instrumental period is important for flood risk analysis.



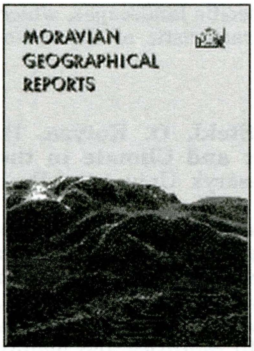
E. Kallabová, A. Vaishar, J. Zapletalová: Geography in Europe of Regions. Institute of Geonics, Czech Academy of Sciences, Brno 2005, 151 p.

Proceedings of the 6th Moravian Geographical Conference CONGEO '05, held in August 2005 in Luhačovice Spa (Eastern Moravia). The book contains 23 papers. Next CONGEO '07 Conference is to be organized in the town of Telč (Bohemian-Moravian Highland) in August 2007.



K. Kirchner, J. Wojtanowicz (eds.): Cultural Landscapes. Regiograph, Brno 2004, 122 p.

Miscellany published in co-operation with Maria-Curie Skłodowska University in Lublin and the Silesian University (Faculty of Earth Sciences) Sosnowiec



Moravian Geographical Reports, published since 1993.

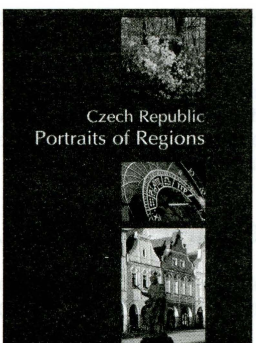
Journal publishes articles contributed by geographers and by other researchers who specialize in allied disciplines, including the geosciences and the geo-ecology, with a distinct regional orientation. One central question faced by all concerned scientists today can be posed as follows: "What are the roles of 'regions' and 'localities' in a globalized society, given the geographic scale at which we evaluate them"? Our emphasis is concentrated on the regional and locality 'problematic' – on questions of regional economy and society, of society in an urban or rural context, on regional perspectives concerning the influence of human activities on landscapes and environments, on the relationships between localities and macro-economic structures in these rapidly changing socio-political and environmental conditions on environmental impacts of technical progress on the landscape, on physical-geographical processes in the landscape including evaluation of hazards. The geographic aspects of a holistic interpretation of regions would be stressed. Theoretical questions in geography, in all of their regional dimensions, are also addressed. We seek to publish original scientific papers, reports on recent scientific projects, as well as critical evaluations of these contributions to current knowledge, academic announcements, and reviews. Scientific papers and selected academic announcements are reviewed. The journal format is A4, and individual issues contain approximately 60 pages. Contributions may include colored pictures, graphs and maps. The journal was published twice a year till 2005. The volume 2006 contains 3 issues, the volume 2007 should contain 4 issues.

Tolasz, R., Valerianová, A., Míková, T., Voženílek, V. (eds.) (2006): Climate Atlas of Czechia. Czech Hydrometeorological Institute, Prague, 256 p.

The Climate Atlas of Czechia is the result of many years of effort to achieve a better understanding of climate conditions in a country at the heart of Europe. Its creation was enabled by several decades of systematic, conscientious work by thousands of voluntary and professional observers, data reviewers, technicians as well as database, computer technology, and telecommunications administrators. When compiling this extensive collection of maps and accompanying texts, the group of authors comprising specialists from the Czech Hydrometeorological Institute and other experts, was able to build reliably on the results of their effort.

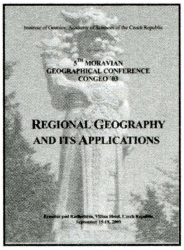
The Atlas consists of 11 chapters: Air temperature; Precipitation; Snow; Humidity and evapotranspiration; Solar radiation, sunshine and cloudiness; Air pressure; Hazardous phenomena; Phenological characteristics; Soil temperature; Dynamics of climate; Climatic classification.

As all the data have been handled in the geoinformation project, the Atlas may be presented in various forms (printed book, CD presentation, web application). The Atlas and the geoinformation project may thus be used in the professional, administrative, educational and practical fields, even after project completion. A major contribution of the Atlas of Climate in the Czech Republic consists of numerous thematic maps, charts, tables, diagrams and photographs. The publication presents elements that have not been included in previous Czech thematic maps. These elements render the whole work more vivid as well as more attractive and relevant for a wide public. This new edition of the Atlas should contribute to raising interest in learning about our country, of which the climate is an integral and natural part.



V. Toušek, I. Smolová, M. Fňukal, M. Jurek, P. Klapka: The Czech Republic – Portraits of Regions. Ministry of Regional Development of the Czech Republic., Praha 2005, 136 p. ISBN 80-239-6346-5

A team of geographers from Brno and Olomouc prepared a publication about Czechia aiming to provide foreign readers with a concise and contemporary portrait of the country and its regions. The first part of the book describes Czechia Republic from the geographer's point of view, including characterization of the natural environment, population structure and economy and its development trends during 1993–2004. The second part of the book provides a more detailed look at the current fourteen self-administrative regions of the Czech Republic. For the ease of comparison, chapters about the regions follow a uniform template and further specify particulars of natural environment, population, economy, and tourist attractions. Besides full-color photographs and maps, a set of plots and tables accompanies the text in order to portray recent statistical data and their development trends. The book was published both in English and Czech and was awarded by the Czech Association of Journalists and Publicists in Tourist Trade (ATchJET) as the best regional publication in 2005.



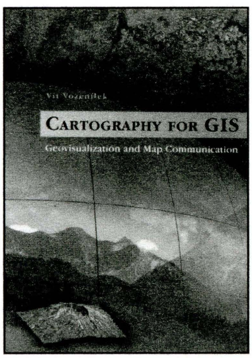
A. Vaishar, J. Zapletalová, J. Munzar: Regional Geography and its Applications. Regiograph, Brno 2003, 193 p.

Proceedings of the 5th Moravian Geographical Conference CONGEO '03, held in September 2003 in Frenštát pod Radhoštěm (Moravian – Silesian Region). The book contains 27 papers.

Voženílek, V. (2005): Cartography for GIS – geovisualization and map communication. Vydavatelství UP, Olomouc, 140 s. ISBN 80-244-1047-8

The reader is presented with a publication devoted to cartography and geographic information systems focused on geovisualization and map communication. It is one of the first books of this type in Central Europe; adequate publications have so far been published in the Western Europe and outside Europe, especially in the USA.

I welcome this publication as a significant contribution not only to the development of the scientific field of cartography but also of other disciplines dealing with geographic information. It is an important enrichment of discussions on current status of cartography, its position in the system of scientific disciplines and changes that take place in cartography and modify it or – on the contrary – changes that cartography, a science that has existed for several millennia, inspires and influences with its requirements. There are two views of current status of cartography in the global cartographic community. One is represented by the opinion that we now experience a period of modification of the cartographic paradigm. However, it is only seldom mentioned what is understood as this paradigm. The second stream argues, that the paradigm of cartography is not changing, and – thanks to new communication and information technologies – cartography fulfills concepts, attempts and sometimes even dreams, which could not have been reached with technologies used formerly. It is for certain that new trends we witness in cartography are significantly influenced by the development of information and communication technologies. Application of ICTs helps cartography and geoinformatics to engage in wider trends related to advancement of information technologies and to facilitate use of cartographic results in practice. These technologies allow better reaction to public demand and utilization of our results in solving everyday problems and tasks as well as in emergency events such as risk situations related to natural disasters.



The society – at least in the developed countries – has shifted from industrial development to and information- and knowledge-based society. This has created completely new conditions for work with geographic data and information. Now we create Spatial Data Infrastructures that improve access to high-quality, reliable and up-to-date data and information with certain legislative regulations and rules. The role of users has also changed. Current cartography tends to be user-friendly and customized. Thus, at last it fulfills long-time ambitions of cartographers – it is able to react to individual needs of users, who are no longer dependent on mass production of maps from national mapping agencies.

Many describe the era in which we live as the age of SDIs, which are created not only on national, but also on regional and global levels. In this process, cartography offers its methods, its experience gained from creation of old SDIs (represented ever since the 16th century by atlases and currently also by digital atlases) and it also offers new types of cartographic products often based on geovisualization. It is the objective of the author of this book to make the reader acquainted with all these new approaches.

In the International Cartographic Association, geovisualization is traditionally developed and accompanied by scientific efforts in other areas also dealt with in the book, such as creation of Internet maps, transfer and visualization of geographic data on mobile devices (ubiquitous mapping), cooperation in creation of standards, and many other activities.

I hope that the book of Vít Voženílek – a graduate of the Masaryk University in Brno – will enrich creative discussion, which will in result lead to further development of the scientific field of cartography.

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D. Drbohlav, J. Kalvoda, V. Voženílek (eds.): Czech geography at the dawn of millenium *(133)* – J. Anděl, M. Balej: Methodical Procedure of Social and Ecological Links Assessment with Economic Transformation: Theory and Application *(134)* – R. Brázdil, P. Dobrovolný, J. Štekl, O. Kotyza, H. Valášek, J. Jež: History of Weather and Climate in the Czech Lands VI: Strong winds *(135)* – R. Brázdil et al.: Historical and recent floods in the Czech Republic *(135)* – E. Kallabová, A. Vaishar, J. Zapletalová: Geography in Europe of Regions *(135)* – K. Kirchner, J. Wojtanowicz (eds.): Cultural Landscapes *(135)* – Moravian Geographical Reports *(136)* – V. Toušek, I. Smolová, M. Fňukal, M. Jurek, P. Klapka: The Czech Republic – Portraits of Regions *(136)* – A. Vaishar, J. Zapletalová, J. Munzar: Regional Geography and its Applications *(137)* – V. Voženílek: Cartography for GIS – geovisualization and map communication *(137)*.

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