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CONTENTS

AN ALGORITHM FOR AUTOMATED DIGITAL ROCK DRAWING IN THE STYLE USED IN CZECH TOPOGRAPHIC MAPS

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ABSTRACT

The Land Survey Office of the Czech Republic developed a method for digital cliff drawing for use in the production of their large-scale topographic maps. At the core of this method is the process of filling a polygon with lines that resemble stylized hachures. As these lines are produced manually, this article aims at the automation of this process, and presents an algorithm for automated digital rock drawing. This algorithm was designed based on a previous detailed analysis of the problem, and experience supported by numerous examples found in maps. The individual steps of this algorithm, which was successfully tested on selected areas of various rocky terrains in the Czech Republic, are described in detail. The results of the tests are assessed, and the pros, cons and limitations of the algorithm are discussed.

Keywords: digital cartography, digital cliff drawing, rock hachures, topographic map

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1. Introduction

Digital cartography has greatly expedited and simplified the process of producing maps. However, digital cartography technology has not resolved all complications faced by the practice. This also applies to the production of rock hachures, a traditional and widely-used means for the cartographic representation of rocky terrain (Imhof 1965). Within the industry, such depictions have been developed to near perfection, particularly in Switzerland. On the other hand, drawing Swiss-style rock hachures requires a great deal of time and experience, and cannot be greatly assisted by digital processing (Gilgen, Jenny 2010). Nevertheless, this method remains an excellent technique for depicting high-mountain relief. Because such depictions are hand-drawn, even using a computer is time-consuming, and therefore expensive. As a result, researchers are seeking ways to automate the production process. Despite partial success, this still remains an issue.

This article focuses on a similar problem that affects another style of rock drawing. Cartographers from the Land Survey Office, the Czech national mapping agency, developed a way to manually produce digital drawings of rock formations. The basic principles of this technique were briefly summarised in the first section of this article. More detailed information about the representation and its components can be found in Lysák (2015). Existing work on the automation of digital rock drawing is presented below; however, they concern other styles of cartographic representation.

The ultimate goal of this work is to design an algorithm for an automatic cartographic representation of rocky terrains in the style used by the Land Survey Office of the Czech Republic in their topographic maps (example in Figure 1). A description of the procedure includes the requirements of its input data, an in-depth explanation of the crucial processing steps, a comparison with manual processing, a discussion of the experimental implementation in ArcGIS for Desktop software, and the results of tests on real data. The proposed algorithm and its experimental implementation should not only help cartographers, but also researchers dealing with large-scale mapping of rocky terrains, such as geomorphologists and geologists. Therein should lie the practical relevance of the outcomes of this research.

2. The style of digital rock drawing used in Czech topographic maps

As this work immediately follows from a previous article by Lysák (2015) discussing this style of digital rock drawing, the description here is brief and limited to the basic principles. More information can be found in the cited article. An example of this type of portrayal can be seen in Figure 1.

The method is based on filling a polygon with lines. First, symbols for a single rock are created, resembling a stylised hachure. These are placed sequentially along the upper edge of a rock (like pearls on a necklace). The symbols (referred to as “upper symbols”) change regularly; the smaller ones serve as transitional strokes between the larger ones, which help to avoid to some extent undesirable regularity. There are also variants for wide and narrow rocks.

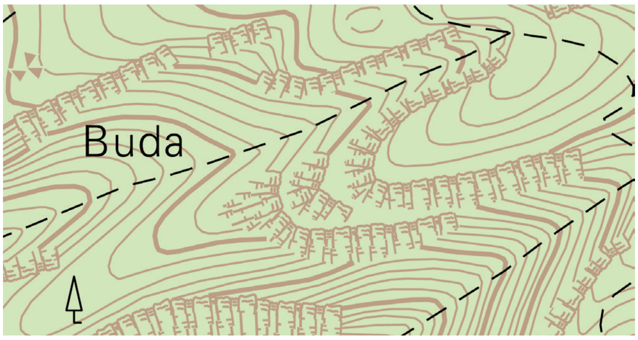

Fig. 1 An example of a digital rock drawing using the described method. Map taken from Geoportal ČÚZK, © ČÚZK.

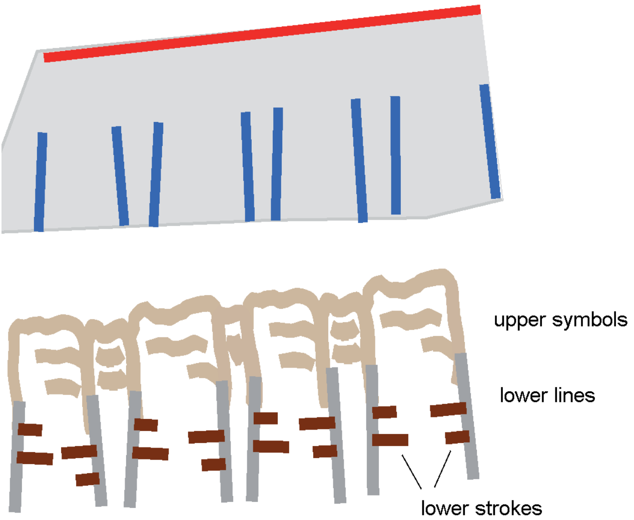

Fig. 2 From lines to hachures. The upper figure portrays the polygon geometry from ZABAGED with lines that needed to be drawn by a cartographer. The lower figure illustrates the resulting representation. To illustrate more clearly, single components of the result are distinguished by colour. Data from Geoportal ČÚZK, © ČÚZK.

For the remaining portion of the polygon, lines depicting the lower part of a rock are utilised (referred to as "lower lines"). These lines generally follow the fall direction and have regularly distributed, short, transverse strokes (referred to as "lower strokes"). These lines are drawn to fill the part of the polygon that is not covered by the upper symbols, and meet them precisely. The process is illustrated in Figure 2. Lower lines are used in the case of larger (and especially wider) polygons. All lines are drawn manually by a cartographer.

3. Existing work on the algorithmization of digital rock drawings

A thorough inspection of existing work concerning rock representation and digital cartography was performed. Although this is not a very active area of cartographic research, digital cliff drawing has been studied, especially in Switzerland at ETH Zürich. The pioneer works in this field are summarised in Hurni, Dahinden, Hutzler (2001). The article contains an in-depth description of digital ridge-line representations and the details of its implementation, as well as attempts to generate shadow hachures used in Swiss-style maps. Further studies of different aspects of digital cliff drawing in Swiss-style were introduced (Dahinden, Hurni 2007; Gilgen 2007; Gilgen, Jenny 2010; Geisthövel 2013). Work on the automation of this type of rock drawing is ongoing and, despite a great deal of effort, there seems to be a long way from the realisation of a fully working solution. Unlike the method used in Czech topographic maps, this "Swiss Manner" produces excellent results and unparalleled representations of three-dimensionality. However, this is based on complicated rules that prove demanding, even for manual depiction, and appear not to be easily algorithmizable (Jenny et al. 2014). Nevertheless, one promising work in this field has been published recently (Geisthövel, Hurni 2015) which combines cartography and advanced algorithms of digital image processing and non-photorealistic rendering.

Articles by authors outside of Switzerland should also be mentioned, despite being scarce: Gondol, Le Bris, Lecordix (2008) focused on automation using oriented hatched patterns; or simulating rock textures using special digital terrain model (DTM) filtering called texture shading described in (Brown 2014), and Yang, Guo, Shen (2009), whose results are a bit closer to the Czech-style representation used on analogue topographic maps. The results of research on slope hachures in general are also particularly useful. Of these, Yoeli (1985) and Regnauld, Mackaness, and Hart (2002) are noteworthy.

From a general point of view, two approaches for creating hachures can be used: one is based mostly on the analysis of raster DTM using algorithms from raster GIS or digital image processing (image filtering, feature extraction, etc.), whereas the second one relies on vector features as an input and tries to perform some kind of "automatic drawing" using algorithms related to computer graphics or computational geometry. The algorithm proposed in this article more likely belongs to the second group, although it also uses information derived from a DTM.

Most of the papers mentioned above aim to design a representation of the large rock masses in high mountains and in their local-specific style; thus they are only applicable to local Czech conditions to a limited extent. With this in mind, we come to another approach described in this article, based on different rules, but leading to a solution to the same problem.

It should be also mentioned in this context that for many practitioners, rock hachures seem to be an anachronism in the era of GIS and detailed DTMs. They also justifiably ask whether it makes sense to put so much effort into the algorithmization of something that is not necessarily needed anymore. The dispute about hachures versus contours is long-standing. Arguments from the pre-GIS period for and against both methods are summarized in Imhof (1965) in the chapter *Critical examination and application of the different methods of rock drawing*. In the Czech Republic, another purely practical problem has appeared. In the time of the first digital processing of topographic maps based on the vectorization of their scanned analogue versions, neither contours nor a DTM was available in rocky areas, expressed with hachures (Lysák 2015). Thus, something needed to be drawn inside the polygons. Despite the fact that DTM from laser scanning data is now available for the entire territory of the Czech Republic (including rocky areas), the same argument can concern other countries, where large-scale topographic maps are only available for detailed spatial information. On the other hand, the idea that the time of a cartographer can be spent more efficiently than in the manual hand-drawing of hachures to reach aesthetic perfection in a map, seems to be generally reasonable. Therefore, the automatic production of rock hachures appears to be the only way to prevent this unique type of portrayal from being consigned to cartographic history.

4. Algorithm for automatic processing

The process of filling a polygon with hachures, based on the principles described in Section 2, is a rather time-consuming task. On the other hand, the individual steps seem to be clear and simple enough to be algorithmized. Generally, details of the rules were inferred from in-depth examinations of rock representations on maps produced by the Land Survey Office, and in consultation with experienced cartographers from the same institution.

4.1 Inputs and outputs of the proposed algorithm

The key input for processing is a polygon layer, representing an extent of the rocky area into which hachures will be drawn. Lines representing details of the rocky terrain inside these polygons can also be used as supporting information. The algorithm can deal with ridge lines, valley lines, and other terrain edges. Delineation of the outer limits of rocky terrain and extraction of relief features can, in some cases and to some extent, be automated. However, these issues are beyond the scope of this paper. The described process assumes the layers mentioned above are present, regardless of how they were created.

A DTM is essential for the classification of a polygon perimeter (described in Section 5.1). Extensive detail is not necessary as it is used only to distinguish between the upper and lower part of a rock object, allowing for the correct orientation of stylized hachures. The level of detail in the DTM should be comparable to or higher than the level of detail of a polygon delimitating the extent of rocky areas; otherwise the results of automatic classification can be very poor. DTMs interpolated from contour lines, lidar or radar data can be used. If a DTM is not available, classification must be done manually, although the other steps can still be automated.

Output data is a set of polylines consisting of upper symbols, lower lines and lower strokes, as defined in Section 2 and shown in Figure 2. Individual phases of the process also have their partial outputs, serving as inputs for the following phases. They can be edited by the user if they do not meet their needs. These phases are described in detail in the following paragraphs.

4.2 Overall description of the algorithm

In the following sections, we describe the design of the algorithm and discuss thoroughly the key steps involved. This was not necessarily aimed at a fully automated solution. The proposed process allows for user interaction in certain phases of processing, in terms of manual editing of intermediate results or correction of minor errors, which seems to be inevitable, even in a complicated terrain. The process should handle the most typical and the most frequent cases, though not necessarily everything, as manual intervention is often a faster and more reliable way to achieve the desired results. In addition, several enhancements to the cartographic representation itself are suggested.

5. Processing steps

The proposed algorithm starts with an analysis of the terrain, followed by checking the results and determination of which input polygons can be processed fully automatically. Each polygon is split into two parts: the lower part is decorated with lower lines and lower strokes, and the upper part is filled with upper symbols. Finally, some improvements to the aesthetic quality of the output are applied. The following text gives an analysis of the studied problem, describing individual phases of the process in Sections 5.1–5.7, and explaining key parameters, techniques and processing alternatives.

5.1 Classification of the polygon perimeter

The following process requires a distinction between the "upper" and "lower" parts of rock, as the resulting symbolization strongly depends on this. More formally, if the perimeter of a polygon is supposed to consist of line segments, each segment will be classified as "upper", "lower", "indefinite" or "conflicting". Because the polyline is a border of the polygon, each segment has the interior of the polygon on one side, and the exterior on the other. Further, the direction of the steepest descent for both the startpoint and endpoint of each segment is computed (referred to as "fall line vector" in this text). A vertex gets a + 1 mark if the corresponding fall line vector lies in the same half-plane as the interior of a polygon, a − 1 mark if it lies in the same half-plane as the exterior of a polygon, and a 0 mark if it lies exactly on or very close to the border (see Figure 3, top). This can be easily performed by a half-plane test (de Berg et al. 2008). The mark is related to the endpoints of the segment, i.e. the same point shared by adjacent segments and can have different marks in each segment. The *alpha* angle between the fall line vector and the direction vector of a line segment was also computed. This value was used to differentiate between "0" and "+/−1" vertices, using a threshold of *t* (if *alpha* < *t*, vertex gets a 0 mark).

For computation of a fall line vector, a DTM is needed. For the given point P = $[x, y]$, a fall line vector f = (dx, dy) using the following formulae can be calculated, based on a derivative of bilinear interpolation of four points:
$dx = -1/s \cdot (-\mathrm{dtm}[x - s, y - s] + \mathrm{dtm}[x - s, y + s] - \mathrm{dtm}[x + s, y - s] + \mathrm{dtm}[x + s, y + s])$,
$dy = -1/s \cdot (-\mathrm{dtm}[x - s, y - s] - \mathrm{dtm}[x - s, y + s] + \mathrm{dtm}[x + s, y - s] + \mathrm{dtm}[x + s, y + s])$,
where dtm$[a, b]$ is the z-coordinate at the position (a, b) and s (sampling) is a distance of points used for interpolation. The lower the value of s is, the more terrain details are taken into account. The higher it is, the more a global perspective is used. The value of s must be set carefully, taking into consideration both the grid size of the DTM and the level of detail of the polygon data (i.e. the desired scale of cartographic representation). Tuning the value of s is advantageous as it helps to avoid undesirable details in the DTM, which might otherwise interfere with classification.

Based on marks of its startpoint and endpoint, segments can be classified, using the following rules (cf. Figure 3, bottom):

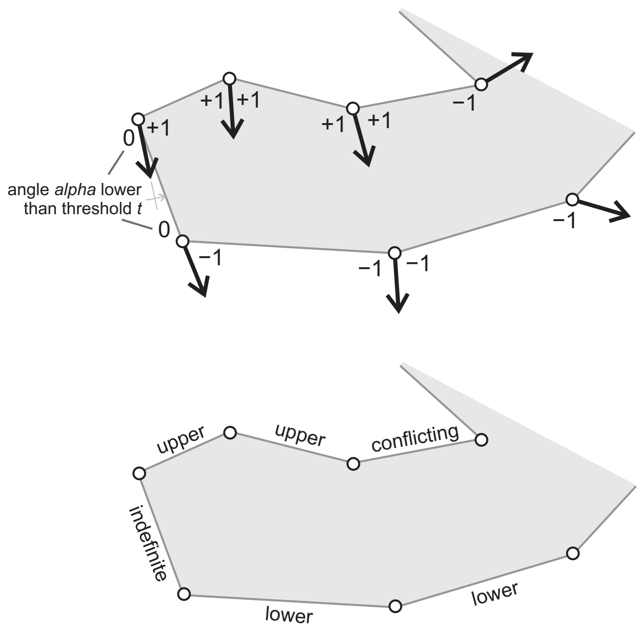

Fig. 3 From fall line vector direction to classification of the polygon perimeter. Top: fall lines vectors (marked by arrows), marks for each endpoint of a line segment on the polygon's perimeter. Bottom: the resulting classification. Taken from Geoportal ČÚZK, © ČÚZK.

- upper, if both vertices have +1 marks or if one has +1 and the other 0,
- lower, if both vertices have −1 marks or if one has −1 and the other has 0,
- indefinite, if both vertices have 0 marks,
- conflicting, if otherwise (one vertex has +1 and the other has −1).

Obviously, the higher the value of the *t* threshold, the more reliable the results obtained, in terms of minimizing the number of erroneously marked vertices. On the other hand, the more vertices that get a 0 mark, the more segments that will be indefinite. To minimize the number of conflicting segments, longer segments should be split. The presence of conflicting segments indicates a discrepancy between the DTM and the delineation of a rocky terrain. This can be solved to some extent by increasing the *t*, i.e. allowing small position errors, resulting in more indefinite segments.

For this reason, the generalization of segment classification is a reasonable step. In this case, generalization means applying simple rules that eliminate conflicting and some indefinite segments. The rules are as follows:
- dissolve segments of the same type, i.e. adjacent segments of the same type become connected and form a single dissolved polyline of a certain type,
- select indefinite and conflicting dissolved polylines, which are connected with an upper dissolved polyline on both sides, or with a lower dissolved polyline on both sides, and both polylines are long enough in comparison with the former ones. These dissolved polylines are reclassified as lower or upper (depending on the type of adjacent lines).

All lower and upper dissolved polylines and all indefinite lines that connect upper and lower polylines (or in other words, the "side parts", i.e. not the upper or lower part of a rock), are considered to be processed correctly. Classification of the remaining indefinite and conflicting parts must be done manually by the user. If the DTM is not reliable enough or not available, the classification of segments can be also performed completely by hand.

5.2 Verifying a polygon

As hachures from the upper to the lower part of a polygon need to be drawn, the natural requirement is that every polygon must have parts on its perimeter classified as lower and upper. In a simple case, the polygon has exactly one upper polyline, one lower polyline, and no more than two indefinite polylines. In this text, this type is called a "simple polygon", and a polygon with more than one upper polyline or more than one lower polyline is a "complex polygon". Complex polygons can be split into parts so that each part has the characteristics of a simple polygon. This process has yet to be automated.

If the polygon completely lacks lower or upper polylines, it indicates a need for information on the inner

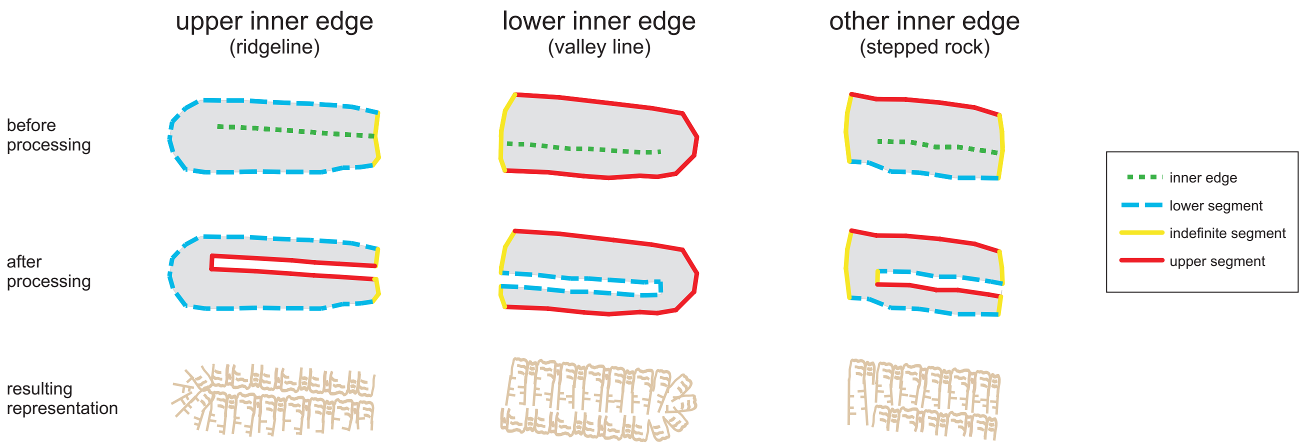

Fig. 4 Incorporation of inner edges. First row: classified segments on the perimeter of a polygon. Second row: the result after processing the edges. Third row: the resulting representation. This example uses artificial data created by the author.

segmentation of rock, expressed by inner edges (these polygons are referred to as "missing inner edge" polygons in following sections). An inner edge can be one of the following types (see also Figure 4):

– upper inner edge: typically a ridgeline with upper symbols on both sides,
– lower inner edge: typically a valley line with adjacent lower line ends on both sides,
– other inner edge: a general terrain edge where the slope of a cliff changes significantly. This type of inner edge is present in a stepped rock. On one side, its adjacent lower lines end; on the other side, upper symbols are present.

For further processing, a small buffer along the edges is created and is virtually deleted from a polygon. Newly arising edges obtain their type based on edge type: for an upper inner edge, all become upper; for a lower inner edge, all become lower; and for other inner edge, one side becomes lower, the other side becomes upper and the connection between them becomes indefinite. Determining which side is the upper and which is the lower in a certain case, can be arranged by pre-processing the other inner edges to guarantee their unified orientation, for example, with a downward direction on their right side.

After incorporating inner edges, each polygon should be simple or complex. While complex polygons can be split and processed part-by-part, not all simple polygons are suitable for further processing. For this the first requirement is that the length of the upper polyline and the length of the lower polyline are comparable. Contravention of this rule leads to problems when placing lower lines automatically without their mutual intersection. In our implementation, the length of the lower polyline has to be at least half, but no more than twice, the length of the upper polyline. The second condition requires the upper and lower polylines to form most, or at least a half, of the polygon's perimeter. This rule is often broken by elongated polygons following the steepest fall direction, which also causes problems with the placement of lower lines. Simple polygons that do not meet the requirement are excluded from other automatic processing (referred as to "simple inappropriate"), whereas the other ("simple appropriate") will be taken in into account in the following procedures.

5.3 Division of a polygon

For further processing, a delimitation of a strip along the upper polyline is required where the symbols for the upper part will reside. Depending on the size of the symbols to be placed along the upper line, generalization is a reasonable step. Small undulations must be smoothed, using any common generalization algorithm, e.g. Douglas-Peuckner or Bend Simplify. In our experimental implementation, simple line sampling was used. Having generalized the upper polyline, a buffer can be created around it with a size that fits the height of the upper symbols (referred to as the "upper belt"). Upper symbols are placed into the upper belt in the following step. The remaining part of a polygon (referred to as the "lower part") will be decorated with lower lines and lower strokes, that represent the lower part of the rock (see Figure 5). If the polygon was too narrow in comparison with the height of the upper symbols, it would be extended in that place to be at least as broad as the height of the upper symbols.

5.4 Design of symbols for the lower part of a polygon

Lower lines for the lower part of a polygon are prepared in this step. They need to be distributed carefully and densely enough to cover the whole lower part without intersecting each other. In a rather simplified way, lower lines should only consist of a straight line segment, not a general, curved polyline.

As the length of the upper and lower lines can differ and optimal density needs to be achieved, the medial axis (de Berg et al. 2008) between the lower polyline and the border line (between the upper belt and the lower part) was utilised. For narrow polygons or narrow parts of a

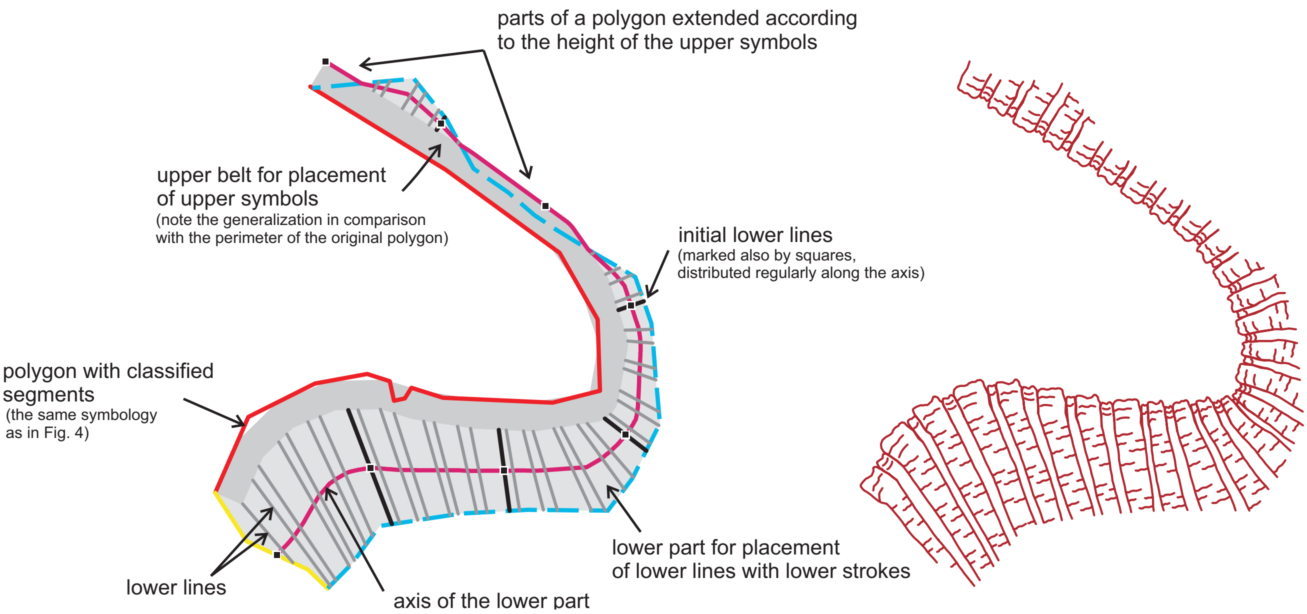

Fig. 5 Explanation of elements used in single steps of algorithm (left) leading to the resulting representation (right).

polygon, which lack lower lines, the lower limit of an upper belt is used instead. In the first step, initial lines are created which are perpendicular to the medial axis, and far enough away from each other that they do not intersect. Sampling depends on the width of the upper symbol. The sampling distance should be a multiple of the upper symbol's width and possibly the lowest value that prevents the initial lines from intersecting. In complicated shapes, user intervention can be inevitable. In our implementation, a distance of 45 m between the initial lines was used, which is an approximate width of 8 upper symbols from Section 2.

Lines are then added between these initial lines with a simple linear interpolation between their startpoints and endpoints. If the appropriate sampling distance in the previous step was chosen, the lines would not intersect and, at least on the axis, they would achieve the desired density. In our implementation, the space between the initial lines was divided into 8 parts, keeping the ratio 11 : 5 : 9 : 4 : 11 : 5 : 9 : 4, based exactly on the upper symbols described in Section 2. If the value for the initial sampling were too high, linear interpolation would not depict changes to the shape of the polygon and the resulting lines would be improperly oriented.

This simple solution has obvious disadvantages: the required density is reached only in the middle of the polygon, and not necessarily in the upper and lower parts. The lower lines can be over-densified or sparse. This is especially true for extremely curved or twisted polygons. If needed, a user can simply delete parts of the lower lines or draw new parts to achieve a result which is more aesthetically pleasing.

With manual drawing in the Land Survey Office, upper symbols are placed first and lower lines are connected to them. In the proposed algorithm, this process is switched for several reasons. The most important is the fact that the lower part of the polygon can be significantly larger than the upper belt and thus it is more important to keep it graphically consistent. Another argument is that filling the lower part with lower lines regularly would be a harder task if the condition following from the position of previously placed upper symbols is added. Moreover, a positive side effect of this approach lies in the increased irregularity of upper symbols, as intersections of lower lines and border lines (between the upper belt and lower part), corresponding to the widths of upper symbols, are not at exactly regular intervals.

A similar task of filling a polygon with linear features, more or less following the fall direction, is also used for symbolisation of embankments and cuttings with rake-like symbols or slope hachures (cf. Regnauld, Mackaness, Hart 2002).

5.5 Design of symbols for the upper part of a rock

In this phase, upper symbols are put into the area of the upper belt, in such a way that:

a) the sides of the upper symbols continue with lower lines, i.e. the lower end of a symbol will fade into a lower line,
b) the upper symbols are perpendicular to an upper polyline,
c) the upper symbols are not deformed, but alternatively distorted only slightly.

These conditions cannot always be met simultaneously and a compromise is necessary.

To symbolize the upper part of a rock, four symbols were prepared. These symbols were based on the solution described in Section 2. Of course, more or fewer symbols can be used. The exact appearance of a symbol is not important. What is important are

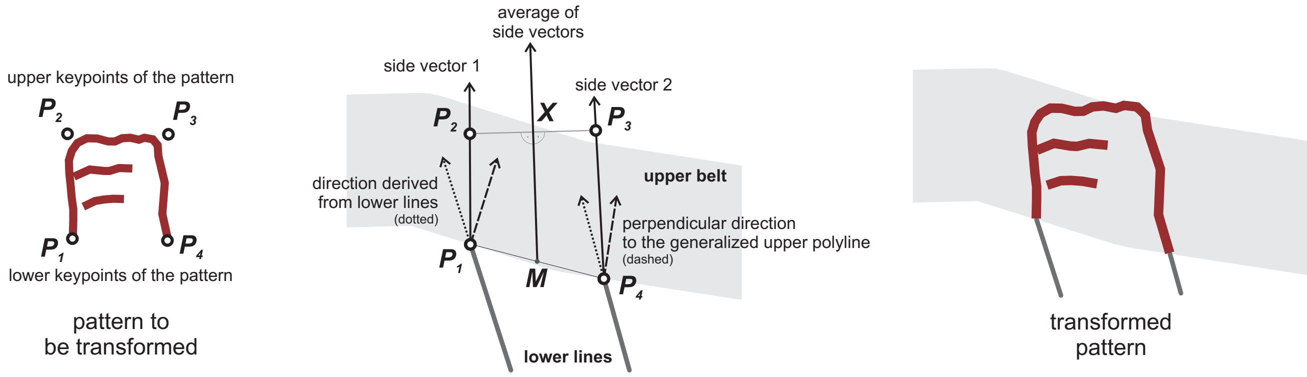

Fig. 6 Explanation of the placement of upper symbols, which is detailed in the following text.

the keypoints of the pattern, based, for example, on a bounding rectangle of a symbol. Their orientation is also important, i.e. distinguishing between lower keypoints and upper keypoints (see Figure 6).

The placement of each upper symbol into a certain position is based on projective transformation. In the first step, 8 coefficients of this transformation using 4 tuples of identical points are computed, and in the following step the transformation of the pattern is performed.

The lower keypoints of a pattern and the intersection of lower lines with the upper belt, are two pairs of identical points. The other two points, which correspond to the upper keypoints of a pattern, are found using the following concept (see Figure 6). Condition a), mentioned above, would need direction vectors $P_1 P_2$ and $P_3 P_4$ to be the same as for a corresponding lower line; and condition b) needs direction vectors $P_1 P_2$ and $P_3 P_4$ perpendicular to a corresponding upper polyline. The overall orientation of the transformed pattern is an average of these two vectors. This means that the transition between the upper symbol and lower line is not necessarily smooth; however, this is also frequently visible in hand-drawn representations. To meet condition c), a trapezoidal shape of $P_1 P_2 P_3 P_4$ should be avoided in order to keep it rectangular. This is achieved in the following way:

- compute a midpoint M between P_1 and P_4,
- compute coordinates of a point X, which is a shifted M in the direction of the average of side vectors by the height of a pattern,
- compute the intersection of a line, perpendicular to MX, passing through X, with bisectors given by the side vectors.

This means that the bounding box of a transformed pattern can slightly protrude from the upper belt. This is not really a problem as the generalization in step 5.1 alters the extent of the polygon more significantly.

The whole upper belt is filled with transformed patterns, processed successively, i.e. for each tuple of intersections of lower lines with the upper belt, coefficients of transformation are computed. With more patterns, they can be changed regularly (or even randomly). As the distance of lower lines at the intersection of the upper belt slightly differs, every transformed pattern takes a slightly different shape. This is a desirable effect, because irregularity is a desirable feature in this case.

5.6 Dealing with lower strokes

Lower strokes are drawn to help fill the lower part of a polygon. They occupy the space between every odd and even lower line due to their regular pattern and constant length. In the proposed algorithm, a few enhancements are applied:

- variable length of strokes, which helps to fill the area constantly and avoids empty spaces,
- shift of strokes on opposite sides of a tuple of lower lines; this prevents strokes from crossing or overlapping, or from being too dense in a certain part,
- adding more irregularity by a slight random change in the interval at which the strokes are drawn.

Variable stroke length is achieved using a relative value for stroke length, related to the width of the space between the lower lines forming a tuple, with respect to the position of the stroke (as lower lines are typically not parallel). Strokes are drawn perpendicular to the axis. The length of each stroke is computed individually, using the distance d between the startpoint S of the given stroke and the axis. The startpoint S of a stroke is on a lower line; endpoint E of a stroke has the following coordinates:

$$E = S + n \cdot w \cdot d \cdot 2,$$

where w is the relative width of a stroke with respect to the distance of adjacent lower lines ($0 < w < 1$), and n is the normalized normal vector of the axis.

The initial points of strokes can be placed along the lower line regularly, which means that they are placed in a fixed position from a startpoint, and when the line is longer, the positions are "copied" with a given interval. Strokes can also be added randomly, which does not seem to be an ideal solution, as they can overlap with the strokes on the corresponding lower line. A fair compromise is to change the interval slightly for the individual lower line. In our implementation, an interval of 19 m was used (based on the solution from Section 2), altered slightly by a random value following a normal (Gaussian) distribution N(0, 0.5). The relative width and exact position of a stroke within the interval can be found in Table 1; cf. also Figure 7.

Tab. 1 Position and relative width of lower strokes used in the implementation.

lower line on left side		lower line on right side	
position from startpoint (m)	relative width	position from startpoint (m)	relative width
4.3	0.3	1.5	0.6
7.3	0.6	4.5	0.3
14.2	0.5	11.5	0.5

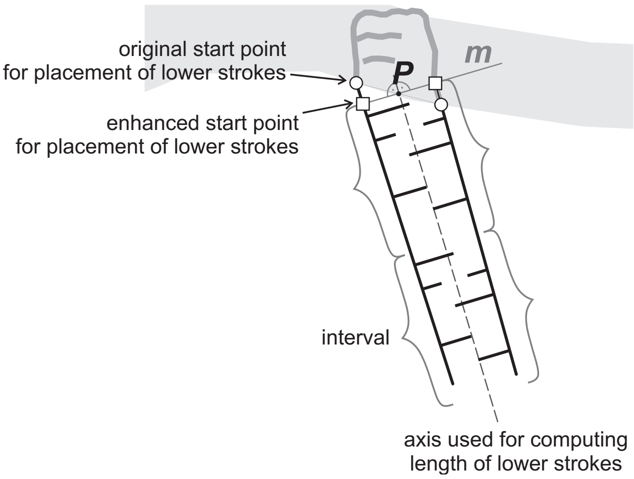

Fig. 7 Enhanced placement of lower strokes, described below in detail.

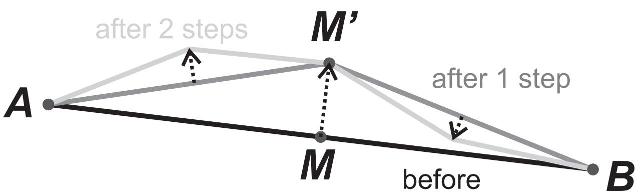

Fig. 8 Random midpoint displacement. The image shows only two steps of the algorithm. The direction and length of displacement is indicated by dotted arrows.

Ensuring that corresponding lower lines are synchronized is favourable in relation to the visual aspect of the result. This means, the strokes do not fill the space in between too irregularly. The greater the difference in length between corresponding lower lines, the more relevant the problem is. This is caused by the difference between the orientation of the upper symbol and the connected lower line, in particular. For this purpose, a virtual start position for placing the initial points of strokes should be changed. For a tuple of corresponding lower lines, the start position for each is determined by the following steps (see Figure 7):

- compute P as the midpoint between the startpoints of corresponding lower lines,
- compute line m perpendicularly to the axis of the corresponding lower lines, passing through P,
- compute the new startpoints for placing the lower strokes as an intersection of m with a lower line (possibly elongated upwards).

The described process helps to keep strokes in mutual, visual harmony and fill the lower part consistently.

5.7 Creating a more irregular appearance

Irregular symbols for upper parts are not visually consistent with straight lower lines and lower strokes (cf. Figure 9 top vs. bottom). To increase the aesthetic value of the result, a more irregular appearance is created. While a more irregular appearance is easier and more natural to achieve with hand drawing, in digital processing, the following actions are necessary:

- transforming lower lines using random midpoint displacement,
- fitting lower strokes to transformed lower lines,
- applying patterns to the shifted strokes.

For lower lines, a method called *random midpoint displacement* was utilised. This is often used in computer graphics for procedural modelling (Ebert et al. 2003). It adds a certain amount of "noise" to a drawing. More formally, line segment l is replaced by a sequence of segments p_i, where each p_i has a length less than or equal to a given threshold m. The maximum allowable shift d (the difference between the original segment and the resulting polyline) is also important. For each lower line l (with startpoint A and endpoint B), the following procedure is performed:

- if l is shorter than m, return l as a result
- compute midpoint M of l
- create point M' by shifting M perpendicularly to AB by a random value from -0.5 to $0.5\ d$ (positive value means shift in the right direction from oriented line AB, negative value in the left direction)
- run this procedure recursively for segment AM', with $d = 0.5\ d$
- run this procedure recursively for segment $M'B$, with $d = 0.5\ d$
- merge results of AM' and $M'B$ into a single polyline and return it as a result

The entire process is illustrated in Figure 8 and the result looks more natural than rigidly straight line segments. However, even slight movement of the lower lines causes lower strokes not to be aligned to the lower line exactly. This can be solved by topology-cleaning functions that re-snap endpoints of lower strokes to the altered lower line. This process can be computationally time-consuming.

For the enhancement of lower strokes, a linear conform transformation of a prepared wavy pattern was used. The idea is similar to the one described in Section 5.5, but in this case, only two identical points are used (the startpoint and endpoint of a stroke and the startpoint and endpoint of a pattern), and 4 parameters (shift in x, shift in y, rotation, and change of scale). For each stroke, parameters of transformation were computed and in the following step, transformation was performed on a pattern.

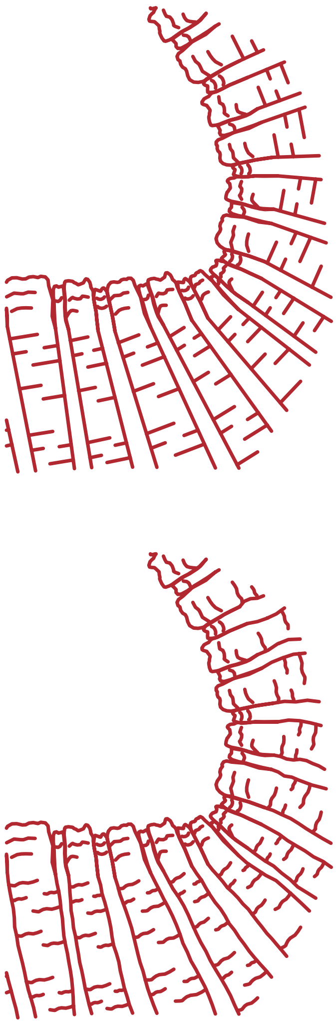

Fig. 9 Adding irregularity of lower lines and lower strokes. Note that some strokes have disappeared.

For lower strokes, transformation of a pattern seems to be a better choice, as the length of the stroke does not vary as much as the length of the lower lines. This is also the reason why the midpoint displacement was adapted for this purpose, as the pattern would have to be too complex for lower lines.

6. Testing and Results

An experimental implementation of the designed algorithm was carried out using the Python and ArcPy module (ArcGIS for Desktop 10.2) and used for testing. It was aimed at creating a representation as similar as possible to the one described in Section 2, i.e. at a scale of 1 : 10,000. Single steps of the designed procedure were performed non-interactively.

For testing purposes, four areas in the Czech Republic that are "rich" in rock were selected. The selection reflected the various types of rocky landscapes in the country. The test sample includes 1,672 objects, covering an area of 3.86 sq. km in total, i.e. approximately 4.2% of the total object count and 3.9% of the total area of all polygons representing rocks in the Czech national topographic database (referred to as ZABAGED. For more details, see ZABAGED, 2014). The test samples were all polygons in one or two sheets of the base map at a scale of 1 : 10,000 (ZM 10). Further details about the test areas can be found in Table 2.

Tab. 2 Description of areas used for testing the algorithm.

test area	total count of polygons	total area of polygons (m²)	type of landscape
České Švýcarsko	1414	2,518,700	sandstone landscape
Krkonoše	60	293,918	glacially modelled rocks in high mountains
Moravský kras	144	541,874	karren region
Údolí Vltavy	54	502,669	rocks on sides of a deep river valley

Raster DTMs with a cell size of 1 m for test areas were created using interpolation from contour lines in ZABAGED, as the level of detail of both layers is comparable. For this reason, a more detailed DTM from laser scanning data was not used, although it was available. This was done because "old" polygons in ZABAGED are often displaced in relation to the "new" laser scanning data. The main disadvantage of rocky areas with interrupted contours is omitting local elevations or depressions, which cause erroneous results of a preliminary classification of a polygon perimeter.

The main aim of testing was to find out how many polygons will be processed fully automatically and how much and what type of interactive work is required to obtain acceptable results. In the first phase, after fully automatic processing, a thorough inspection of the results was performed manually by comparison with ZM 10. The rock drawing of each polygon was classified as "acceptable", if the result was visually comparable or even better than manual placement by a professional cartographer. The polygon was marked as "requires reclassification" in cases where the result showed errors following the incorrect classification of the perimeter. In this case, for an acceptable result, only a change of attributes (not geometry) is required. Polygons that required some manual editing of intermediate geometry in a certain phase of processing were labelled as "requires editing". Finally, the polygons with very poor results, where neither a change of attributes nor simple editing could help to provide a visually acceptable result, were classified as "unsatisfactory". Overall, the success rate was 57% (949 out of 1,672 processed fully automatically with the acceptable result).

However, there were significant differences between test areas (see Table 3). For the record, the resulting representation consisted of 24,283 upper symbols, 22,482 lower lines, and 42,807 lower strokes.

Tab. 3 Results of automatic processing.

test area	total count of polygons	result of classification (polygon type, see Section 5.2)					result of drawing			
		complex	error	missing inner	simple inappropriate	simple appropriate	acceptable	requires reclassification	requires editing	unsatisfactory
České Švýcarsko	1414	71	47	13	73	1210	838	232	108	32
Krkonoše	60	8	0	0	1	51	28	6	10	7
Moravský kras	144	58	8	0	5	73	62	2	7	2
Údolí Vltavy	54	11	1	0	4	38	21	7	8	2
total	1672	148	56	13	83	1372	949	247	133	43

Tab. 4 Results after manual refinement of the polygon perimeter.

test area	total count of polygons	result of classification (polygon type, see Section 5.2)					result of drawing			
		complex	error	missing inner	simple inappropriate	simple appropriate	acceptable	requires reclassification	requires editing	unsatisfactory
České Švýcarsko	1414	10	0	17	0	1387	1190	0	155	42
Krkonoše	60	8	0	0	0	52	35	0	10	7
Moravský kras	54	2	0	1	0	51	35	0	12	4
Údolí Vltavy	144	9	0	6	0	129	109	0	15	5
total	1672	29	0	24	0	1619	1369	0	192	58

In the second phase of testing, all polygons that were not marked as “simple inappropriate” (and thus remain unprocessed), were examined. Manual reclassification of segments on their perimeters as well as manual correction of segments belonging to the polygons whose rock drawing in the previous phase finished with “requires reclassification”, were performed. All simple polygons (even those marked as inappropriate) were forced to be processed. If this manual, but not demanding, work is accepted, the success rate increases to 82% (1,369 of 1,672 processed successfully, see table 4). In most cases, there are only a few segments on a polygon perimeter that need to be altered.

6.1 Discussion

There are several reasons that prevent some polygons from being processed fully automatically. One is the misclassification of the polygon perimeter, often caused by the lack of details in the DTM and in some cases also the generalization used in the interpolation method for finding the steepest direction (the value of *s* described in Section 5.1), which omitted, for example, narrow valleys. Another problem was the excessive level of detail in some polygons (in comparison with a DTM and other map features, especially in the test area Moravský kras), which caused poor classification results. Such polygons need to be generalized before processing.

The fact that the number of really complex (and thus not yet automatically resolvable) polygons decreased to 29 (of 1,672) after manual checking is important. Complex polygons seem thus not to be a serious problem from a global point of view.

Generally speaking, the proposed algorithm works well for elongated features, even of variable width, located on hillsides. For this reason, results from the test area of České Švýcarsko were relatively successful, because that type predominates there. But this cannot be generalized to all sandstone landscapes, as in the case of extremely rugged plateaus the algorithm will fail because this type of landscape requires other means of cartographic representation (cf. Lysák 2015). The bigger and more complicated a polygon becomes, the more problems arise. In some cases, it is very difficult to place straight lower lines automatically, especially if the length of the upper and lower polyline differs or the polygon is too wide. Despite a simple procedure for lower line placement, the intersection of lower lines was not detected. Poorly placed lower lines will cause upper symbols to be deformed, twisted, or impossible to place. This is also caused by bent or crooked upper polylines, where generalization will not be of much help.

To overcome most of the described limitations, the following tasks should be considered more carefully for a more general solution or better results:

– better generalization of a polygon's perimeter classification, which would take more information into account (for example, the inner angles in a polygon),
– the division of a complex polygon into simple parts should be performed automatically,
– a generally better solution for finding initial lower lines, using, for example, inflection points of a medial axis,
– automatic intelligent shortening and/or adding lower lines in areas where the upper and lower polyline lengths differ dramatically instead of excluding them from processing,
– allow lower lines not to be only line segments but general polylines; this allows them to be placed more irregularly in the case of larger polygons. On the other hand, it means complications with intermediate lower lines and lower strokes,
– better handling of the lower lines close to the sides of a polygon, as they do not fill these areas ideally,
– find a generally better solution for narrow rock ridges/stripes, following the fall line direction, as the depiction of those using just one or very few upper symbols and extremely elongated and straight lower lines is very poor.

Moreover, there are also other important issues, not related to algorithm itself, but to its implementation:
– Adding more interactivity would help for practical usability. It is more natural to do the entire process from the classification of the perimeter to the enhancement of lower strokes interactively, feature-by-feature, rather than batch processing, phase-by-phase for all features, followed by ex-post editing. The entire processed area must be checked repeatedly, which is a time-consuming and low-value task.
– The result (polyline representation of upper symbols, lower lines and lower strokes) is very difficult to edit. For efficient editing, intermediate outputs need to be saved and edited. These can also be partly used for the generalization of the result to a smaller scale representation.
– Some parts of the process can be computationally demanding. From these, estimation of the fall direction for tens of thousands of points and locating the medial axis of the lower part are the weakest part of chain.

Further work should aim towards the automation of the ladder manner (as described in Lysák 2015), which shares many features of the solution described above. However, shading may be incorporated so that a plastic and more visually appealing result can be achieved.

7. Conclusion

This article introduced an algorithm for the automation of digital rock drawing, based on a method developed and used in the Czech Land Survey Office. Although the resulting representation is very schematic, it brings the map reader extra information in an illustrative way. Despite it being relatively easy, from a human point of view, for a cartographer to create using simple principles, complete automation of this task is a non-trivial process. Its key steps are thoroughly discussed, indicating that for more sophisticated styles of rock drawing such as in the Swiss manner, the algorithmization of rules will be a difficult and challenging task. The author hopes that this article helps, even marginally, improve the depiction of rocky terrains which are often expressed poorly in contemporary digital maps, and that this article may provide further argument for keeping rock hachures as a useful means of cartographic representation.

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Author's Note

Experimental scripts used for testing are available upon a request.

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RESUMÉ

Algoritmus pro automatizované znázornění skal ve stylu používaném na českých topografických mapách

Článek podrobně popisuje možnosti automatizace metody pro znázorňování skal s využitím prostředků digitální kartografie, vyvinuté Zeměměřickým úřadem a používané na topografických mapách jím vydávaných. Podstatou této metody je vyplňování půdorysu skalního útvaru liniemi, které mají připomínat stylizované skalní šrafy. Tento postup je dosud prováděn ručně a je poměrně časově náročný. Na základě analýzy práce kartografů a výsledné reprezentace na mapách je proto navržen a detailně popsán algoritmus, který tuto činnost umožní do značné míry zautomatizovat. Vlastnímu návrhu algoritmu předchází srovnání s podobným typem prací, které se ale pokouší více či méně úspěšně automatizovat jiné styly skalní kresby. V článku jsou popsány vstupy a výstupy algoritmu, je provedena podrobná analýza klíčových fází zpracování, ilustrovaná na konkrétních případech. Vytvořený algoritmus byl implementován s využitím ArcGIS 10.2 a úspěšně otestován nad reálnými daty. Součástí článku je též diskuse dosažených výsledků včetně možných vylepšení.

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COMBINED METHODS FOR RISK ASSESSMENT OF MASS MOVEMENT AND EROSION SUSCEPTIBILITY IN THE ETHIOPIAN HIGHLANDS

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ABSTRACT

The Ethiopian Plateau and the Rift Valley typically display various symptoms of intensive erosion, mass movement and land degradation, which have arisen in response to rapid changes in land cover in an area of high dynamics of relief development. In order to assess the risk of these symptoms of intensive erosion and mass movement it is necessary to apply a method for the evaluation of non-linear systems. Therefore, our aim was to develop a combined method for evaluating the risk of landslides or erosion using complex system theory. This combined integrated method has been tested on two selected localities with landslide hazards on the border of the Ethiopian Highlands and the Main Ethiopian Rift. The method is suitable for a prompt risk evaluation and swift decision making.

Keywords: integrated methods; complex systems; landslides; erosion; multi-criteria analysis; Ethiopian Highlands

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1. Introduction

Nowadays, data evaluation and decision making connected with risk have to be performed under increasingly complicated circumstances. Natural risk creates very complex and dynamic systems with unstable behavior, whose description can be very complicated and more or less unreliable. That is why the evaluation and decision making processes require a combined approach, based on exact methods working with both qualitative and quantitative information as well as natural uncertainty and vagueness.

The characteristics and evolution of landforms at the zone of contact of the Ethiopian Plateau and the Rift Valley have not yet been studied in detail. This is a typical area with various symptoms of intensive erosion, mass movements and land degradation, which arose in response to rapid changes in land cover in an area of high dynamics of relief development. At the same time, infrastructure and settlements are increasingly exposed to a direct threat. In order to assess the risk of mass wasting and erosion susceptibility a combined method should be applied integrating a deterministic approach with complex system theory.

The natural non-linearity of an unstable system (i.e. an unstable slope) prevents data from being evaluated using a classic model based on linear methods because this approach may not lead to reliable conclusions (Zvelebil et al. 2006). It is also necessary to consider the fact that not all the required data are available within the requested time and spatial density. That is why it is necessary to combine classic mathematical or statistical methods of evaluating time series with tools enabling us to transform immeasurable, estimated or even approximate factors into the numerical model with the aim of evaluating and predicting features of the system after extreme changes in the conditions of certain input parameters. In this study our aim was to develop a combined method for evaluating the risk of landslides or erosion using complex system theory.

1.1 Previously used methods of evaluation in the study region

Various different approaches and methods have been used to evaluate landslide risks and erosion susceptibility on the Ethiopian Plateau. It is important to remember that not only the evaluation methods but also the availability, quality and relevance of data play an important role. Due to a lack or incompleteness of data or time series or even the non-existence of measurements, as well as the different characteristics of the sites, there are many of these sites that have not yet been evaluated or only partially or have been evaluated without a complex approach.

There are several studies describing the evaluation of the risk of landslides and erosion, where the authors present various qualitative and quantitative, as well as analytical and empirical approaches.

First example, the application of remote sensing and GIS for landslide disaster management (Ayele et al. 2014), where the natural stability of slopes is evaluated using methods for the classification of factor maps of parameters (geology, groundwater, drainage, slope, structure, aspect, etc.). Another example is the application of weights of evidence modeling for landslide susceptibility (Meten et al. 2014). This method evaluates landslide influencing factors such as slope, aspect, profile curvature, plan curvature, lithology, land use, distance from a lineament and distance from a water course. Weights of evidence modeling uses the Bayesian probability approach and was originally designed for the assessment of mineral potential. A study on the landslide susceptibility and causative factors evaluation of the landslide area of Debresina (Abay and Barbieri 2012) uses remote sensing and GIS for mapping and evaluating landslides. The study evaluates the landslide susceptibility based on factors such as lithology, geological structure, land use, drainage, slope gradient, slope aspect, elevation, rainfall and earthquakes. Another example is landslide hazard zonation mapping (Woldegiorgis 2008) where land hazard evaluation factors were used to characterize the landslide hazard potential in the study area, applying the limit equilibrium method. A quantitative analysis for critical slopes was also performed. Teferi (2005) carried out research on the evaluation of land degradation and landslides using an integrated GIS and remote sensing approach around the area of Sodo-Shone in Southern Ethiopia.

Ayenew and Barbieri (2004) performed landslide studies and susceptibility mapping in the Dessie area. Temesgen (2001) researched landslides in the Wondo-Genet area and evaluated occurrences of landslides and their relationships with various event controlling parameters using GIS and remote sensing techniques. A study involving a mass movement hazard assessment in Betto, Goffa district, determined that the main cause of landslide was the existence of old landslides on steep slopes that were covered by deeply weathered, closely jointed or sheared basaltic rocks (Lemmesa et al. 2000).

1.2 Model study sites

Representative sites were found within the Ethiopian Highlands and on the margin zone of the Main Ethiopian Rift (MER). Several selected sites with geohazards (especially erosion-denudation processes and mass movements) were assessed in the first step – e.g. the Andit Tid catchment area, Debre Libanos/Fiche Valley, the Dessie area, the Debre Sina area, Lake Maybar and the Melka Kunture archeological site. The two most suitable study sites were subsequently comprehensively documented through a literature search, analysis of data from DMT, satellite data and a field survey.

Two demonstrative sites in the eastern part of the Ethiopian Highlands on the border with the MER were selected for detailed analysis: 1) the Dessie graben (a hanging tectonic basin located along the western rift margin with young, high energy relief and a quantity of different types and ages of landslides and reactivations – e.g. Fubelli et al. 2008; Abebe et al. 2010; Vařilová et al. 2015) and 2) a mega-landslide area near the town of Debre Sina (a tectonically disturbed slope on the edge of the MER with a huge catastrophic landslide in 2005/2006, repeated reactivation and associated shallow debris/earth slides/flows – e.g. Alemayehu et al. 2012; Abay and Barbieri 2012; Kropáček et al. 2015).

The spatial and temporal distribution of the landslides and their typology within the study localities are mainly related to complex interactions between the local predisposed conditions and the external triggering factors. Heavy summer rainfall has been identified as the major

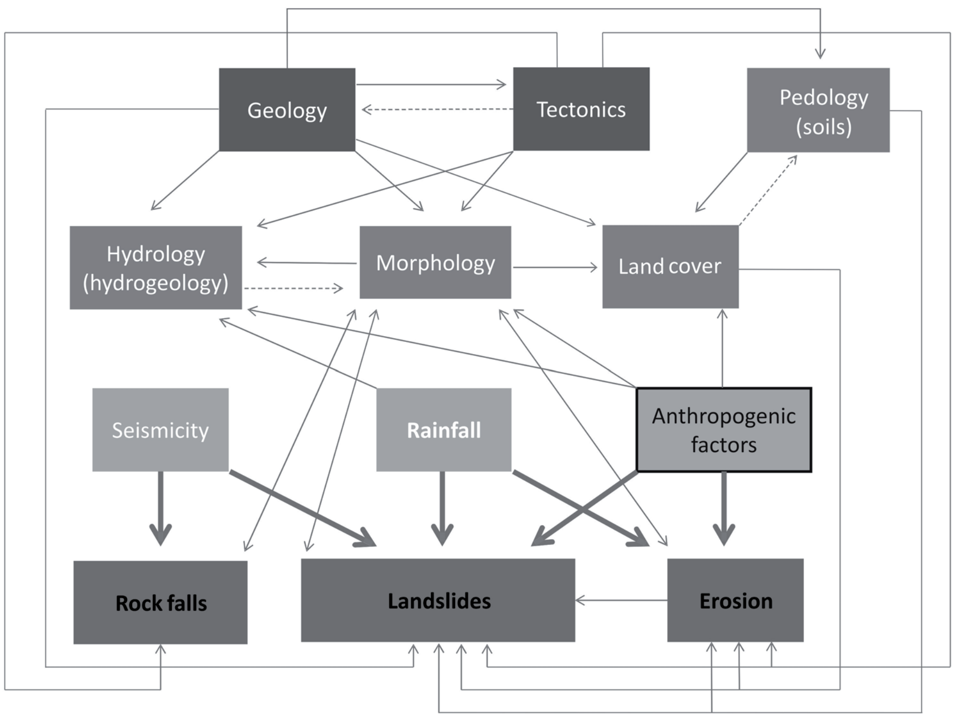

Fig. 1 Schematic representation of interactions between causative factors and consequences for studied localities.

Tab. 1 Main predisposed conditions and external factors inducing landslide activity at the Dessie graben and Debre Sina localities (assessed in a scale of several years from a common point of view); the estimation of the effect of individual influences is represent by an index number (expert estimate in per cents, separately evaluated for conditions and external factors).

Influence			Characteristic of Dessie landslides	Index (%)	Characteristic of Debre Sina landslide	Index (%)
Conditions	Relatively constant condition	**Geology** (lithology and structure, intensity of weathering, including soil characteristics)	**Tertiary volcanic terrain and its weathered products, alluvial-colluvial deposits:** Highly weathered weak basalt and vesicular basalt, un-cohesive colluvial-alluvial deposits; stratified beds – changing of more or less weak/permeable layers; abundant presence of clays and silty clays; highly plastic soils (e.g. Ayenew and Barbieri 2005)	**40**	**Tertiary volcanic terrain and its weathered products, alluvial-colluvial deposits:** Bedrock of alternating layers of basalt, rhyolitic or trachytic ignimbrites as well as tuffs (intensively fractured, highly altered and weathered) and agglomerates of different volcanic material; overlaid by basalts in the head scarp area (e.g. Abay and Barbieri 2012)	**35**
		Tectonics (faults/active faults/proximity to faults, fissures, etc.)	**Tectonic depression along the Main Ethiopian Rift margin:** major parallel faults running in a N–S direction limit the Dessie Graben, locally crossing of faults (sets of E–W trending faults), slow descent of valley along both faults, highly jointed basalt basement	**15**	**Main Ethiopian Rift escarpment with extensional regime:** major morpholineaments striking SSW–NNE related to the African Rift; several minor morpholineaments striking NE–SW, NW–SE, E–W, and N–S are dissected by the major ones (probably of older age)	**35**
	Changing condition (by self-development and by external influences)	**Hydrology regime, hydrogeology** (aquifers and aquitards, system of drainage, etc.)	Fast drainage of infiltrated water by steep slopes and numerous tectonic lines together with a lateral movement of groundwater due to the existence of layers of impermeable rock and interbedded paleosoils, which also prevent deeper infiltration; low storage capacity; higher stream density (Ayenew & Barbieri 2005)	**15**	System consisting of several aquifers (and aquitards) – gradual infiltration by fissured permeability together with aquifer with porous permeability (Alemayehu et al. 2012)	**15**
		Morphology (elevation, slope gradient, erosion features, etc.)	Steep fault slopes along both sides of the basin generate high runoff, deeply incised gully erosion; reactivation of old landslide bodies	**20**	Rugged relief, with rock outcrops, deeply dissected creeks and erosion channels but also less steep areas with terraced arable land; reactivation of old landslide body	**15**
		Land cover	Deficiency of natural vegetation due to deforestation of slopes – bare soil covers the majority of area	**10**	Intensively cultivated terraced slopes	**0**
External factors	Triggering factors changing over time, acting as a long-term and also as single pulses	**Rainfall**	Bi-modal rainfall pattern (heavy rainfall period from July to August), mean annual precipitation reaches 1,256 mm/year (1990–2013)	**70**	Bi-modal rainfall pattern (heavy rainfall period from July to August), mean annual precipitation reaches 1,748 mm/year (1990–2013)	**75**
		Seismic activity	Tectonic active fault zone near the Ethiopian Rift with relatively frequent earthquakes	**15**	Tectonic active fault zone near the Ethiopian Rift with relatively frequent earthquakes	**25**
		Anthropogenic influence	Densely inhabited area with urban/housing development, changing of natural conditions (morphology and land cover) and water regime; due to town infrastructure, road construction, pipe-lines, quarrying, agricultural activity, deforestation, reforestation etc.	**15**	Agricultural landscape, scattered village development, artificial system of field irrigation	**0**

cause of numerous slope deformations in both areas. The faults of the rift edge can suffer occasional earthquake tremors leading to activation of unstable ground. Finally, human activity has been a specific trigger of landslide activity (especially in the Dessie area) during the last five decades and can also be considered as one of the appreciable external factors.

Table 1 provides a complex overview of the major causes of landslides using a classic assessment approach. The conditions of the studied sites are relatively stable in terms of tectonic structure and geological settings as well as the relatively variable dependence on external influences (e.g. the hydrology regime or morphology and their changes). All of these together form a complete system of interactions of elements/parameters that change over time, and their mutual combination repeatedly creates optimal triggering impulses for geodynamic processes (Figure 1).

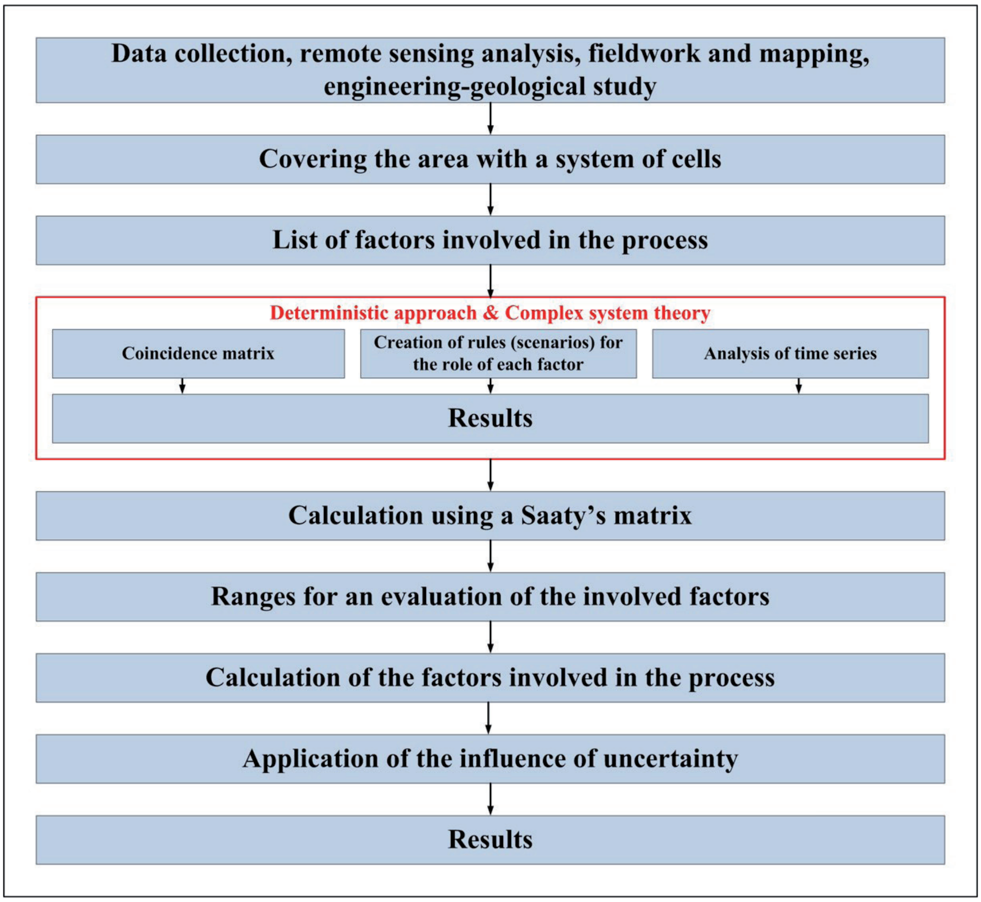

Fig. 2 Flow chart showing the evaluation process.

2. Methods

When performing a multi-criteria evaluation of risks, a method should be used that allows the total value of the risk connected with the landscape and its future exploitation to be evaluated. To be able to calculate such clearly defined risk values for each locality, we proposed a system of finite steps, which enable us to calculate or estimate the crisp risk value for the study sites. In the same time, it has to provide information on the uncertainty or plausibility of this value for future decision making.

It was necessary to create a comprehensive procedure (method) to evaluate a definite size of risk for each site. This procedure should be able to calculate a clear value of risk at the site after certain exactly defined steps and evaluate the plausibility of this value for future decision making. It should be noted that exactly measured real time values or values with the required frequency describing the causative factors are not usually available.

Step 1 – Data collection, remote sensing analysis, fieldwork and mapping, engineering-geological study

The basis for an objective assessment is the maximum amount of relevant data and information. For this purpose the available data and published results of previous studies for each study site were carefully collected. These data provide information especially on the main types of geodynamical processes, geology and geomorphology units. This basis was supplemented with new information derived from digital elevation models (DEMs) and remote sensing data. The slope characteristics were calculated from the available medium resolution SRTM DEM and newly derived high resolution DEMs from ALOS/PRISM image triplets. The SRTM DEM is a homogeneous global DEM with a grid spacing of one arc second corresponding to 30 meters (Farr and Kobrick 2000; Rabus et al. 2003). The ALOS (Advanced Land Observing Satellite) is a Japanese system which was operational between 2006 and 2011 and was primarily dedicated to cartography and disaster monitoring. The triplet consists of three images taken by the PRISM instrument consisting of backward, nadir and forward pointing cameras which enable stereo-processing (Takaku and Tadono 2012). The DEM derivatives such as hillshading and slope inclination allowed us to identify morpho-lineaments which can indicate the tectonic predisposition of landslides. The DEM derivatives also allowed us to carry out a detailed landslide inventory. The concave shape of the head area and the convex shape of the frontal lobe were used for the identification of landslides. We also used typical shades, patterns of open cracks and scarps in the Kompsat-2 image. The very high resolution satellite images acquired by Kompsat-2 were used to obtain information on the land cover of the study sites. The conformity with published inventories (e.g. Ayenew and Barbieri 2005; Fubelli et al. 2008; Suyum 2011; Alemayehu et al. 2012; Abay and Barbieri 2012) was also checked.

During the field investigation the obtained results were validated and new reactivations were identified. The localization of the delimited landslides was compared with the fault zones and lineaments to reveal the possible influence of tectonics on the landslide predisposition. Further possible triggering factors such as precipitation and anthropogenic factors were evaluated. More than 50 years (1962–2013) of rainfall and temperature records measured at the Dessie station and more than 20 years (1993–2013) of rainfall records from the Debre Sina station were provided by the National Meteorology Agency of Ethiopia. These data were used to analyze the distribution of precipitation and temperature variations.

Step 2 – Covering the area with a system of cells

In this case, we covered part of the study area with a regular mesh of cells. This mesh should cover all of the important points, i.e. old landslides, old environmental issues, areas of interest for investors etc.

The study area is a large geographic region, where several sub-areas can be found with very different factors, which have different influences on the stability of the rock massif, i.e.:
– complex geologic conditions,
– different factors caused by human activities.

Due to these facts there is no complex and closed analytic instrument for a precise description of all of the aspects of interest. That is why it was decided to apply a statistical approach with a certain percentage of approximation or an acceptable risk of uncertainty.

The next argument is that the explored processes are non-linear due to the simultaneous engagement of several non-linear influences and their parameters change during time.

For this reason it was decided to use a non-linear approach for describing the process. This approach is based on splitting the large area with different conditions into several smaller sub-areas, where the conditions can be considered to be nearly constant. The criterion for deciding on the suitable size of each sub-area is to reduce the number of different factors in each cell as much as possible; however, the size of these sub-areas should not be too small as it has to reflect the fact that the accuracy of the description cannot be 100% due to the limits given by the available time, costs and technology and, that we are willing to accept a certain risk given by uncertainty.
In practice, the study area is divided by covering it with a rectangular 2D-mesh (or several meshes) with acceptable grid spacing in both perpendicular directions. Then, a coordinate system (X and Y axes) can be assigned to each mesh, which in the next step enables us to create a matrix-like database of cells characterized by their (X,Y)-position in the matrix.
It then becomes possible to use each cell of the matrix to describe the conditions inside each sub-area of an acceptable size, which further enables to use relatively simple descriptive methods.

Step 3 – List of factors involved in the process

In this step, it is necessary to establish a list of all possible factors, which could have any influence on the given process. The inclusion of each factor into the list has to be done independently of its real intensity in any single cell. This means that it should be done from a complex point of view, covering the whole area. These factors have to cover the following scope:
– natural phenomena, such as rainfall, temperature changes, soil susceptibility, evaporation, vegetation cover, degree and velocity of erosion, tidal forces etc.;
– anthropogenic activities, such as cutting of slopes or excavating for roads, deforestation, agricultural activities, civil engineering, pumping of water, exploitation of rivers etc.

In principle, all of the natural factors are of a destructive nature. The human activities are mostly destructive but, under some circumstances, they can also contribute to stability and security.

In our application we assume that a combination of the following factors can characterize a selected locality: hydrology, land cover, anthropogenic activities, vegetation cover, slope characteristics, tectonics, erosion, lithology, engineering-geology, climatic influences and the influence of tidal forces.

Tab. 2 List of considered causative factors.

ID	CRITERION	SUB-CRITERION
1	**Geomorphology**	Slope characteristic (slope inclination, length of slope, slope aspect, morphology affected by old landslides)
		Erosion (sheeting, rilling, gullying, fluvial erosion, undercutting of slopes)
2	**Geology**	Engineering geology (geomechanical properties of rocks and soils, degree of saturation)
		Lithology (thickness, structure, weathering and erosion resistivity)

2	**Geology**	Tectonic (presence of faults and seismicity)
		Hydrogeology (ground water level, aquifer and aquitard)
3	**Soils**	Soils (soil texture, infiltration, soil saturation)
4	**Climatic and astronomic influences**	Climatic influences (cumulative precipitation, extreme precipitation, evaporation and runoff, variation in temperature)
		Tidal effects (solar and lunar tides)
5	**Vegetation cover**	Vegetation cover (vegetation density, vegetation type – grass, shrubs, forest)
6	**Anthropogenic influence, land use**	Anthropogenic influence, with a stabilizing (1) and destabilizing (2) effect (1) drainage, retaining walls, strengthen the surface, reforestation, etc. and 2) induced seismicity, undercut of slopes, changes in the hydrogeological conditions, etc.)

Step 4 – Coincidence matrix and the creation of scenarios for each factor

There are several factors that can have an influence on the geological process. However, these factors do not act on the principle of "each with all of the others, one by one". In other words, the coincidence matrix of these factors is not full because relations between certain factors cannot be equivalent in both directions (Nechyba et al. 2014). For example, rainfall can have an influence on the stability of a slope but it cannot be influenced by stability, etc., therefore the coincidence matrix will not be symmetrical.

Having created a list of possible factors that could have an (even very small) influence on the area, it is helpful to establish a matrix of possible coincidences between these factors. The aim of this step is to exclude relations, which rarely happen in reality. For example, rainfall intensity (factor A) could cause the soil to become slushy (factor B). Thus, we can set up the rule A → B but it does not function in the opposite direction, so it is not necessary to evaluate the relation B → A.

Step 5 – Analysis of time series

Several factors involved in the process can be described by time series. The longer the time series, the more information can be gained from them. However, classic statistical methods cannot reveal certain non-linear information hidden in these time series. Thus, more universal modern methods should be used (Zvelebil et al. 2006).

In the case of the Ethiopian Plateau (two model localities – Dessie and Debre Sina), time series for air temperature and rainfall are available.

Classic methods can also be used to gain as much information as possible from the time series. In this case, the analysis was performed by applying periodograms, correlation, and numerical and graphical methods from the tools of nonlinear science (Zvelebil et al. 2006).

The method based on *periodograms* allows us to calculate statistically important periods in the time series, which are the most significant in the process. This approach can reveal valuable information hidden in the time series. Knowing these periods, we can make conclusions about possible sub-processes, which are incorporated into the total process described by the time series. In principle, decompose the process into certain spectral components characterized by their angle shift φ and amplitude A, using harmonic functions. From these spectral components we create a formula i.e. the sum of a limited amount of harmonic functions with different parameters φ, A, providing us with an analytic instrument, which a) describes the process with a known accuracy (likelihood) and b) can be used for other calculations (forecasting the next development, derivation to know the process velocity etc.).

The method aimed at calculating the *correlation* between two time series makes it possible to obtain information about the grade of dependency between these time series. As an example, the correlation between time series of rainfall and water levels in rivers results in a high correlation coefficient. On the other hand, this method can also be used to reject the idea about a possible dependency between two other sub-processes. Thus, this is an effective instrument for providing an overview of the process as a whole.

For localities where landslides (i.e. unstable rocks) are monitored, the recommended methods for evaluating data are based on the theory of complex systems (Zvelebil et al. 2008) as the interaction and co-operation of two elementary factors can induce dramatically new effects. The unexpected rise of new structures in time-and-space, whose features and relations between them could totally differ from the basic rules, can lead to abrupt qualitative changes in behavior, creation of new features, or possibly even the creation of a new set of different states with unstable and unpredictable development in time and space. The tools for description of such systems can be found in the newest results of basic physical and mathematic research of complex systems. These tools include a phase-portrait in 2D and 3D space, a numeric risk diagnostic based on qualitative differences in time-correlations between residuals in 'near-to-equilibrium' (NTE) and 'far-from-equilibrium' (FFE) time series, recurrence analysis, and power spectra etc.

Step 6 – Calculation using a Saaty's matrix

Having selected the N factors we then create a matrix N × N. The relation "The importance of factor X against factor Y" should be described (by numbers) in each cell of the matrix. Several methods known from economics or statistics can be applied, so we assume the use of a Saaty's matrix (SM) because of its simplicity. The cells of the SM have to be filled in by numbers, which are ratios stating how many times (we assume) factor X is more (or lesser) important than factor Y.

The Saaty's matrix is highly suitable for this purpose. If we begin to fill in the i-th line of the matrix, then there will be a number in the cell with indices [i, j], which states how many times the influence of factor i is higher than the influence of factor j. If the ratio of both influences is 1 : 1, then the value in the cell will be 1. If the importance of the second factor is only 1/3 against the first one, then this ratio can be expressed as 0.33 etc.

Note that on the diagonal there have to be values equal to 1 only because each factor has an importance of 1 compared to itself.

After filling in this matrix, the calculation has to be done for to gain a weight of each factor in comparison to others.

The SM should be defined for various scenarios that describe the possibilities of future development. These scenarios should cover foreseen possible (real) combinations of input conditions, which can occur. In this way, it is possible to be prepared for more hazardous situations in advance. The automatic system for decision support should have access to actual data and after their evaluation it should be able to switch over to another scenario when it finds an extreme change of input conditions (Nechyba et al. 2014). In such a case, the SM has to be re-calibrated (automatically or manually) in order to be in accordance with reality.

As mentioned above, it is important to elaborate scenarios, which count on extreme changes in inputs, i.e. when the stability of the system changes. Let us call them critical scenarios (CS). The CS should cover the entire spectrum of possible hazardous situations, such as heavy rain + soil saturated by water + inconvenient slope + … etc.

Step 7 – Ranges for an evaluation of the involved factors

For the next steps it will be necessary to set up boundaries of possible intensity for each factor.

After setting up the possible minimums and maximums of each factor, the next step should follow. In this step, any possible influence of a factor has to be evaluated from the point of view of what happens, when the intensity of the factor changes. To make this evaluation easier, it is a good idea to split the whole range of the factor into more sub-intervals, which are interesting from certain point of view. In other words, this dividing has to be based on the fact that in most cases different intensities of factors produce different results. For example, a better evaluation of the influence of various air temperatures can be made when the total range of temperatures (i.e. between the maximum and minimum temperatures) has been divided into individual sub-intervals, which cover very low, moderate and very high temperatures. Alternatively, the factor rainfall can be divided into sub-intervals called no rain, low intensity etc. up to heavy rain. Another example could be the factor vegetation cover, which could be divided into sub-intervals of between 0% and 100%.

This dividing has to be performed by giving numeric values of intervals for boundaries of sub-intervals. In the case of the factor temperatures the following set of sub-intervals can be specified:

a) very low temperatures: from -5 °C up to +3 °C,
b) low temperatures: from +3 °C up to +10 °C,
c) moderate temperatures: from +10 °C up to +30 °C,
d) high temperatures: from +30 °C up to +50 °C,
e) very high temperatures: more than +30 °C.

Step 8 – Calculation of the involved factors in the process

In this part of the method we have to set up a value, which can be described by the words how strong is the influence of each factor.

The range of factors that have (or can have) an influence on the process is very wide and their nature can also differ enormously. They mostly cannot be easily evaluated by comparison based on direct (linear) methods. In other words there is no all-explaining rule based on superposition of respective influences of all the factors. In fact, the evaluated factors can be compared only after their values have been transformed into a common comparative basis, which for example could be a scale from 0 to 10 points. Let us call this *evaluation of the value of intensity*.

In our method we used a scale from 0 to 10. The resolution (step) of this scale has to be chosen based on how many values the intensity of the factor can occur. Expressed in mathematical language, we have to map the possible intervals from 0 to 10. The simplest way to do this is by linear interpolation; however, other alternative methods of interpolation (i.e. logarithmic) can be used. The interpolation method should be chosen by experts that understand the problems connected with the occurrence of the factor(s).

Step 9 – Application of the influence of uncertainty

It is also necessary to state that not all of the intensities of the factors have been detected with the same reliability and accuracy. This fact can be expressed by multiplying the value of intensity of the factor by an uncertainty coefficient, which can be set up based on the following example:

1. the intensity of the factor has been determined by direct measurement or laboratory analysis, with high repeatability, also with high plausibility:
   … the uncertainty coefficient can be from 80% to 100%,
2. the intensity of the factor has been gained by interpolation from direct measurements by linear, bi-linear, exponential etc. interpolation:

… the uncertainty coefficient can be from 60% to 80%,
3. the intensity of the factor has been gained by qualified estimation:
… the uncertainty coefficient can be from 30% to 60%,
4. the intensity of the factor has been roughly estimated using comparison based on analogy, experience, qualified estimation etc.:
… the uncertainty coefficient can be from 10% to 30%,

Step 10 – Results

In the end of this step, the total evaluation of risk (TER) connected with the process should be calculated for each cell [i, j] from the numeric values using the above-mentioned procedures, by applying the following formula:
$TER_{i,j} = Sum_k\ (UC_{k,i,j} \times VFI_{k,i,j})$
where $UC_{k,i,j}$ = uncertainty coefficient of the factor with index k, assigned to the cell [i, j] in the 2D-mesh,
$VFI_{k,i,j}$ = value of intensity of the factor with index k, assigned to the cell [i, j] in the 2D-mesh,
Sum_k = the function summation of all products assigned to the factor with index k.

From a mathematical point of view the TER is equal to the scalar product of 2 vectors:
– vector of uncertainty coefficients,
– vector of values of factor intensities.

3. Example

The method described here has been tested on the model localities of the Dessie Graben and Debre Sina landslides. Figs. 3–7 show the examples of the results of each step of the multi-criteria analysis.

4. Discussion

It is necessary to bear in mind that in most cases the risk of landslides or erosion has to be evaluated in sites where there is not enough data available to base the prediction on an evaluation of time series, for example from the area of non-linear dynamics. That is why it is necessary to create and use models, which are able to work out data of a different nature, in different formats, gained by different methods or from different areas. The data can come from actual measurements, from past times, in the form of time series or plain text or even in graphic form, discontinued, from mapping in situ or from remote sensing.

The combined method is based on the principle of a multi-criterion evaluation system, which describes and evaluates the respective criteria from different points of view. For the partial calculation of criteria, it is possible to apply classic statistic methods together with newer methods, such as fuzzy logic, which help to evaluate criteria with limited data sets, described more or less in a qualitative form.

Due to the above-mentioned lack of data there is a question about the plausibility of the results of evaluations made by applying the method we have proposed. In other words, whether realistic results can be gained from the insufficient amount of data or by the simultaneous use of both qualitative and quantitative data. This problem can be solved by introducing the terms certainty and uncertainty. These terms enable us to determine on what level of plausibility the data can be considered in the calculation or on what level of accuracy the calculated result needs to be considered. Instead of one numeric value, this level of accuracy gives us certain fluctuation range, in which the overall result can be found. Together with the knowledge of the possible accuracy gained by this kind of evaluation, we also get a general idea of what data have to be incorporated or improved in terms of accuracy in the future to make the result more precise.

Application of the method requires a multi-disciplinary approach and sufficient knowledge of the issues connected with the area of interest. In addition to knowledge of engineering geology and geomorphology, it is necessary to focus on knowledge from the areas of mathematics, statistics and informatics. Empirical experience should also be applied together with a phenomenological point of view. This means that not only the processes should be described but also the relationships between them.

The combined method enables us to also evaluate natural risks at sites where no evaluation has been performed due to the mentioned lack of data and their different characteristics. By applying this method, a basic overview can be gained in a very short period of time of the actual and future level of risk connected with rockfalls, landslides or erosion in a selected area. Such areas could be in developing countries where the insufficient technical, technological and personal resources prevent continuous and complex monitoring of risk phenomena in order to obtain enough data to analyze and predict possible threats.

The general methodology describes a process, which is suitable also for sites, where there are only limited knowledges about the region and, the high degree of subjectivity must be applied. The methodology had been verified also in other regions, i.e. in a region of North-Western Bohemia, where there are data enough, thus the subjectivity is low and it was possible to calibrate this methodology (Nechyba 2014).

5. Conclusions

The described integrated method is suitable for a basic evaluation of landslide or erosion risks, based on data gained from both historical and actual real-time measurements, from surveying in situ or from remote sensing. These data can be evaluated by classic deterministic methods or by methods from the theory of complex systems.

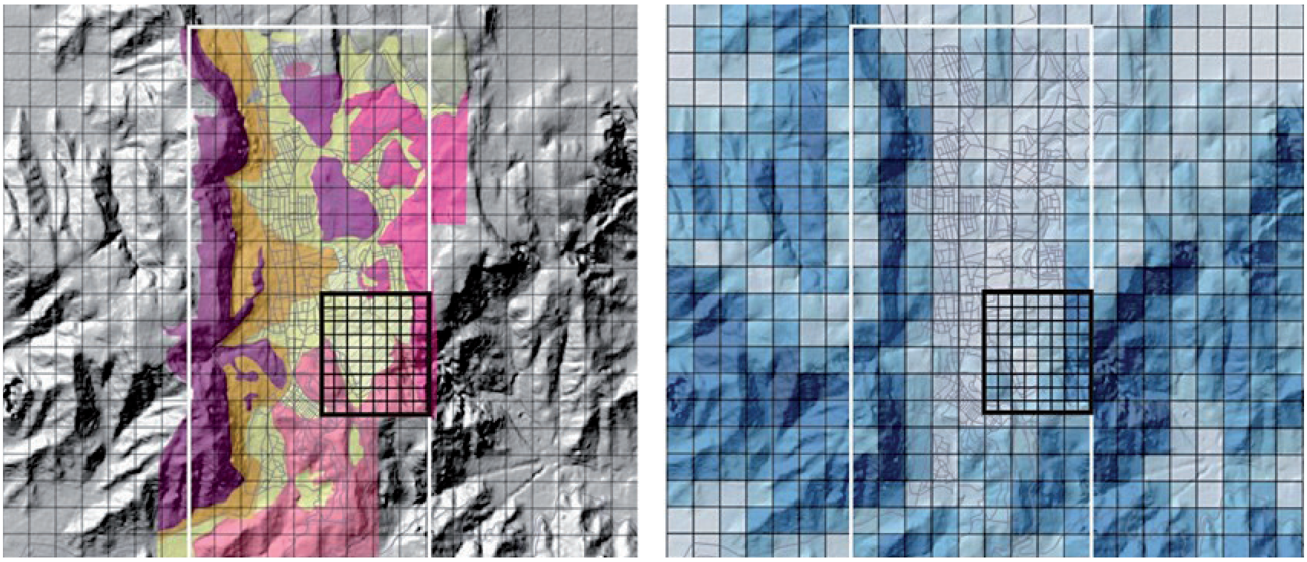

Fig. 3 Example of the "Covering the area with a system of cells" step in two scales (the central and southern parts of Dessie town are marked by a white rectangle represented by single squares of 360 × 360 m, the study area with active landslides is marked by a black rectangle represented by single squares of 180 × 180 m): a) with a geological map, b) with slope inclination in the study nets.

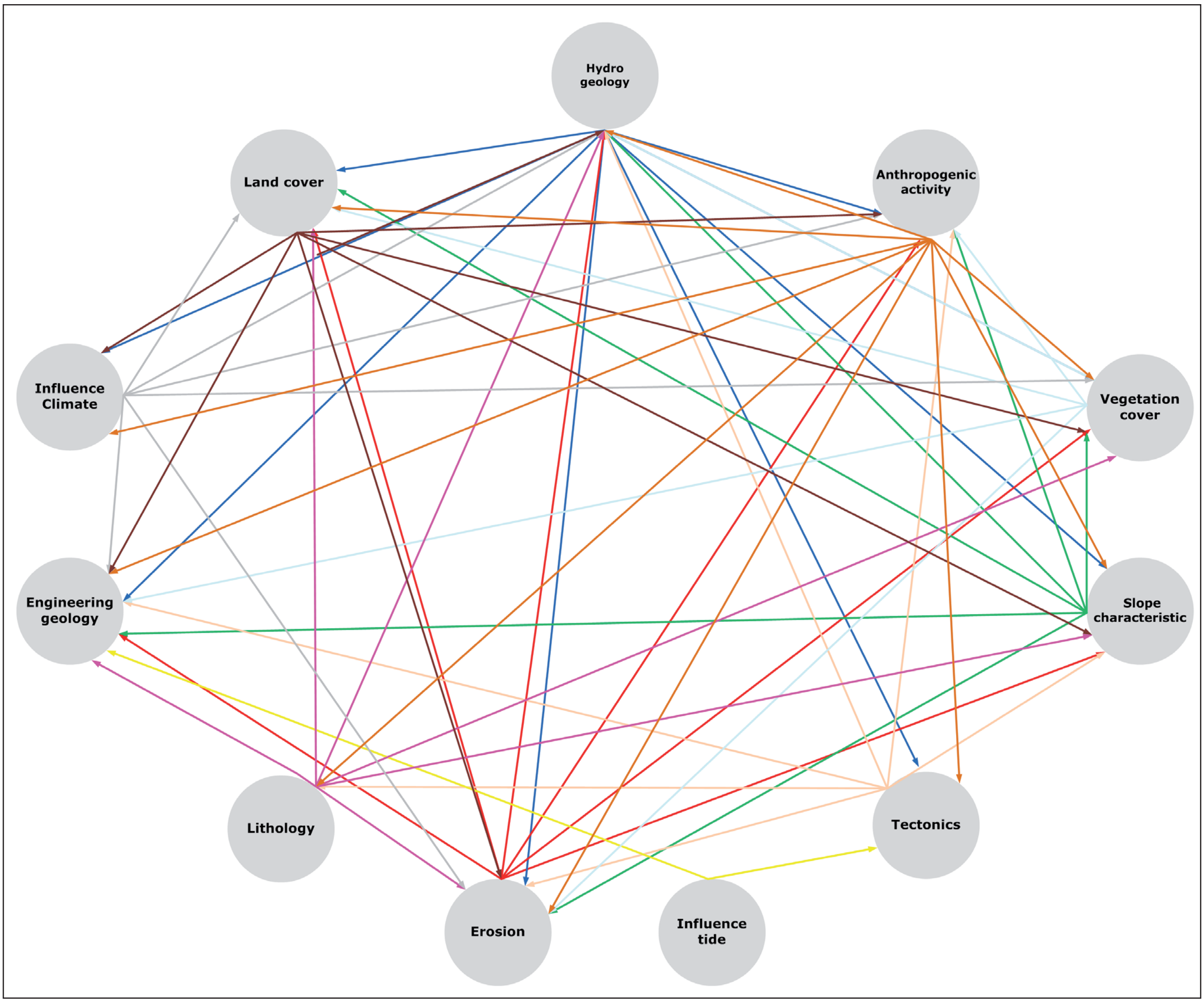

Fig. 4 Example of the "Coincidence matrix" step.

	Crit 1	Crit 2	Crit 3	Crit 4	Crit 5	Crit 6	Crit 7	Crit 8	Crit 9	Crit 10	Crit 11	GA	WEIGHT	
1. Slope characteristic	1	4	1	1	0.6667	0.6667	0.6667	0.6667	0.8	8	0.5	1.088	0.0792	7.92%
2. Erosion	0.25	1	0.25	0.25	0.1667	0.1667	0.1667	0.1667	0.2	2	0.125	0.27202	0.0198	1.98%
3. Engineering geology	1	4	1	1	0.6667	0.6667	0.6667	0.6667	0.8	8	0.5	1.088	0.0792	7.92%
4. Lithology	1	4	1	1	0.6667	0.6667	0.6667	0.6667	0.8	8	0.5	1.088	0.0792	7.92%
5. Tectonic	1.5	6	1.5	1.5	1	1	1	1	1.2005	12.0482	0.7502	1.63267	0.11884	11.88%
6. Hydrogeology	1.5	6	1.5	1.5	1	1	1	1	1.2005	12.0482	0.7502	1.63267	0.11884	11.88%
7. Soils	1.5	6	1.5	1.5	1	1	1	1	1.2005	12.0482	0.7502	1.63267	0.11884	11.88%
8. Climatic influences	1.5	6	1.5	1.5	1	1	1	1	1.2005	12.0482	0.7502	1.63267	0.11884	11.88%
9. Tidal effects	1.25	5	1.25	1.25	0.833	0.833	0.833	0.833	1	10	0.625	1.35978	0.09898	9.9%
10. Vegetation cover	0.125	0.5	0.125	0.125	0.083	0.083	0.083	0.083	0.1	1	0.0625	0.1358	0.00988	0.99%
11. Anthropogenic influence	2	8	2	2	1.333	1.333	1.333	1.333	1.6	16	1	2.17577	0.15838	15.84%

Fig. 5 Example of the "Saaty's Matrix" step.

SUB-CRITERION	WEIGHT	EVALUATION	RISK
1. Slope characteristic	0.0792	6,1	0.48312
2. Erosion	0.0198	4,8	0.09504
3. Engineering geology	0.0792	5,5	0.4356
4. Lithology	0.0792	5,3	0.41976
5. Tectonic	0.11884	2	0.23768
6. Hydrogeology	0.11884	1,8	0.213912
7. Soils	0.11884	6,2	0.736808
8. Climatic influences	0.11884	2,4	0.285216
9. Tidal effects	0.09898	1,1	0.108878
10. Vegetation cover	0.00988	6,8	0.067184
11. Anthropogenic influence	0.15838	7,2	1.140336
SUM	1	49.2	4.223534

Fig. 6 Example of the "Calculation of the involved factors in the process" step.

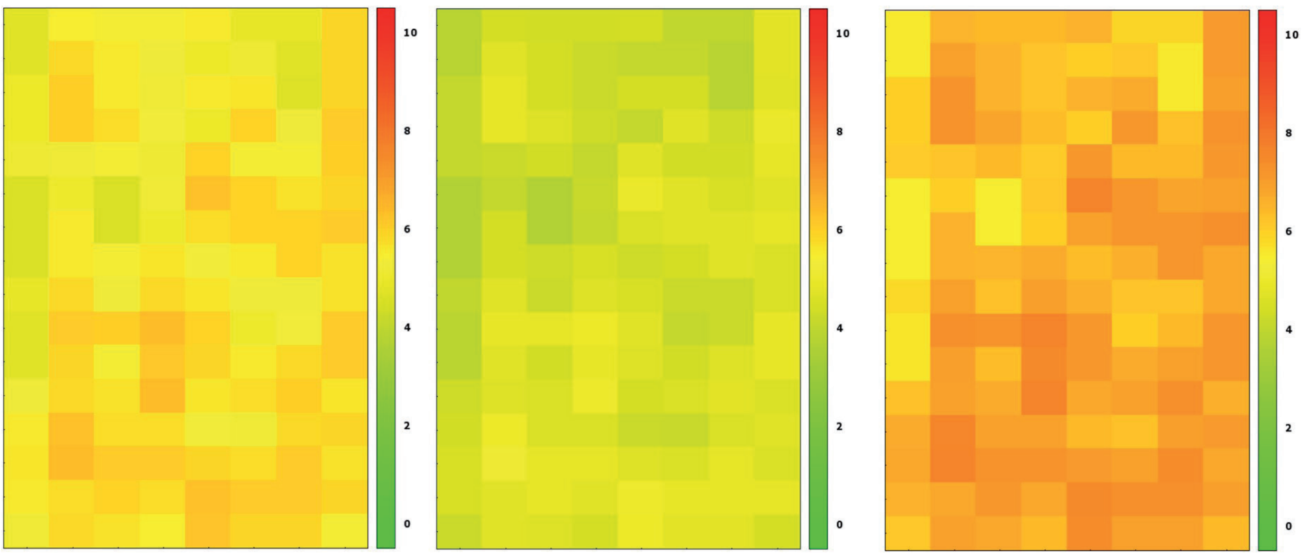

Fig. 7 Example of the "Results" step (risk assessment in Dessie graben): a) general result b) minimal risk c) maximal risk.

The combined integrated method has been tested on two selected localities with landslide hazards on the border of the Ethiopian Highlands and the Main Ethiopian Rift. The result gives a basic overview of the susceptibility to risks for the utilization of the study area. At the same time, it presents a level of data relevancy, which can influence possible uncertainty during risk evaluation and forecasting. The method is suitable for a prompt risk evaluation and swift decision making. The method represents an effective tool in the case of incomplete geological and geomorphological data.

A combined method, exploiting the advantages both of the deterministic approach and an approach from the theory of complex systems, brings significant added value for risk evaluation of certain types of sites.

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RESUMÉ

Kombinovaná metoda pro hodnocení rizik svahových pohybů a náchylnosti k erozi na území Etiopské vysočiny

Řešitelský tým česko-německého výzkumného projektu se zaměřil na vytvoření nové kombinované metody, která by byla schopna ohodnotit rizika související se svahovými pohyby a erozí v oblasti Etiopské vysočiny. Realizace hodnocení dat a rozhodování z pohledu rizik se dnes uplatňuje ve stále složitějších podmínkách. Přírodní rizika tvoří velmi komplexní, dynamický systém, který není vždy stabilní z pohledu chování a jeho popis může být složitý a ne vždy spolehlivý. Je třeba si uvědomit, že problematika hodnocení nespočívá pouze v samotných metodách hodnocení, ale obecně i v dostupnosti dat, jejich kvalitě a relevantnosti. Procesy hodnocení a rozhodování tak vyžadují nové kombinované přístupy, založené na exaktních metodách, s využitím kvalitativních i kvantitativních informací, a se zkoumáním přirozených nejistot a neurčitostí.

Nová kombinovaná metoda vychází z klasického deterministického přístupu a z teorie komplexních systémů. Pro vlastní hodnocení využívá data z dálkového průzkumu země, vlastního terénního průzkumu a dostupných časových řad sledovaných parametrů. Metoda využívá z části kvalitativního hodnocení, kdy pro tyto účely je možné aplikovat principy umělé inteligence. Metoda vycházela z poznatků většího počtu lokalit, ověřena byla na dvou lokalitách nacházejících se v Etiopské vysočině (Dessie, Debre Sina).

Nová metoda přináší nástroj, pomocí něhož je v relativně krátké době možné provést základní ohodnocení rizik sesuvů a eroze, a to i na lokalitě, kde doposud neexistují relevantní data k jejímu stavu. Prezentovaný výsledek do určité míry obsahuje neurčitost a nejistotu, které jsou ovšem zcela jasně definovány. Metoda tak připouští využití i subjektivně hodnocených či zabarvených informací, a tyto informace dokáže formulovat a efektivně využívat.

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COMPARING A HYDRODYNAMIC MODEL FROM FIFTH GENERATION DTM DATA AND A MODEL FROM DATA MODIFIED BY MEANS OF CROSOLVER TOOL

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ABSTRACT

Flooding is a natural phenomenon that occurs with varying intensity and at irregular time intervals. Floods are the natural disasters that pose the greatest direct threat to the Czech Republic. They may cause serious critical situations during which not only extensive material damages are incurred, but so too is the loss of human life in affected areas as well as vast devastation of the cultural landscape including environmental damages. The information issued by flood forecasting services about the character and size of flood areas for individual N-year flood discharge events and specific flood scenarios is important for eliminating the potential threats and consequences of such events. Hydrodynamic models provide an adequate image of depths and flow velocities at the longitudinal or cross profiles of the watercourse during a flood event. This is why information obtained from hydrodynamic models occupies a privileged position from the viewpoint of protecting human life and mitigating property damage.

Altimetry data are the basic input into hydrodynamic models. One way to obtain such data is through the method of aerial laser scanning (ALS) from the digital terrain model (DTM). This method is considered one of the most accurate methods for obtaining altimetry data. Its major drawback is however its inability to record terrain geometry under water surfaces due to the fact that the laser beam is absorbed by the body of water. The absence of geometric data on watercourse cross sectional area may perceptibly affect results of modelling, especially if the capacity of a missing part of the channel represents a significant cross sectional area. One of the methods for eliminating this deficiency is sufficiently calculating channel depth by means of software tools such as CroSolver.

This paper deals with the construction of a hydrodynamic model using fifth generation DTM data and compares outputs from this model at various discharges with a model based on the altimetry data modified using CroSolver. Outputs from the two hydrodynamic models are compared using HEC-RAS software with the use of depth estimate data and with the use of the unmodified DTM. The comparison is done on two watercourse reaches with different terrain morphology and watercourse size. A complementary output is the comparison of inundation areas issuing from both model variants.

Our results indicate that differences in the outputs are significant, namely at lower discharges (Q_1, Q_5), whereas at Q_{50} and Q_{100} the difference is negligible with a great role played by the morphology of the modelled area and by the watercourse size.

Keywords: aerial laser scanning (ALS), hydrodynamic model, HEC-RAS, CroSolver, cross profile – floods

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1. Introduction

Hydrodynamic models are used to simulate hydraulic phenomena and are derived from the physical characteristics of flow, namely the laws of mass, momentum, and energy conservation. As to output details and input data requirements, they are divided into one-dimensional (1D), two-dimensional (2D), and/or combined (1D/2D) models (Roub et al. 2015).

The main factor in the creation of hydrodynamic models is input data for developing watercourse computational geometry (Ernst et al. 2010). Requirements for input data differ with respect to the hydrodynamic model used. One-dimensional (1D) hydrodynamic models feature lower requirements for input data as the computing track is formed by channel cross profiles. By contrast, in two-dimensional (2D) hydrodynamic models, a digital terrain model has to be constructed for the entire area in question. An alternative to the above-described models are quasi-2D modelling approaches, which combine the computational 1D or 2D approaches (Lindenschmidt 2008). In the latter, the actual complicated spatial geometry is artificially divided into parts of a branched or ring network composed of several partial models, e.g., the channel and inundation area (Valentová et al. 2010; Valenta 2005).

In the case of one-dimensional modelling, methods used to obtain data on the computational geometry of the watercourse and its adjacent inundation area include geodetic surveying, photogrammetry, ALS, or a combination thereof (Novák et al. 2011).

Geodetic surveying of the channel and adjacent inundation areas of watercourses is the most time- and cost-consuming method to ascertain information about

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the geometry of watercourses with respect to the size of the surveyed point field (Bharat and Mason 2001). In order to obtain data for hydrodynamic models the topography of watercourse axes is surveyed as is the topography and altimetry of cross profiles and objects on the watercourse. The distance between individual surveyed cross profiles ranges from several tens to several hundred of metres and depends especially on the variability of river channel shape. The surveying should involve the recording of watercourse spatial changeability, namely changes in channel cross sections and changes in longitudinal gradient. The usual distance between cross profiles on streams in the Czech Republic ranges from 50–100 m in built-up areas to 200–400 m outside of built-up areas (Drbal et al. 2012).

Geodetic surveying is also a necessary part of aerial photogrammetry, where it is used for surveying geodetic coordinates and the elevation of ground control points. Ground control points serve to determine orientation and scale and for transformation into the geodetic system. This procedure identifies the captured images with the actual terrain (Pavelka 2009).

Photogrammetry is a scientific discipline falling under geodesy and cartography, which deals with the acquisition of geometric data from image records, i.e., from photographs. Aerial photogrammetry uses two appropriately captured images (stereo-photogrammetry) that show the same area with a certain overlap. Data collection is further limited due to the use of a passive sensor, which is affected by atmospheric processes. Aerial photogrammetry is used for mid- and large-scale collection of topographic and altimetry data with sufficient accuracy and in considerably less time and at lower cost than with the use of geodetic methods. The low time consumption makes it possible to repeat the scanning and hence to keep data up to date (Metodický pokyn [Methodological instruction], 28181/2005-16000).

The third method of collecting spatial data for the construction of watercourse computational geometry in hydrodynamic models is aerial laser scanning. The ALS method is one of the most advanced technologies for harvesting topographic and altimetry data. Aerial laser scanning has been developed for the fast and operative mapping of large areas where standard methods (tachymetry, GPS, photogrammetry) are not sufficient (Dolanský 2004).

The ALS method is based on the principle of laser beam reflection; the precise position of the scanner and at the same time the precise direction of the emitted beam must be known. The principle consists in recording the time between the emission of the laser beam (which is as a rule within the infrared spectrum) and the reception of its reflection. The position of a given point is computed by processing this parameter (Wehr and Lohr 1999; Dolanský 2004; Novák et al. 2011; Oršulák and Pacina 2012). The advantage of this method consists in fast data collection, relatively low costs, and the ability to survey difficult terrain and large areas (Charlton et al. 2003).

Currently a new altimetry survey is being conducted in the Czech Republic with the use of the ALS method. It draws from current altimetry databases that contain data that are already obsolete for certain territorial types, their quality and accuracy adversely affecting the quality of national map series as well as digital geographic databases of the Czech Republic (Brázdil 2009). The goal is to ensure in collaboration with the State Administration of Land Surveying and Cadastre (ČUZK), the Czech Ministry of Agriculture, and the Czech Ministry of Defence a high-quality geographic data infrastructure that would be uniform and standardized for the whole territory of the Czech Republic.

2. Methodology

2.1 The underlying data

The basic groundwork was altimetry data from the fifth generation DTM of the Czech Republic. The data were provided by the State Administration Land Surveying and Cadastre (ČÚZK) and delivered in the S-JTSK coordinate reference system and the Baltic Vertical Datum after adjustment in ASCII coding and formatted with X, Y, and H values.

Data on N-year discharges were taken from the Registration Sheet of Crier Profile no. 127 for the Otava River and no. 182 for the Úhlava River (Tab. 1).

Tab. 1 Flow volumes corresponding to N-year discharges.

Site	N = year discharges Q_n [m³/s]				
	Q_1	Q_5	Q_{10}	Q_{50}	Q_{100}
Otava R.	146	300	394	680	837
Úhlava R.	36.7	82.4	111	201	250

2.2 Description of the study areas

The hydrodynamic models were constructed for two watercourse reaches with different terrain morphology and stream size. The first site of interest was a reach on the Otava River in Písek and the second one was a reach on the Úhlava River in Přeštice.

2.2.1 The Otava River site

The Otava River site is represented by a reach of 2,224 m in the cadastral area of Písek municipality. The reach is delimited by river km 22.4–24.6 and was divided into a total of 20 cross profiles (Fig. 1). The selected stream reach is situated in the central and north-eastern parts of the town

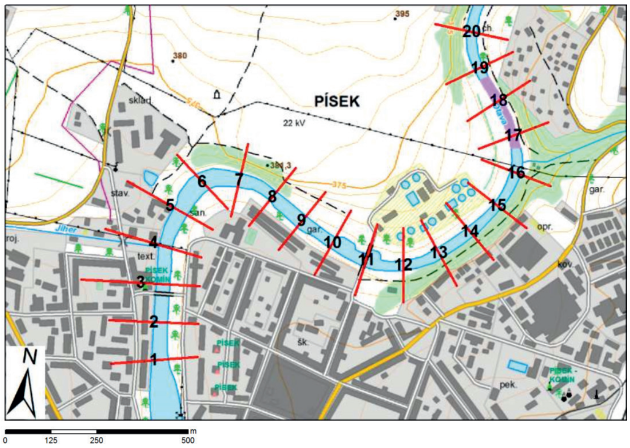

Fig. 1 Localization of cross profiles on the Otava River reach.

The Otava River is a third order stream and a left-bank tributary of the Vltava (Moldau) River, originating at the confluence of the Vydra River and Křemelná River in the Šumava Mountains near Čeňkova Pila. In the selected stream reach, the Otava River already indicates typical lowland features with an average top width of about 35 m. The average annual discharge in this section is 23.4 m^3/s and the average annual water level height is 90 cm (ČHMÚ 2015a).

2.2.2 The Úhlava River site

The second concerned site is a 1,280 m reach of the Úhlava River situated in the cadastral area of Přeštice. The reach is delimited by river km 30.5–31.7 and was divided into a total of 13 cross profiles (Fig. 2). The Úhlava River is a watercourse smaller than the Otava River, and its average annual discharge is 5.51 m^3/s (ČHMÚ 2015b). Terrain morphology is very specific with the entire right-bank side lying very low, and therefore extensive spills can be expected when the stream overflows its banks.

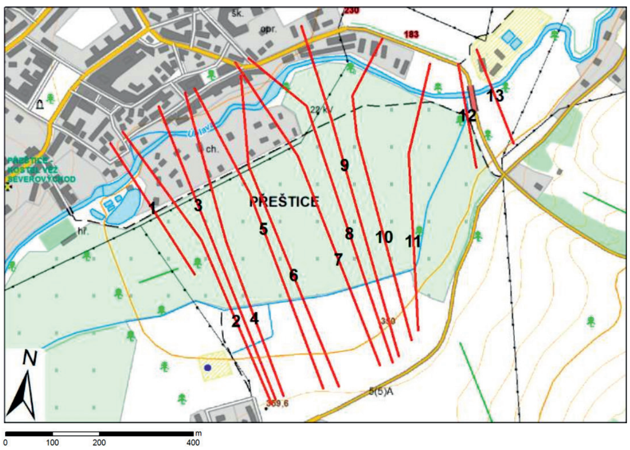

Fig. 2 Localization of cross profiles on the Úhlava River reach.

2.3 CroSolver Toolbox

As during ALS the laser beam does not penetrate the water's surface, the real shape of the channel is neglected, which may considerably distort the results of hydrodynamic modelling (Podhoranyi and Fedorcak 2014). The CroSolver (Cross section Solver) tool was developed to resolve this problem; it is available in two variants: CroSolver as a library of functions in the R programming language (Roub et al. 2012b) and as the CroSolver Toolbox consisting of Python scripts for use in ArcGIS (Roub et al. 2015).

The basic computing diagram of the tool is shown in Figure 3. During pre-processing, cross profiles are constructed first based on the specified distance between the profiles and watercourse width; the distance between the profiles affects the details of the results. The depth is then determined based on other channel parameters at the time of ALS, such as discharge, channel roughness coefficient, slope gradients, water surface smoothing distance, and the selected method for determining depth (Roub et al. 2015).

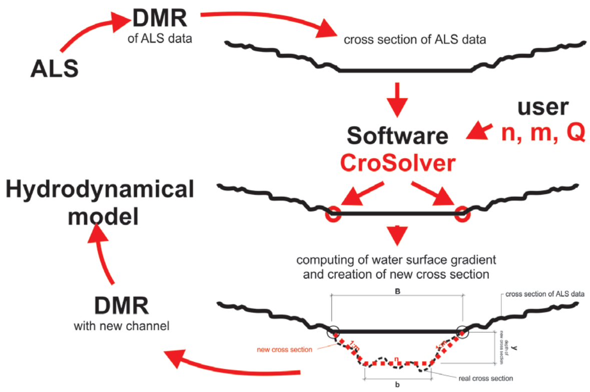

Fig. 3 The basic working scheme of CroSolver software (CroSolver 2014).

In the next step, the constructed cross profiles are prepared for depth computation. The constructed cross profiles are two-dimensional only. The extreme points of the cross profiles should characterize the contact points of the water surface and channel bank. Because we are searching for a point that is as close to the water surface as possible, it holds that such a point has the lowest height. Thus, a search radius for this point must be entered into the software. The tool will find the lowest point in the search field and will return its height and position vertical to the cross profile. A point defined in this way characterizes a point on the bank slope at the water surface.

The computation of watercourse channel depth is based on pre-processing data and on the characteristics of the watercourse channel. The computation is carried out for steady, uniform flow using the continuity equation and the Chézy formula with the calculation of flow rate coefficient according to Manning:

$$Q = v\,S,$$
$$v = C\,\sqrt{(R\,i)},$$
$$R = S/O,$$
$$C = R^{1/6}/n,$$

where Q is discharge (m³ s⁻¹), S – cross-sectional area (m²), v is flow velocity (m s⁻¹), C – flow velocity coefficient, (m$^{0.5}$ s^{-1}), i is water level gradient (–), R is hydraulic radius (m), n is Manning's roughness coefficient (–) (Roub et al., 2015).

2.4 Construction of the digital terrain model in ArcGIS

The fifth generation DTM data were delivered in ASCII coding stored in *.xyz format. Therefore, it was necessary to convert them into a shapefile first (namely a point layer) in ArcGIS using the 3D Analyst extension's "ASCII 3D to feature class" function. Subsequently, a digital terrain model was constructed from the point layer in TIN format. The resulting TIN model of the Písek site is shown in Figure 4.

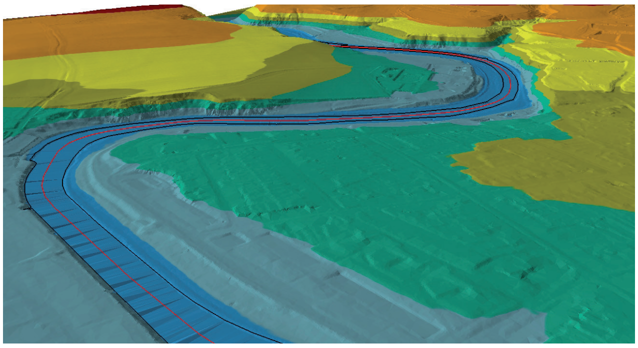

Fig. 4 3D display of the Písek site digital terrain model.

2.5 Creation of geometry with the HEC-GeoRAS extension

One of basic inputs into the HEC-RAS program is the geometry data of a watercourse. It is formed primarily by the watercourse axis, embankment lines, and cross profiles with altimetry data. All input data were created in ArcGIS using the HEC-GeoRAS extension, which allows the direct export of data in the form applicable for HEC-RAS.

In the case of the Otava River, cross profiles were automatically distributed with minor manual modifications so that the profiles do not cross one another and characterize watercourse geometry as realistically as possible. For the Úhlava River, asymmetric profiles had to be constructed with respect to the large inundation area on the right bank of the watercourse. The profiles were plotted manually and wrapped to prevent their crossing.

A 3D layer of cross profiles was constructed using the "RAS Geometry – XS Cut Line Att. – All" function. Thus, the attribute table of cross profiles was filled (namely the stationing added), and a layer was created of cross profiles with the altimetry information taken from the digital terrain model.

2.6 Determining channel depth by means of CroSolver Toolbox

The input layer into the CroSolver tool is the stream axis vectorized against the flow direction. Another input is the DTM stored in the *.txt text format. Data from the State Administration of Land Surveying and Cadastre (ČÚZK) were provided stored in *.xyz format, and therefore it was necessary that they be stored in the required format first. The actual process of calculating depth consists of three steps.

In the first step, a set of watercourse input axes had to be chosen as did parameters for dividing the watercourse into individual polygons, i.e., the distance between cross profiles and average width of the watercourse. For the Otava River the distance between profiles was set at 80 m and watercourse width at 30 m. For the Úhlava River, these figures were 60 m and 15 m, respectively.

In the second step, the output file from the previous step was entered (either as a text file or as a shapefile) and the DTM stored in the *.txt format. In both cases, the radius for finding the lowest point was set at 10 m.

In the third step, the input to be entered was the output from the previous step and optional parameters, including the method of depth computation, discharge, Manning's roughness coefficient, slope gradient, and minimum distance for water level calculation (Table 2). The discharge value entered was the actual value measured at the time of data acquisition by ALS.

Tab. 2 Parameters chosen when determining depth.

Parameter	Otava R.	Úhlava R.
Method of calculation	by gradient	by gradient
Discharge [m³ s⁻¹]	15.2	3.612
Roughness coefficient [–]	0.033	0.026
Slope gradient 1 : m [–]	2	2
Min. distance for water level calculation [m]	100	100

2.7 Hydrodynamic model construction in HEC-RAS

The freely available HEC-RAS program was used, which allows for one-dimensional calculations of steady and non-steady, non-uniform flow and sediment transport (movable bed), as well as the modelling of temperature changes in flowing water. In order to assess whether it is possible to use hydrological surveying for the creation of flow geometry, a steady flow calculation was used. The calculation of steady flow is based on a calculation of non-uniform water flow in the stream channel in sections. The program can divide the cross section into the actual stream channel (i.e., the effective area of flow), and the left and right inundation zones. Determining water surface profiles with HEC-RAS is based on a one-dimensional method using Bernouilli's principle. Energy losses are calculated by friction loss using Manning's equation, while local losses are expressed with contraction and expansion coefficients. Areas that are more hydraulically complex such as overfalls, confluences, bifurcations, bridges, and culverts are dealt with using modified equations of movement.

Two models were constructed for the two sites in HEC-RAS 4.1.0, which differed only in their input geometry data. The entered discharge, roughness, and boundary condition values were identical. Values entered for the Otava River were as follows: channel – 0.033, left bank at the first three profiles where a smooth concrete wall occurs – 0.026, remaining banks with mainly grasslands – 0.03. Roughness values chosen for the Úhlava River were as follows: channel – 0.026, banks with grasslands – 0.027.

The upper boundary conditions were given by N-year discharges Q_1, Q_5, Q_{10}, Q_{50} and Q_{100}. Critical depth was selected as the lower boundary condition, where the program computes a critical depth for each profile and other data need not be entered. The models were simulated in the subcritical flow regime.

In the case of the Úhlava River, geometry data had to be additionally modified. Considering the great similarity between fifth generation DTM data and the width of cross profiles, the number of points exceeded the maximum value (500 points) in some profiles. In such profiles, the excessive points had to be filtered off with geometry data editing (Fig. 5).

Other modifications were necessary on the Otava River, where the "levees" option had to be selected (Fig. 6). HEC-RAS models flooding in the cross section based on altitude but does not consider obstacles that water has to overcome first. The stationing and altitudes of needed points were inserted into the cross sections.

This measure was not used on the Úhlava River due to its terrain morphology. Based on the exploration of the DTM and aerial photographs of the area, spilling was considered over the entire surface since terrain roughness was low and sparse.

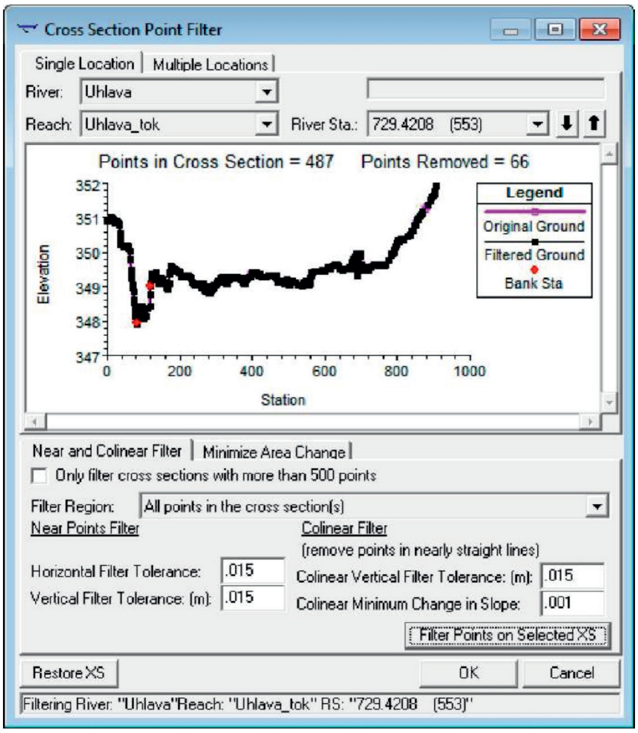

Fig. 5 Filtering off points in cross profiles.

3. Results

Results are presented in the form of graphic comparisons of three output characteristics from the HEC-RAS models:

a) water surface elevation,
b) cross sectional areas,
c) top width.

For comparison, the course of values along the entire longitudinal profile is illustrated as are the average values of differences in the characteristics of all cross profiles for the respective N-year discharges. Average deviations were calculated by subtracting the value of the models with and without depth computation. In addition, inundation areas derived from each model were compared. Summary charts include plotted results for the channel without

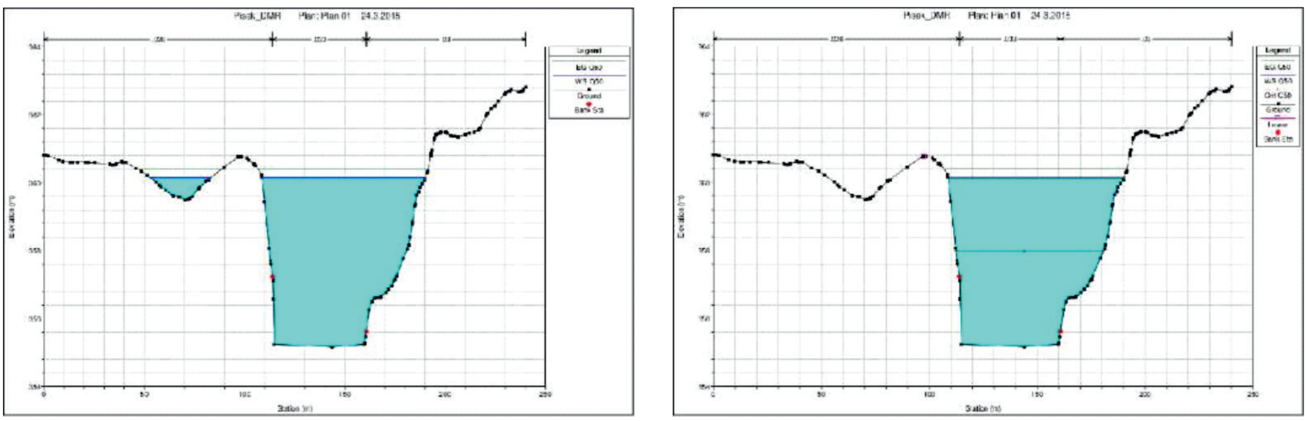

Fig. 6 Comparison of models with/without the "levee" option. (a) Result without using "levees". (b) Result using "levees".

depth calculation (fifth generation DTM) and with depth calculation (CroSolver).

3.1 Evaluation of the Otava River site

Figure 7 shows an example of watercourse channel depth determined by using the CroSolver software as compared with an untreated profile from the fifth generation DTM data. The only difference in geometry apparently occurs only in the channel while the inundation area and surroundings do not change in the process.

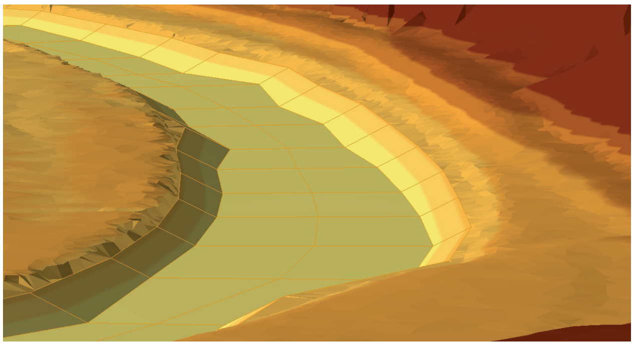

Fig. 7 Example of profile with calculated depth as compared with a profile without depth calculation.

3.1.1 Comparison of water surface elevations

It follows from Figures 8 and 9 that the difference between water surface elevations for the watercourse channels with and without depth calculation steadily decreases. At some discharges we can even see a phenomenon when the fifth generation DTM result corresponds to a different N-year CroSolver result (for example, a fifth generation DTM–based model for Q_5 gives nearly identical results as a depth-calculated model for Q_{10}).

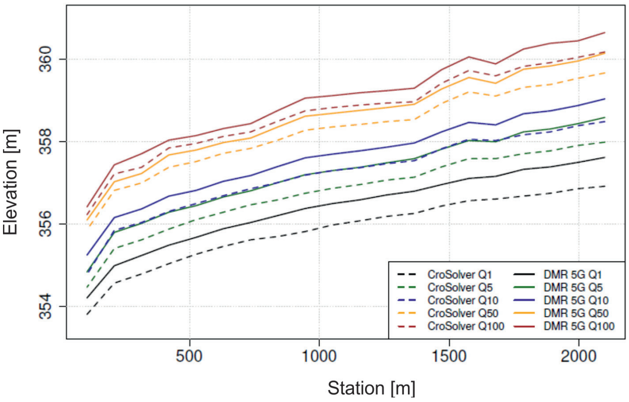

Fig. 8 Comparison of water surface elevations along the longitudinal profile at individual discharges.

3.1.2 Comparison of cross sectional areas

In cross sectional areas the trend is less clear (Fig. 11). The difference in the cross sectional areas gradually decreases at first, being generally insignificant, and the cross sectional area from the depth-calculated model at Q_{50} is even larger than that from the non-depth-calculated model. A shift in Q_{100} can be explained based on Figure 10, where a sudden increase of the area of two cross sections is obvious in the results based on the fifth generation DTM. These deviations were caused by the watercourse overflowing at given places in the non-depth-calculated model and by the subsequent spill, which significantly changed the shape of the cross sectional area. An example of the spill difference at the specific profile is shown in Figure 12.

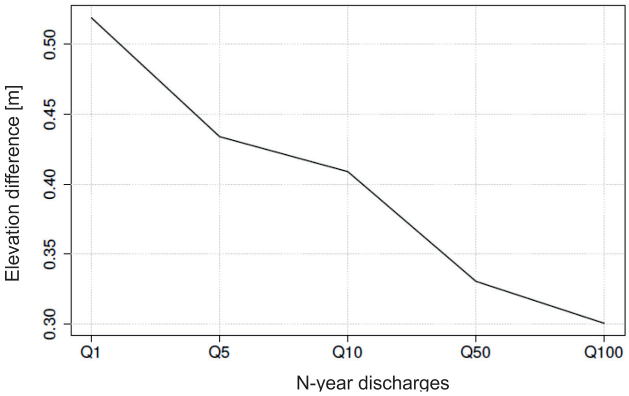

Fig. 9 Average deviation of elevations at individual discharges.

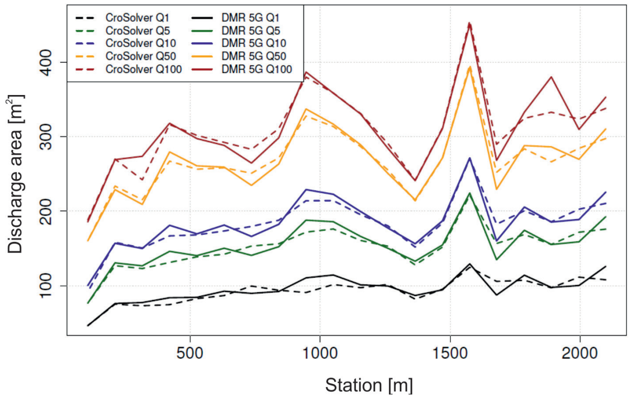

Fig. 10 Comparison of cross sectional areas along longitudinal profile at individual discharges.

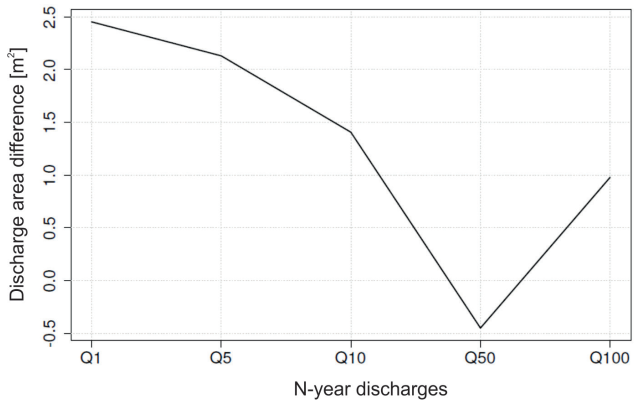

Fig. 11 Average deviation of cross sectional areas at individual discharges.

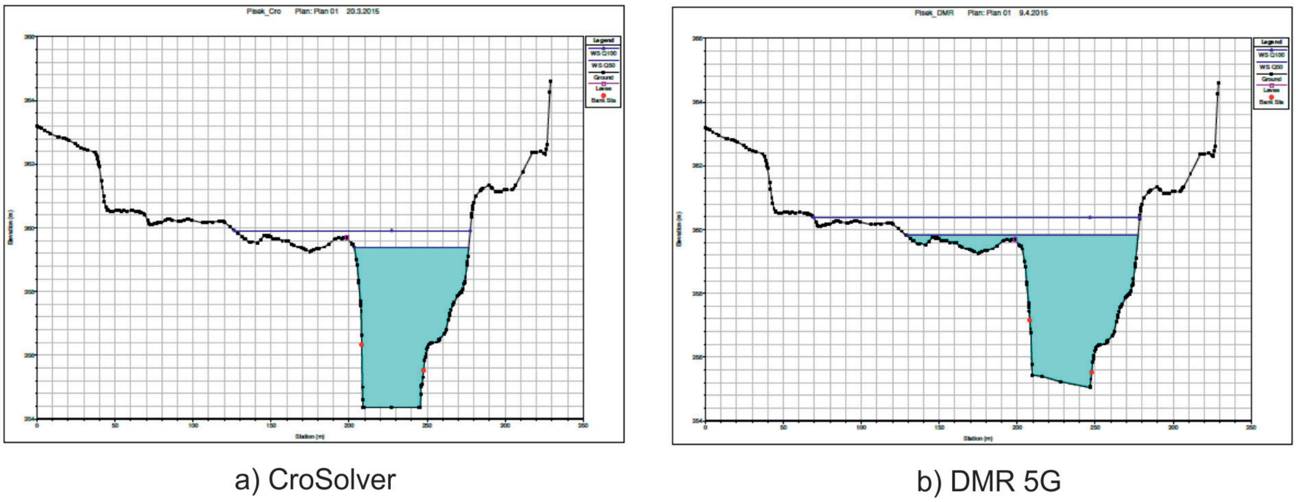

Fig. 12 Comparison of spills at profile no. 3 – Q_{50} and Q_{100}.

3.1.3 Comparison of top widths

Top width significantly depends on terrain morphology. Due to different spills, average differences are distorted (Fig. 14). The situation is similar as in the case of cross sectional areas. The result can be better seen in Figure 13. Top width difference is apparently pronounced namely at lower discharges (Q_1, Q_5, and Q_{100}), whereas the course is practically identical on a greater part of the reach at Q_{50} and Q_{100}. Exceptions are several cross profiles where larger spills occurred into the inundation area in the fifth generation DTM–based model, and hence an abrupt growth of top width difference was recorded (Fig. 12).

3.1.4 Comparison of inundation areas

Inundation area Q_1 was chosen to illustrate differences in spill. Figure 15 shows that differences in the inundation area were minimal even for the lowest discharge for which all monitored characteristics exhibited the greatest differences between the depth-calculated model and the non-depth-calculated model.

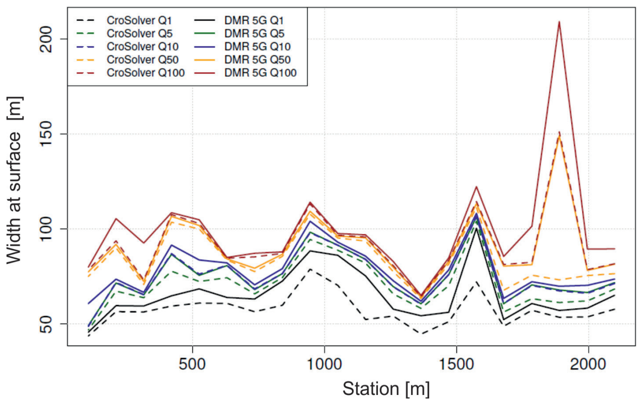

Fig. 13 Comparison of top width along longitudinal profile at individual discharges.

3.2 Evaluation of the Úhlava River site

Figure 16 depicts the longitudinal profile of the studied reach of the Úhlava River. It provides a typical example of terrain morphology in the given locality. An extensive inundation area stretches along the right bank.

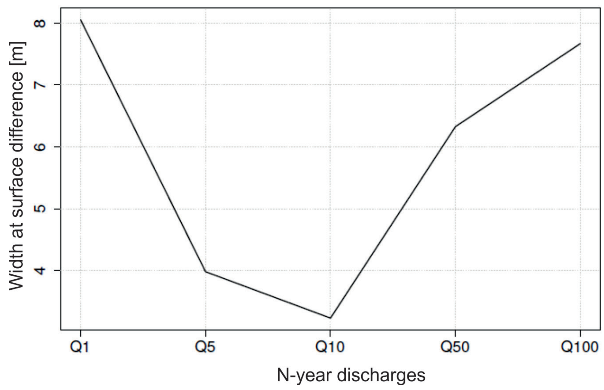

Fig. 14 Average top width deviation at individual discharges.

Fig. 15 Comparison of inundation area at discharge Q_1 at the Otava River site.

3.2.1 Comparison of water surface elevations

Figures 16 and 17 indicate that a significant difference in water surface elevations was observed namely at Q_1. At this discharge, overflowing occurred only in the non-depth-calculated model, and the channel modified with CroSolver still had sufficient capacity for handling this discharge. At Q_{50} and Q_{100}, the difference in water surface elevation was already negligible.

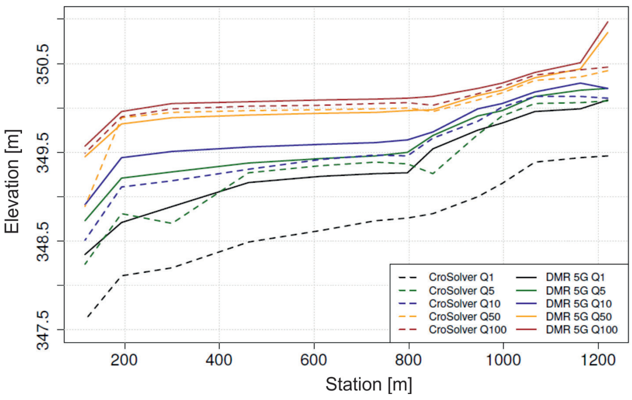

Fig. 16 Comparison of water surface elevation along the longitudinal profile at individual discharges.

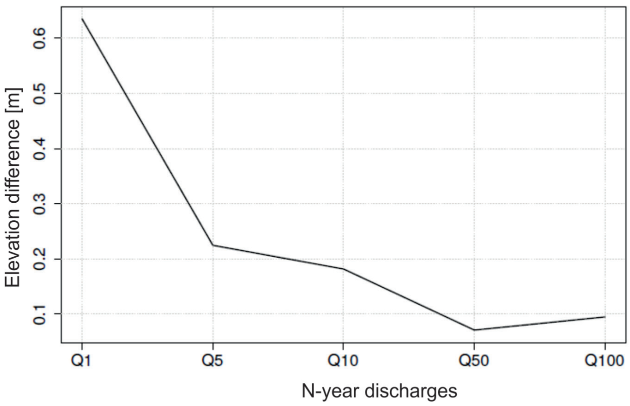

Fig. 17 Average elevation difference at individual discharges.

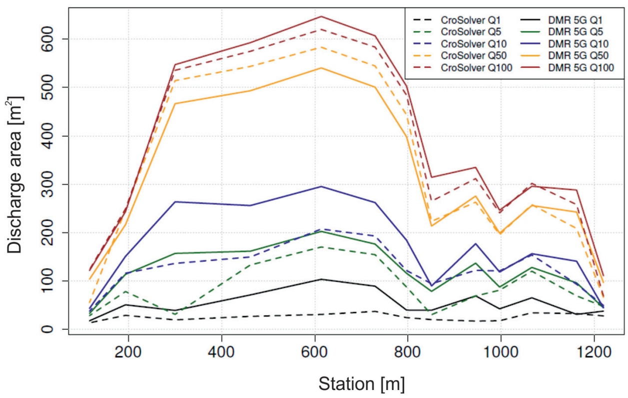

Fig. 18 Comparison of cross sectional areas along the longitudinal profile at individual discharges.

3.2.2 Comparison of cross sectional areas

Considering the rugged terrain and extensive spill, the cross sectional area was considerably variable here. Figures 18 and 19 show the ambiguous results for this characteristic.

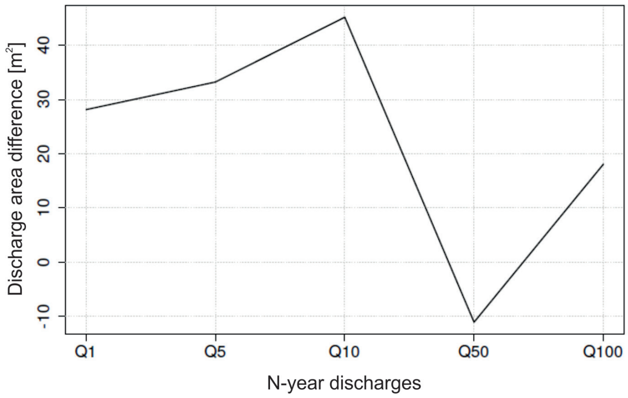

Fig. 19 Average deviation in cross sectional areas at individual discharges.

3.2.3 Comparison of top widths

The resulting top widths reflect once again the mode of water spill into the inundation area. Figures 20 and 21 show that differences in the top widths gradually dwindle up to Q_{50} and Q_{100}, where the courses of top widths are practically identical for the two model options.

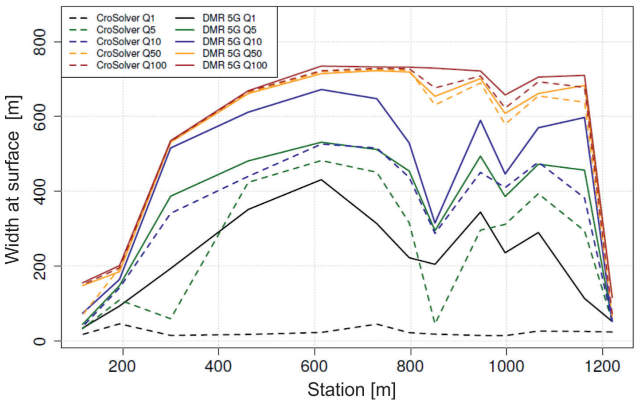

Fig. 20 Comparison of top widths along the longitudinal profile at individual discharges.

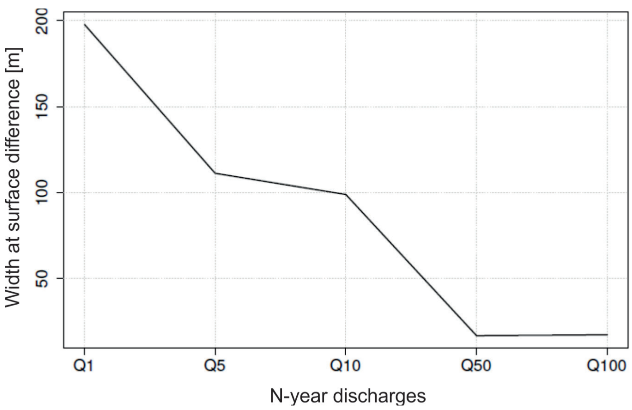

Fig. 21 Average deviation of top widths at individual discharges.

3.2.4 Comparison of inundation areas

A simulation of Q_1 was chosen for illustration. Figure 22 shows the difference in spills caused by the sufficient retention capacity of the channel in the model with calculated depth channel as compared with the insufficient channel capacity in the non-depth-calculated model. In the other variants, the difference was not so conspicuous due to the fact that bank overflow occurred also in the non-depth-calculated model.

Fig. 22 Comparison of inundation areas at discharge Q_1 at the Úhlava River site.

4. Discussion

This paper deals with the synthesis of data from hydrological measurements and ALS, which provide an alternative to the use of geodetic measurement data for hydrodynamic modelling. One of outputs is the assessment of the possibility for using ALS data in water management, while the development of specialized tools such as CroSolver attempts to eliminate errors in ALS-based input data for hydrodynamic modelling.

The main source of error when using the unmodified DTM derived from ALS data is neglect of the submerged part of the watercourse channel by which the size of the cross sectional area and the wetted perimeter in particular are affected.

It should be pointed out however that even the use of geodetic surveying itself may pose some problems, such as, for example, cross profiles of insufficient capacity or a too large distance between the cross profiles. When using the cross profiles from the DTM, these deficiencies can be easily eliminated; however, the use of geodetically oriented data requires, for example, additional elongation of the cross profile or cross file interpolation directly in the modelling software (HEC, 2010). These procedures may introduce errors into the computation.

Errors can also be introduced by using the CroSolver tool. Based on a sensitivity analysis, Roub et al. (2015) confirm that CroSolver is sufficiently robust in regards to input parameters (slope gradients, roughness coefficient). One of the disadvantages of this software however is the impossibility of choosing the schematic shape of the watercourse channel cross section.

The tool currently uses trapezoidal schematization. Nevertheless, this shape cannot characterize natural channels. Podhoranyi and Fedorcak (2014) inform that the influence of the shape used for schematization on the results of modelling has not been clearly demonstrated so far. Complications can be brought also by objects along the watercourse, with which CroSolver currently cannot work satisfactorily. On the other hand, Roub et al. (2015) expect the tool's accuracy to improve along with the improving accuracy of DTM input data.

Other sources of error include inaccurately measured discharge used in determining depth with the software. Moreover, the ALS-based digital terrain model is very heavy in terms of data volume, and this factor may prove to be limiting in working with a large area. In this respect, it would be possible to reduce appropriately the use of TIN without impairing its accuracy (Roub et al. 2012a).

5. Conclusion

This paper aims at a comparison of outputs from hydrodynamic models based on two computational geometries: (1) cross profiles obtained from the DTM based on fifth generation DTM data and (2) cross profiles obtained from the DTM including watercourse channel depth calculated using the CroSolver tool.

The above-mentioned results indicate that outputs from the hydrodynamic model based on the fifth generation DTM are – as expected – overestimated compared with the model with calculated depths. These differences are most apparent at lower discharges (Q_1 and Q_5) on both studied reaches. In contrast, differences at Q_{50} and Q_{100} are negligible. These are corresponding results considering the fact that a lower influence of discharge reached during ALS (used for determining depth) was assumed at higher modelled discharges.

The differences were obvious when comparing the two monitored sites. While the differences of all characteristics on the Otava River were relatively insignificant with respect to the watercourse size, the differences on the Úhlava River were greater. This was due to the effect of terrain morphology as the deeply incised Otava River channel does not practically allow spill into the inundation area, whereas the Úhlava River floods nearly its entire inundation area after bank overflow. Thus, the significance of the CroSolver tool is best demonstrated in the inundation results as well as where thanks to depth calculation a sufficient channel capacity can be expected for handling the required discharge.

The results of our work demonstrate that the CroSolver tool has high potential for use. Further research could be focused on comparing the models with calculated depths directly with models based on geodetic measurements, possibly with the readout of discharge measured at the time of scanning. At the same time, a more extensive comparison of the influence of watercourse morphology and size on resulting differences when using the CroSolver tool would be useful.

Acknowledgements

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RESUMÉ

Porovnání hydrodynamického modelu z dat DMR 5. generace a modelu z dat upravených pomocí nástroje CroSolver

Povodeň je přírodní jev, který se vyskytuje v různé intenzitě a nepravidelných časových intervalech. Povodně představují pro Českou republiku největší přímé nebezpečí v oblasti přírodních katastrof a mohou být i příčinou závažných krizových situací, při nichž vznikají nejenom rozsáhlé materiální škody, ale rovněž ztráty na životech obyvatel postižených území a dochází k rozsáhlé devastaci kulturní krajiny včetně ekologických škod. Z hlediska eliminace potenciálního ohrožení a samotných následků těchto událostí jsou významné informace předpovědní povodňové služby o charakteru a o rozsahu záplavových území pro jednotlivé N-leté povodňové průtoky a konkrétní povodňové scénáře. Adekvátní představu o hloubkách a rychlostech při povodňové události, v podélném či příčném profilu vodního toku, poskytují hydrodynamické modely. Získané informace z hydrodynamických modelů tak

zaujímají výsadní postavení z pohledu ochrany životů i zmírnění škod na majetku občanů.

Základním vstupem do hydrodynamických modelů jsou výškopisná data. Jedním ze způsobů získání dat je jejich pořízení metodou leteckého laserového skenování (LLS) pro tvorbu digitálního modelu reliéfu (DMR). Tato metoda je označována za jednu z nejpřesnějších metod pro získání výškopisných dat. Jejím úskalím je však neschopnost zaznamenat geometrii terénu pod vodní hladinou, a to díky pohlcení laserového paprsku vodní masou. Absence geometrických dat o průtočné ploše vodního toku může citelně ovlivnit výsledky modelování, zejména pokud chybějící část koryta reprezentuje svou kapacitou významnou průtočnou plochu. Jedním ze způsobů odstranění této chyby je dodatečné zahloubení koryta pomocí softwarových nástrojů, jakým je například CroSolver.

Předkládaný příspěvek se zabývá sestavením hydrodynamického modelu s využitím dat DMR 5. generace a porovnává jeho výstupy při různých průtocích s modelem založeným na výškopisných datech upravených pomocí nástroje CroSolver. Jedná se o srovnání výstupů hydrodynamických modelů v programu HEC-RAS při použití zahloubených dat a při použití neupraveného DMR. Srovnání je provedeno na úsecích dvou vodních toků s odlišnou morfologií terénu a velikostí vodního toku. Doplňujícím výstupem je porovnání záplavových území vycházejících z obou variant modelů.

Z výsledků vyplývá, že rozdíly ve výstupech jsou významné především u nižších průtoků (Q_1, Q_5), zatímco pro Q_{50} a Q_{100} je rozdíl zanedbatelný, přičemž velký vliv má samotná morfologie modelovaného území a velikost vodního toku.

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PRECIPITATION TOTALS AT TWO CZECH METEOROLOGICAL STATIONS AFTER CORRECTION OF SYSTEMATIC ERRORS IN MEASUREMENT

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ABSTRACT

This contribution presents the results of correcting the systematic errors that accompanied precipitation measurements at the Svratouch and Hradec Králové meteorological stations from 1961 to 1990. The selected stations are located in eastern Bohemia: the Svratouch station is situated 735 metres above sea level, the Hradec station at 270 metres above sea level. A slightly modified correction procedure constructed by R. Tihlárik was used in this study. After correction, the yearly precipitation totals recorded at the Svratouch and Hradec stations were greater by 32% and 17% of the original values, respectively. Undervaluation in Central European conditions is more significant in winter – between November and March, the average monthly undervaluation at Svratouch and Hradec reached 58–69% and 31–33%, respectively. From May to September, the average monthly undervaluation reached 7–17% at both stations. April and October were transitional months. Corrections in winter are generally indicative; corrections in the summer months are more reliable. According to the results and to literature, we can conclude that there is an undervaluation of at least 5% from May to September and an undervaluation of at least 25% from November to March at most stations in the Czech Republic. The year-to-year variability in annual and monthly corrected precipitation totals was also studied. The purpose of correcting such data is to provide more accurate precipitation totals, which subsequently provides a more accurate picture of trends in precipitation and of rainfall-runoff relationships.

Keywords: atmospheric precipitation, measurement errors, systematic errors, Czechia

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1. Introduction

Precipitation totals are among the most difficult meteorological variables to measure and predict, and may be significantly undervalued due to non-systematic and systematic errors. Neither manual or automatic gauges, nor measurements using radar adequately measure precipitation. Systematic errors undervalue precipitation totals by tens of percent depending on the conditions; therefore, there is a need to reduce the size of errors. Precipitation is inevitably a critical variable in any assessment of water resources. By correcting systematic errors, we strive to acquire accurate knowledge of rainfall-runoff relationships (Stisen et al. 2012). Without accurate measurements or estimates of precipitation, water balance studies and modelling become meaningless (Larson, Peck 1974). Corrections can also affect the calculation of trends in precipitation totals; in addition, it is possible that climate change could affect the size of systematic errors (Forland, Hanssen-Bauer 2000). Sevruk covered the problem of systematic errors in precipitation measurement in his book (Sevruk 2004). Other major contributions on this topic include: Goodison et al. 1998; Michelson 2004; Ye et al. 2004; Bogdanova et al. 2006; and Ye et al. 2012. Currently, the WMO experiment SPICE (Solid Precipitation Intercomparison Measurement) is being conducted (Nitu et al. 2014). This intercomparison is aimed at determining the systematic errors that arise during the measurement of solid precipitation.

The aim of this article is to present the results of correcting systematic errors in precipitation totals measured at two stations in the Czech Republic (Svratouch and Hradec Králové). The results should provide more accurate values for the precipitation totals measured at these stations during the period 1961–1990. During this period, Czechoslovak Metra manual gauges measured the precipitation (Ptáček 2012). It was decided to use this period because the Metra gauge was replaced by automatic gauges in 1997. The correction method suggested by Tihlárik (1995) was used, although many adjustments had to be made to input parameters. Earlier corrections of systematic errors in the Czech Republic were made by Brázdil (2007). Other corrections were made by Ptáček (2014) for several different stations.

2. Systematic errors in precipitation measurement

The undervaluation of precipitation totals measured by manual gauges is caused by the following three main systematic errors:

1. Wetting (water sticking to surfaces of the gauge and other surfaces during measurement).
2. Evaporation from the gauge.

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3. The diversion of precipitation from the receiving area of the gauge due to a strong wind above the receiving area (the aerodynamic effect of the gauge).

According to Sevruk (2004), the amount of wetting can be equivalent to between 2 and 10% of the measured total for most gauges. Wetting appears before precipitation is measured and, later, while pouring the collected water from the gauge into a volumetric vessel. Evaporation is usually small; Sevruk (2004) reported values of up to 2%. The Metra gauge has a higher evaporation rate due to its construction (Ptáček 2014). The aerodynamic effect of a gauge leads to rain precipitation being undervalued by 2–15% and snowfall by 10–50% or more (Sevruk 2004); therefore, this error is very important. Wind has different effects on precipitation particles depending on their mass, size, and shape. Light particles (snowflakes and small rain drops) can be blown away from the receiving area of the gauge more easily than heavier particles. For this reason, correction equations are performed separately for solid, liquid, and sometimes also for mixed precipitations. Wetting and evaporation are determined by experimental measurements, and the error caused by the aerodynamic effect is determined by intercomparison measurements with reference gauges (Goodison et al. 1998). Systematic errors are usually not included during procedures for checking the measured precipitation (procedures for testing homogeneity).

3. Correction method used in this study

Currently, in the Czech Republic and Slovakia, it is only possible to correct precipitation data that was measured by a Metra manual gauge. This gauge was used in this region from the 1950s. Proper experimental measurements and comparison measurements with reference gauges were conducted in the 1970s and 1980s. Bratislava-Koliba became the main experimental station. On the basis of these experiments, Lapin et al. (1990) developed correction equations determining all of the three main systematic errors (Lapin, Priadka 1989; Lapin 1993). Then, these equations were applied to data from Slovak stations (Lapin et al. 1990). Tihlárik (1995) adopted the correction equations for evaporation and wetting from Lapin et al. (1990), but developed his own equations for errors caused by the aerodynamic effect. His study was primarily focused on the region of the High Tatra Mountains. Tihlárik's approach appears to be more reliable – his results are comparable with intercomparison measurements (Ptáček 2014). For this reason, it was decided to use Tihlárik's equations in this research; however, many modifications had to be made to input parameters. Brázdil also used Tihlárik's procedure (in modified form) to correct data from Milešovka, Lysá Hora, and Brno Tuřany (Brázdil 2007).

To calculate rain losses caused by the aerodynamic effect, Tihlárik (1995) used intercomparison measurements from Bratislava-Koliba. Some data had to be re-calculated because they were no longer available. Subsequently, Tihlárik derived this equation (1):

$$\boldsymbol{k_{lq}} = 0.03146\ (\boldsymbol{N} \cdot \boldsymbol{u_{hpg}})^2 + 0.07398\ (\boldsymbol{N} \cdot \boldsymbol{u_{hpg}}) + 1 \quad (1)$$

where $\boldsymbol{k_{lq}}$ is a conversion factor for liquid precipitation, $\boldsymbol{N}$ is a rain structure parameter, and $\boldsymbol{u_{hpg}}$ is the wind speed at the level of the gauge orifice during precipitation [m s^{-1}]. The procedure constructed by Lapin et al. (1990) does not include parameter $\boldsymbol{N}$. This parameter determines the proportion of liquid precipitation falling out with an intensity of less than 0.03 mm min^{-1}. This threshold was found experimentally (Sevruk 2004). Under this threshold, liquid particles are usually smaller and lighter and the influence of wind is stronger on the trajectory of particles (Tihlárik 1995). This experimental observation confirms the results of mathematical and physical simulations (Nespor, Sevruk 1999).

The procedure constructed by Lapin et al. (1990) distinguishes mixed precipitation, unlike that the procedure constructed by Tihlárik (1995). For solid and mixed precipitation, Tihlárik derived the following regression equation from the intercomparison measurements taken at the Harzgerode in Germany from 1986 to 1993 (Günther 1993):

$$\boldsymbol{k_{s+m}} = -0.004878\ (\boldsymbol{u_{hpg}})^3 + 0.02206\ (\boldsymbol{u_{hpg}})^2 + 0.1821\ \boldsymbol{u_{hpg}} + 1, \quad (2)$$

where $\boldsymbol{k_{s+m}}$ is a conversion factor for solid and mixed precipitation and $\boldsymbol{u_{hpg}}$ is the wind speed at the level of the gauge orifice during precipitation [m s^{-1}]. The unification of mixed and solid precipitation is debatable because snowfall is carried away more easily than mixed precipitation and not all stations can have the same proportion of mixed and solid precipitation as the station Harzgerode had. There could also be different methods of differentiating mixed precipitation from rain and snow in different countries.

It is necessary to take into account the fact that a different version of the Metra gauge (with all internal parts removed) is used in winter, approximately from November to April. Errors caused by evaporation and wetting are usually larger under winter operation and the corrections take this into account. Wetting is accounted for by adding 0.1 or 0.2 mm to the daily amount of measured precipitation (Lapin et al. 1990). Evaporation losses are determined by temperature; the evaporation equations derived by Lapin et al. (1990) are extensive and, for this reason, are not presented in this paper.

In this study, the procedure derived by Lapin et al. (1990) was used for wetting and evaporation, and the equations derived by Tihlárik (1995) were used for the aerodynamic effect. The correction calculation used in this study is described schematically as

$$\boldsymbol{P_c} = \boldsymbol{k} \cdot (\boldsymbol{P_g} + \Delta \boldsymbol{P_{1+2}} + \Delta \boldsymbol{P_3}), \quad (3)$$

where P_c is the amount of corrected daily precipitation [mm], P_g is the measured amount of daily precipitation [mm], ΔP_{1+2} is the daily loss by wetting [mm], ΔP_3 is the daily loss due to evaporation [mm], and k is a conversion factor – formula (1) in the case of rain; formula (2) in the case of solid and mixed precipitation. Corrected values of precipitation were determined for each day; for more details, see: (Ptáček 2012).

All of the equations included many parameters which had to be calculated. In order to calculate the corrected precipitation, it is necessary to know the wind speed at the level of the gauge orifice, the weather conditions at climatological observation times or an estimate of the proportion of solid and mixed precipitation, the times of usage of summer and winter versions of the gauge, and air temperature (to determine the amount of evaporation). It is also necessary to know the time which elapses between the end of precipitation and measurement (Lapin et al. 1990).

During intercomparison measurements, the wind speed is measured at the level of gauge orifices. Most stations do not measure at this level, so it is necessary to calculate wind speed at the level of the gauge orifice (commonly 1 m). This is usually done using the following logarithmic equation (Sevruk 2004):

$$u_{hp} = u_{Hp} \cdot (\ln(h) - \ln(z_0))/(\ln(H) - \ln(z_0)), \tag{4}$$

where u_{hp} is the wind speed at height h during precipitation (the height of the gauge orifice), u_{Hp} is the wind speed at height H during precipitation (the height of the station anemometer), and z_0 is a terrain roughness coefficient. WMO (2008) recommends the coefficient from 0.01 to 0.03 for the case when snow cover occurs and 0.03 for summer conditions. Thus, 0.02 was chosen for the winter and 0.03 for the summer period. This conversion is one of the most questionable parts of the correction procedure, as wind speed values significantly influence the corrected precipitation totals.

The daily average wind speed was taken to be the wind speed at the time of precipitation. Corrections were based on observations at 7 AM, 2 PM, and 9 PM local time. In the Czech Republic, precipitation is measured at approximately 7 AM. Thus, a precipitation day was taken to be the period from 7 AM to 7 AM of the following day. It was not possible to determine the form of precipitation (solid, mixed, or liquid) directly from the data because weather observations were incomplete. The form of precipitation was therefore determined from the temperature. The temperature at 2 PM seemed to be the best for determining the form of precipitation. Solid and mixed precipitation theoretically appeared at temperatures below 2.0 °C, rain at above 2.1 °C. Detailed information may be found in: (Ptáček 2012; 2014).

4. Description of the stations used in the study

The Svratouch and Hradec Králové meteorological stations fall under the administrative branch of the Czech Hydrometeorological Institute. The Svratouch station is situated on Otava Hill (735 m), near the town of Hlinsko. The hill is treeless and has a slightly sloping gradient (Figure 1). The station in Hradec Králové is located in a suburb of the city of Hradec Králové (Figure 2). The gauge and anemometer are situated at an observatory complex at an altitude of 270 m. The anemometers at the Svratouch and Hradec stations are elevated 16 m and 25 m above the ground, respectively. Svratouch is a very windy station; the average wind speed during the period 1961–1990 was 5.6 m s^{-1}, calculated from three observations per day. At Hradec, it was only 2.9 m s^{-1}. The maximum monthly average wind speed at Svratouch was 6.9 m s^{-1} in January and the minimum was 4.1 m s^{-1} in July. The maximum monthly average wind speed at Hradec was 3.5 m s^{-1} in March, and the minimum was 2.4 m s^{-1}, also in July. The mean annual temperature was 5.7 °C at Svratouch and 8.5 °C at Hradec. The data were not interrupted.

Fig. 1 The Svratouch meteorological station.
Source: http://www.ok2af.nagano.cz/omne.htm

Fig. 2 The Hradec Králové meteorological station.
Source: http://www.astro.cz/clanky/multimedia/v-lete-se-zacne-v-hradci-kralove-stavet-digitalni-planetarium.html

5. Results

The corrections led to significant changes in precipitation totals. In Figure 3 (Svratouch) and Figure 4 (Hradec Králové), it is evident that all three systematic errors were more substantial in the winter months. Wetting was more significant in winter because there were relatively more days with precipitation and the winter version of the gauge was used. The wetting loss reached comparable values at both stations. Evaporation losses were also usually higher under the winter version. The highest evaporation losses were in transitional months (March or April and October or November), when the winter version was already in use but temperatures were relatively high. The most significant error was caused by the wind, especially in the winter months due to the frequent occurrence of solid precipitation. This error was far more pronounced at the windy Svratouch station than at Hradec Králové. After correction, the annual course of precipitation at Svratouch changed significantly: the winter subsidiary maximum increased and the climate assumed a more oceanic character. Overall, the average annual precipitation at Svratouch increased by 32% due to correction (from 762 mm to 1007 mm); at Hradec, it increased by 17% (from 617 mm to 723 mm). At Svratouch (Figure 3), the greatest systematic errors occurred, on average, in January (69% of the measured total) and the smallest in August (12% of the measured total). At Hradec Králové (Figure 4), the highest undervaluation was in January and December (33%) and the lowest undervaluation was also in August (7%).

The systematic errors at the studied stations differed from year to year (Figure 5 and Figure 6): at Svratouch, they ranged from 25% of the measured total in 1985 to 43% in 1974; at Hradec they ranged from 14% in 1964 to 23% in 1990; standard deviations were 4.6% (Svratouch) and 2.4% (Hradec). The year-to-year variability in systematic errors for January and July was also investigated. In January, the variability was relatively large: at Svratouch, corrections ranged from 31% in 1972 to 108% in 1970; at Hradec Králové, corrections ranged from 17% in 1969 to 62% in 1964. The variability in systematic errors results mainly from the fact that the proportions of snowfall and wind speeds differ year after year. In the summer months, the variability in systematic errors is considerably lower. In July, corrections at Svratouch ranged from 8% in 1967 to 21% in 1969; at Hradec, they ranged from 5% in 1975 to 13% in 1983. Even in this case, the variability was caused by differences in wind speed; however, evaporation was also found to have a significant influence on measurement at the Hradec Králové station. Wetting and evaporation, in general, have a slightly greater variability in winter. In July 1990, an outlier undervaluation occurred at Hradec (24%); this outlier was caused by that particular month's low rainfall (12 mm). In general, when the total for a month is low, the undervaluation can deviate far from its average value.

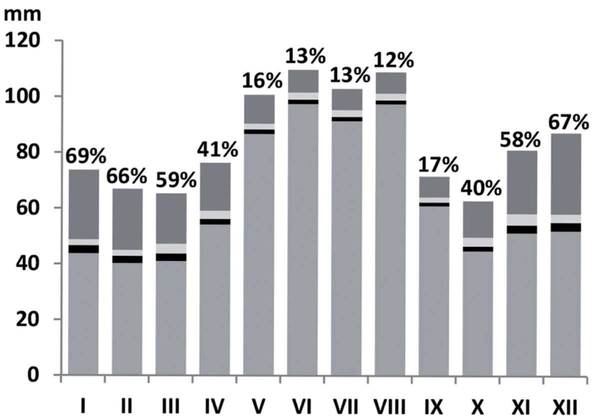

Fig. 3 Precipitation totals at the Svratouch meteorological station (1961–1990) after the correction of systematic errors in measurement. Each column shows (from the bottom up): 1) measured precipitation – light gray colour; 2) wetting losses – black colour; 3) evaporation losses – very light gray colour; 4) losses due to the aerodynamic gauge effect – gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

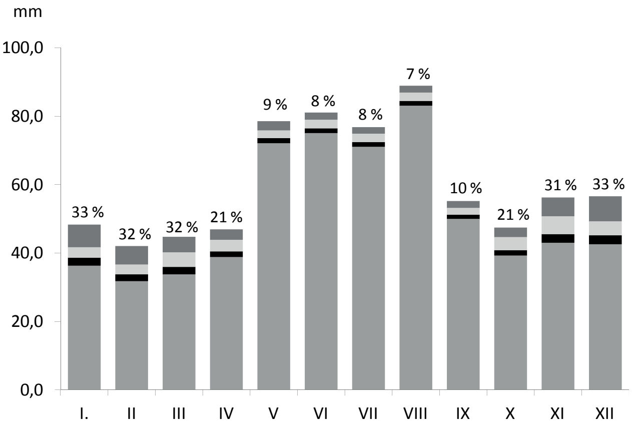

Fig. 4 Precipitation totals at the Hradec Králové meteorological station (1961–1990) after the correction of systematic errors in measurement. Each column shows (from the bottom up): 1) measured precipitation – light gray colour; 2) wetting losses – black colour; 3) evaporation losses – very light gray colour; 4) losses due to the aerodynamic gauge effect – gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

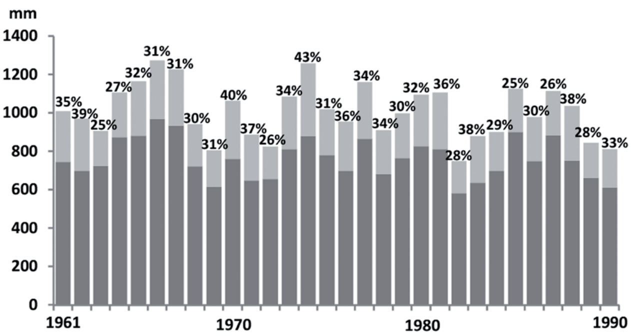

Fig. 5 The year-to-year variability in precipitation totals at the Svratouch meteorological station (1961–1990). Columns show (from the bottom up): 1) measured precipitation – gray colour, and 2) losses resulting from all three systematic errors – light gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

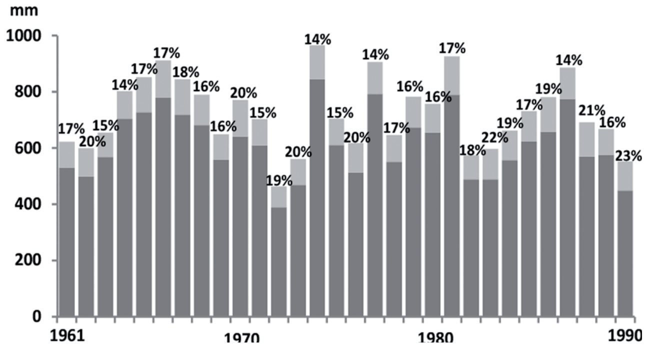

Fig. 6 The year-to-year variability in precipitation totals at the Hradec Králové meteorological station (1961–1990). Columns show (from the bottom up): 1) measured precipitation – gray colour, and 2) losses resulting from all three systematic errors – light gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

4. Discussion and Conclusion

The corrections of precipitation data from the Svratouch and Hradec Králové stations suggest that the true annual precipitation at Svratouch and Hradec was greater by some 32% and 17%, respectively. The errors in winter were far more significant. The corrections also change the annual course of precipitation, mainly at Svratouch. The results presented here are comparable with those of previous corrections in the territories of the Czech Republic and Slovakia (Tihlárik 1995; Brázdil 2007; Ptáček 2012) and with the results of intercomparison measurement in Harzgerode (Günther 1993). For the winter months, undervaluation usually varies between 25% and 100% of the measured precipitation total; for the summer months, undervaluation is around 10%. This is generally valid for conditions in Central Europe, although there could be higher levels of undervaluation in mountainous areas. Spring and autumn are transitional periods for systematic errors. Regarding the Metra gauge, it is necessary to take into account the significant changes in undervaluation which occur when the winter and summer versions are exchanged for each other. This is because the winter version of the Metra gauge suffers higher losses from evaporation and wetting.

The correction of systematic errors in precipitation measurement could be subject to uncertainty. Precipitation is most accurately measured by means of intercomparison measurements, as, for example, in Harzgerode. The further determination of precipitation undervaluation could be uncertain. Uncertainty is caused by many variables (wind speed conversion; precipitation time; the amount of solid, mixed, and liquid precipitation; the parameter ***N***, etc.). Also, Tihlárik's correction equations have some imperfections, such as the combining mixed and solid precipitation. A procedure for the determination of wetting and evaporation losses was constructed by Lapin et al. (1990). These authors note that corrected values for daily or monthly precipitation have little relevance; extremes, however, are equalized over longer periods of correction and the results of correction are admissible. Results are more credible for the summer period and, in general, are more accurate for occurrences of rain precipitation. Also, the correction of summer precipitation is more credible due to lower levels of year-to-year variability during this period. Even in summer, however, undervaluation could be considerable in the case of rain of weak intensity subject to high wind speeds.

After correcting the total precipitation, we should expect higher values of evaporation from the landscape (Ye et al. 2012). Corrections can give us a better idea of hydrological balance, especially in regions where there is not permanent snow cover in the winter. Finally, the correction of precipitation may have an influence on long-term changes in precipitation totals. The correction could have an impact on the perceived trends with respect to climate change conditions. In particular, the trends of winter precipitation could be affected by climate change (Forland, Hanssen-Bauer 2000). The undervaluation of precipitation due to the aerodynamic effect concerns all types of gauges including the automatic gauges currently used in the Czech network (from the Meteoservis company). Comparison measurements of Metra and automatic gauges have already been made; it appears that automation has not significantly affected the homogeneity of the precipitation data (Gajdušková 2009).

In brief, this contribution presents the results of correcting precipitation totals at two meteorological stations in the Czech Republic. The Svratouch station is situated in a mountainous area and the Hradec Králové station is situated in the lowlands. The method of correction was adopted from R. Tihlárik (1995), but many adjustments were made to input parameters. The special merit of this contribution is a description of the variability in systematic errors. According to this and previous research: (Brázdil 2007; Gajdušková 2009; Ptáček 2014), we should expect that there is at least a 5% undervaluation of precipitation from May to September and at least a 25% undervaluation from November to March in most stations in the Czech Republic. At the present time, attention should be paid to systematic errors associated with automatic gauges from Meteoservis (Lanza et al. 2005; Nitu 2014). Attention should also be focused on how corrections influence perceived trends in precipitation and also on the question of how climate change influences the trends of corrected precipitation.

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RESUMÉ

Příspěvek přináší výsledek korigování systematických chyb doprovázejících měření srážek na meteorologických stanicích Svratouch a Hradec Králové. Stanice Svratouch je položena ve výšce 735 m n. m., stanice Hradec Králové ve výšce 270 m n. m. Korigována byla srážková data za období 1961–1990. Ke korigování byl použit již dříve osvědčený postup a rovnice R. Tihlárika. Pro určení některých vstupních parametrů bylo potřeba vlastních metod. Po korigování došlo na Svratouchu k navýšení ročního úhrnu srážek o 32 % a na Hradci o 17 % naměřeného úhrnu. Podhodnocení je v podmínkách střední Evropy významnější v zimě, na použitých stanicích dosahuje v zimních měsících i více než 50 % naměřeného úhrnu. V letních měsících dosahuje podhodnocení na obou stanicích kolem 10 %. Je nutné počítat s tím, že korigování může být hlavně v zimních měsících zatíženo nejistotou. S přihlédnutím ke stávajícím výsledkům korigovaných srážkových úhrnů v Česku lze konstatovat, že v období od května do září je nutné na většině stanic v Česku počítat minimálně s 5% podhodnocením a od listopadu do března minimálně s 25% podhodnocením. Studována byla taktéž časová variabilita systematických chyb na daných stanicích. Důsledkem korigování je například změna ročního chodu srážek a změna srážko-odtokových vztahů.

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INTEGRATION OF THE CZECH BREWING INDUSTRY INTO GLOBAL PRODUCTION NETWORKS

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ABSTRACT

This article analyzes the Czech brewing industry and its integration in transnational production networks by drawing on the perspective of global production networks (GPNs). It evaluates the geographical structure of the Czech brewing industry, the inflow of foreign direct investment after 1990, and the integration of Czech breweries into GPNs dominated by foreign transnational corporations. The article analyzes major changes the Czech brewing industry has experienced during the post-1990 economic transformation, presents the current state of the industry from the geographical perspective, and identifies four different forms of involvement of Czech breweries in brewing industry GPNs.

Keywords: brewing industry, breweries, global production networks, Czechia

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1. Introduction

This article seeks to contribute to debates about the Czech brewing industry by analyzing the key processes that have taken place during the past twenty-five years. Its aim is to analyze the Czech brewing industry by drawing on the Global Production Networks (GPN) and Global Value Chains (GVC) perspectives, which deal with the organization of economic activities in the contemporary globalizing economy.

It also evaluates the ways in which Czech breweries have integrated into GPNs since 1990. The brewing industry has been rapidly internationalized and globalized in the past few years (Dörenbächer, Gammelgaard 2013). Formerly nationally oriented brewing corporations expanded extensively to foreign markets thanks to the liberalization of foreign trade and foreign direct investment (FDI). This foreign expansion has taken place through increased exports and, more importantly, through mergers and acquisitions. As a result, the ownership within the international brewing industry has become far more concentrated among a relatively small group of Western European and North American transnational corporations (TNCs) (The Economist 2011).

According to Dicken (2004) we live in the world in which deep integration, organized primarily within and between geographically extensive and complex GPNs, is becoming increasingly pervasive. However, globalization processes and mechanisms do not take place exclusively at the global scale and interactions at regional levels continue to be fundamental.

Significant factors contributing to the growth of TNCs, such as their coordination and management, geographic flexibility, their ability to benefit from different socio-economic and institutional environment of national states, are crucial for the continuing existence and further evolution of the global economic system. We attribute the significant importance to operations of firms within regions in which they are embedded.

In Central and Eastern Europe (CEE), state socialistic governments managed the food and beverage industry in the context of centrally planned economy before 1989. The brewing industry started to attract foreign investors during the post-1990 economic transformations, a process made more complicated by restitutions and privatizations during the 1990s. Additionally, each government followed different FDI policies. Both foreign investors and states were predominantly motivated by profit and business opportunities (Dicken 2011). The brewing industry has had a great potential in CEE because of high consumption of beer and geographical and the cultural proximity to the EU (Swinnen, Van Herck 2010). Foreign corporations had started to invest in the brewing industry in post-socialistic countries by 1991. In the case of Czechia, foreign investors were attracted by a long tradition of the brewing industry, which has been an important cultural and historical phenomenon.

Four largest corporations account for more than half of the global beer production (The Economist 2011): AB Inbev (Belgium)[1], SABMiller (United Kingdom), Heineken (Netherlands) and Carlsberg (Denmark). Two of these (SABMiller and Heineken) were operating in the Czech

1 The parent economies are mentioned in brackets.

market in 2013. In addition to these two, Molson Coors Brewing Company, a large brewing transnational company, was also operating in Czechia.

There were 237 breweries in Czechia in 2013, including 195 microbreweries and 42 big industrial breweries[2] (pivovary.info). The total beer production in Czechia exceeded 17 million hectoliters each year since 1993, though production has fluctuated depending on demand and economic cycles (czso.cz, ceske-pivo.cz). The Czechs are the biggest beer drinkers in the world. The average consumption was 148 liters of beer per person per year as of 2012, and the share of beer sales among alcoholic drinks was 80% (czso.cz). The production of Pilsner type of beer prevails. The share of Czechia of global beer production fluctuates around 1%.

This article addresses three main research questions: i) What are the main characteristics of the geographical structure of the brewing industry in Czechia? ii) Are Czech brewing companies integrated into GPNs and to what degree? iii) What are the impacts of foreign investment in the Czech brewing industry?

The article consists of three main sections. The first part introduces the basic information about the organization of GPNs in the brewing industry. The second section analyzes the contemporary geographical structure of the global and Czech brewing industry and the production volumes, ownership, and employment of the Czech brewing industry. It also examines changes in the geographical structure of the Czech brewing industry during and after the economic transformation. The last part analyzes the integration of Czech brewing companies into GPNs.

2. The GPN analysis

The production chain refers to a sequence of functions in the production of a particular commodity in which each step adds value through the combination of technological, organization and labor inputs (Dicken 2004). Several related analytical approaches, such as Global Commodity Chains – GCCs, GVCs and GPNs, apply this concept in order to better understand the organization and functioning of the contemporary globalizing economy. In this article, I employ the analytical approach of GPNs because of its ability "to incorporate the complex actions and interactions of variety institutions and interests groups – economic, political, social, cultural – which operate at multi-scalar levels and territorialities and through dynamic and asymmetrical power relationships to produce geographical outcomes" (Coe et al. 2008: 271). Additionally, the GPN approach goes beyond merely vertical ties between firms and tries to examine and evaluate all relevant actors' interests in this system of production, distribution, and consumption (Coe et al. 2008).

Unfortunately, there is a lack of studies dealing with the food or beverage industry from the GPN perspective (e.g. Gwynne 2006; Ponte 2007; 2009) as it tends to focus on more technologically sophisticated industries, such as the automotive (e.g. Humphrey, Memedovic 2003; Pavlínek, Janák 2007), aviation (Bowen 2007) and electronics industry (Sturgeon, Kawakami 2010). However, there are some studies that are indirectly drawing on the GPN approach to analyze the European and Czech brewing industry (e.g. Larimo et al. 2006; Swinnen, Van Herck 2010; Materna 2011).

These studies seek to identify the type of coordination or governance of the particular GPN based on the typology developed by Gereffi (1994; Gereffi et al. 2005) and Humphrey and Schmitz (2002). However, the application of the ideal types of governance in the brewing industry tends to be difficult because different parts of its value chain might be governed in different ways and, thus, fall into different governance categories. For example, the upstream processes (from the leading brewery to its suppliers) are coordinated differently than downstream processes (form the leading brewery to customers).

The integration of firms into GPNs improves their access to foreign markets, innovation systems, foreign capital, and the development of new competencies. It also increases demand for goods produced by suppliers. These firm level advantages are typically available only in those cases when foreign lead firms incorporate local domestic firms into their production networks. When they do not, FDI effects tend to be limited to newly created jobs. FDI effects further depend on whether the newly created jobs are high-skill jobs, which contribute to the development of skills in the host economy or low-skill jobs, which can lead to deskilling (Dicken 2011). Linkages and spillovers between firms in GPNs are complex as Pavlínek and Žížalová (2014) show on the example of the automotive industry.

This article analyzes how the Czech breweries are integrated into GPNs, how this integration affects the geographical structure of the Czech brewing industry, and also how the inflow of foreign capital and entry of TNCs on the Czech market affect individual breweries and the Czech brewing industry as a whole.

3. The contemporary structure of the global and Czech brewing industry

The increasing number of mergers and acquisitions between international beer producers leads to the consolidation in the brewing industry. Ten leading corporations dominate 74% of the global beer market; four leading firms dominate more than 50% of the global beer market and the largest one, AB InBev, controls almost 25% of the market (Dörrenbächer, Gammelgaard 2013; McCaig 2010; The Economist 2011). The comparison of the brewing industry with non-alcoholic beverages suggests that there is further

2 Critical production for this separation is 10,000 hl of beer per year (Chlachula 2001).

space for consolidation. Coca-Cola and PepsiCo together control around 75% of the global market with non-alcoholic beverages (The Economist 2011). It is, therefore, reasonable to expect further concentration of ownership and control in the global brewing industry in the future.

The brewing industry was much more fragmented and decentralized two to three decades ago than it is today. Even in 1998, five leading firms dominated only 22% of the global market (Dörrenbächer, Gammelgaard 2013), a result of divergence of national markets, different consumer habits and preferences, relatively high transportation costs, and also of strong regulatory mechanisms of national states. The consolidation of the brewing industry took place especially quickly in the past several years as mergers and acquisitions have become more common. The biggest transaction so far was concluded in 2008 when the American corporation Anheuser-Busch created a joint venture with the Brazilian-Belgian corporation InBev, for 52 billion dollars (The Economist 2011). Recently, InBev has attempted to take over SABMiller, the second biggest beer producer in the world.

The contemporary brewing industry has several specific characteristics (Dörrenbächer, Gammelgaard 2013): i) it has adopted similar technologies globally, ii) it offers homogenous products, iii) it is dominated by a few large TNCs, and iv) it is highly internationalized.

The reasons for the internationalization efforts by leading TNCs are simple. They want to gain footholds in new markets, such as Central and Eastern Europe (CEE), which either have the rapidly growing beer consumption or strong beer-drinking traditions. TNCs penetrate these markets by taking over the strongest local firms, sometimes through hostile takeovers. Then they introduce their global marketing campaigns tailored in these new markets and capitalize on effects of synergy, gained through upgrading processes of technologies and management, cost efficiencies through layoffs, and control over value chains and distribution channels (Dörrenbächer, Gammelgaard 2013; Larimo et al. 2006; Swinnen, Van Herck 2010).

Almost 40% of products made by breweries are sold through transnational retailers, which play significant role in GPN structures of the brewing industry (McCaig 2010). These retailers can quickly adapt to changing consumer preferences and they expect the same flexibility from transnational brewing corporations who supply their retail networks with beer.

The world production of beer has been rising for the past fifteen years, exceeding 1,9 billion of hectoliters of beer per year (Chart 1). China is the leading producer country (Table 1) while AB InBev is the leading beer-making corporation (Table 2). China also has the largest total beer consumption but the Czechs are the leaders in per capita beer consumption with more than 145 liters per year (Berkhout et al. 2013). Germans, Austrians, Canadians, Irish and Australians have also high per capita beer consumption, although the precise data from a reliable source is not available.

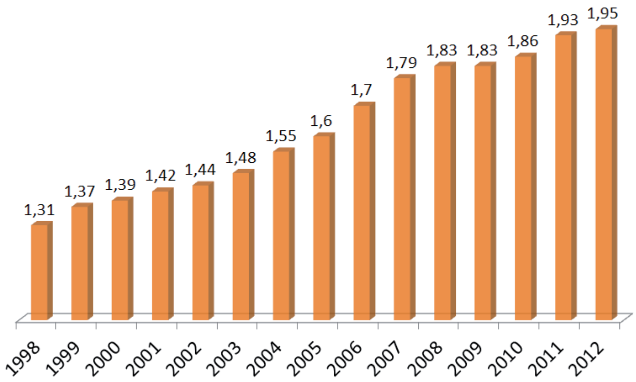

Chart 1 The world beer production (billions of hectoliters).
Source: ceskapotravina.net, Barth-Haas Group (2012), McCaig (2010).

Tab. 1 The ranking of countries by beer production in 2012

	State	(mil. hl)	(%)
1.	China	490.2	25.1
2.	USA	229.3	11.8
3.	Brazil	132.8	6.8
4.	Russia	97.4	5.0
5.	Germany	94.6	4.8
6.	Mexico	82.5	4.2
7.	Japan	55.5	2.8
8.	UK	42.0	2.2
9.	Poland	37.8	1.9
10.	Spain	33.0	1.7
24.	Czechia	18.3	0.9

Source: Barth-Haas Group (2012).

Tab. 2 The ranking of corporations by beer production in 2012.

	Corporation	Parent Economy	(mil. hl)	(%)
1.	AB InBev*	Belgium	352.9	18.1
2.	SAB Miller**	UK	190.0	9.7
3.	Heineken	Netherlands	171.7	8.8
4.	Carlsberg	Denmark	120.4	6.2
5.	CRB	China	106.2	5.4
6.	TBG	China	78.8	4.0
7.	Grupo Modelo	Mexico	55.8	2.9
8.	Molson-Coors	USA/Canada	55.1	2.8
9.	Yanjing	China	54.0	2.8
10.	Kirin	Japan	49.3	2.5

* without Grupo Modelo
** without China Resource Brewery
Source: Barth-Haas Group (2012).

Developed countries (the United States, Western Europe and Japan) represent key markets for brewing TNCs. For example, the AB InBev earns one-third of its profits in North America alone (The Economist 2011). These countries have the most efficient production with

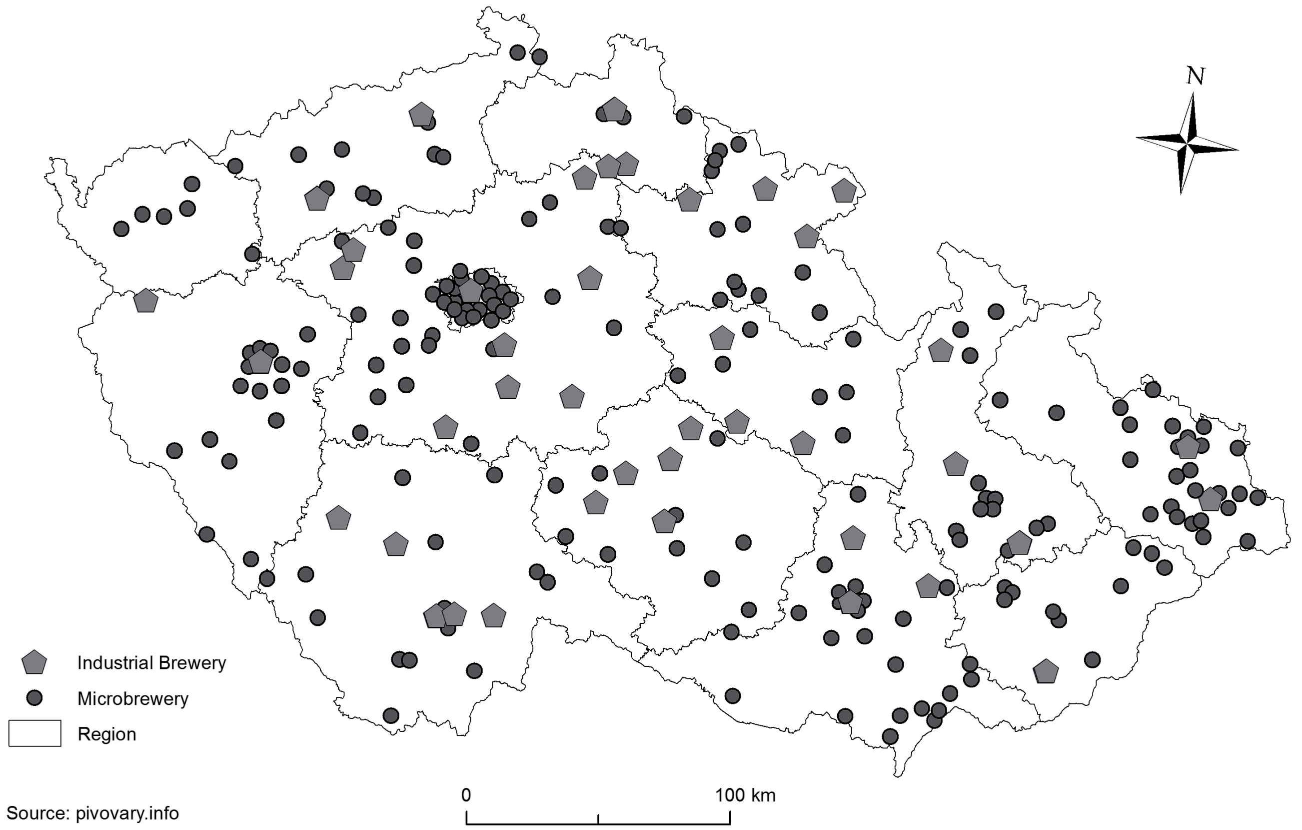

Fig. 1 The spatial distribution of Czech breweries in 2013.

the lowest costs per hectoliter. However, the majority of brewing companies still admit that it is more difficult to combine the automation of production with unique know-how, which is crucial for making unique brands of beer (ARC Group 2004).

Brewing TNCs have been expanding their activities to new markets in the past several decades, including post-socialistic countries since the 1990s, China, which is already the world's biggest producer of beer by volume, and other Asian countries with large populations that represent the greatest future potential for growth in beer consumption. The African market also has a great potential and all the biggest beer producers are starting to focus on it (sabmiller.com). This expansion often is in the form of strategic alliances, mergers and joint ventures: China Resource Brewery (the biggest Chinese beer producer) formed a strategic alliance with SABMiller, AB InBev took over Mexican Grupo Modelo (the seventh biggest producer in the world), Heineken took over Asia Pacific Breweries, and Carlsberg formed joint venture with regional leader in Thailand ThaiBev (sabmiller.com, Smith 2012). There are few exceptions among regional leaders that have not yet made any alliances with Western corporations, such as Indian United Breweries or Japanese Asahi Breweries and Sapporo Breweries.

Important changes have also taken place at the national level where small and medium-sized breweries have been growing at the expense of bigger producers because their beer is increasingly popular among consumers, even though they produce negligible volumes of beer. Sometimes these small companies operate as "gypsy breweries", renting a free production capacity from big industrial breweries (The Economist 2011).

Finally, there have been important changes in the individual consumption because of the growing home consumption of beer as the on-trade consumption (restaurants or bars) changes to off-trade consumption (retail corporations and then the households). According to Berkhout et al. (2013), retail stores sell almost two-thirds of produced beer and only one-third is consumed in restaurants and bars. Brewing TNCs have reacted to this trend by global marketing campaigns aimed at boosting the image of their strongest brands in order to increase their sales to households.

3.1 The geographical structure of the Czech brewing industry

Our database was constructed in 2014 and it has 237 breweries, which corresponds with 240 breweries that existed at the end 2013.[3] 42 breweries produced at least 10,000 hl of beer per year. The remaining companies were microbreweries and their numbers continue to grow. The spatial distribution of all breweries in Czechia is visualized in Figure 1.

One of the aims of this article is to evaluate the fundamental characteristics of the geographical structure of the

3 By September 2015, there were more than 320 firms producing beer in Czechia (pivovary.info).

Tab. 3 Top producers of beer in Czechia in 2012.

	Ownership	Firm	Incorporated Breweries	Production (×1000 hl)	Share (%)
1.	SABMiller	Plzeňský Prazdroj	Plzeňský Prazdroj* Radegast Velké Popovice	7777	42.0
2.	Molson Coors Brewing Company	Pivovary Staropramen	Staropramen Ostravar	3140	17.0
3.	Heineken	Heineken Česká republika	Starobrno Krušovice Velké Březno	2437	13.2
4.	Czech state		Budějovický Budvar	1338	7.2
5.	Czech owners**	Pivovary Lobkowicz	Vysoký Chlumec Černá Hora Klášter Protivín Rychtář Jihlava Uherský Brod	970	5.2
6.	Czech owners	LIF Group	Svijany Malý Rohozec Náchod	788	4.3
7.	Czech owner	PMS Přerov	Litovel Zubr Holba	757	4.1
8.	50% Duvel Moortgat NV. 50% Czech owners		Bernard	213	1.1
9.	Czech owner		Samson	145	0.8
10.	Czech owner		Nymburk	137	0.7

* The Gambrinus brewery is traditionally mentioned as Plzeňský Prazdroj as a whole.
** Predominantly owned by Lapasan (79.4%) owned by CEFC (China) since 2015. (HN 2015)

Source: Nádoba, Fraňková (2013), Český svaz pivovarů a sladoven.

Czech brewing industry, which is the outcome of several processes. We consider three closely related indicators: the ownership structure, volume of production, and the rate of employment in the brewing industry.

In 2012, three TNCs operating in the Czech brewing industry controlled close to three quarters of the Czech market (Table 3). The biggest brewing corporation in the world AB InBev was not among them, although it used to own the Pražské pivovary group, which had an almost 20% share of the Czech beer market until 2009. SABMiller, a South African corporation headquartered in Great Britain, was the largest beer producer in Czechia in 2012 with 42% of the total beer production. It owns Plzeňský Prazdroj a.s. (Pilsner Urquell), which controls Plzeňský Prazdroj[4], Velké Popovice and Radegast breweries.

The Pivovary Staropramen group, owned by the North American Molson Coors Brewing Company, is the second largest company operating in the Czech market. Two Czech breweries, Staropramen in Prague and Ostravar in Ostrava, are incorporated with this corporation. The Braník brewery also used to belong to this group but it was closed and its production was transferred to Prague to Staropramen (pivovary.info).

The group of breweries owned by Dutch Heineken accounts for another tenth of the Czech beer production. In 2008, Heineken bought the Drinks Union company, the owner of Starobrno, Krušovice and Velké Březno breweries. Additional four breweries belonging to this group were closed or transformed to distribution centers in order to optimize production. These included Kutná Hora and Znojmo (2009), Louny (2010) and Krásné Březno (2011). (pivovary.info, heinekenceskarepublika.cz)

Budějovický Budvar is the fourth biggest brewery in Czechia and it is unique because it is state-owned. It has a long-standing brand name dispute with AB InBev and the state ownership has prevented the acquisition of Budvar by AB InBev. Pivovary Lobkowicz is the fifths largest

4 The Gambrinus brewery is traditionally included under Plzeňský Prazdroj as a whole.

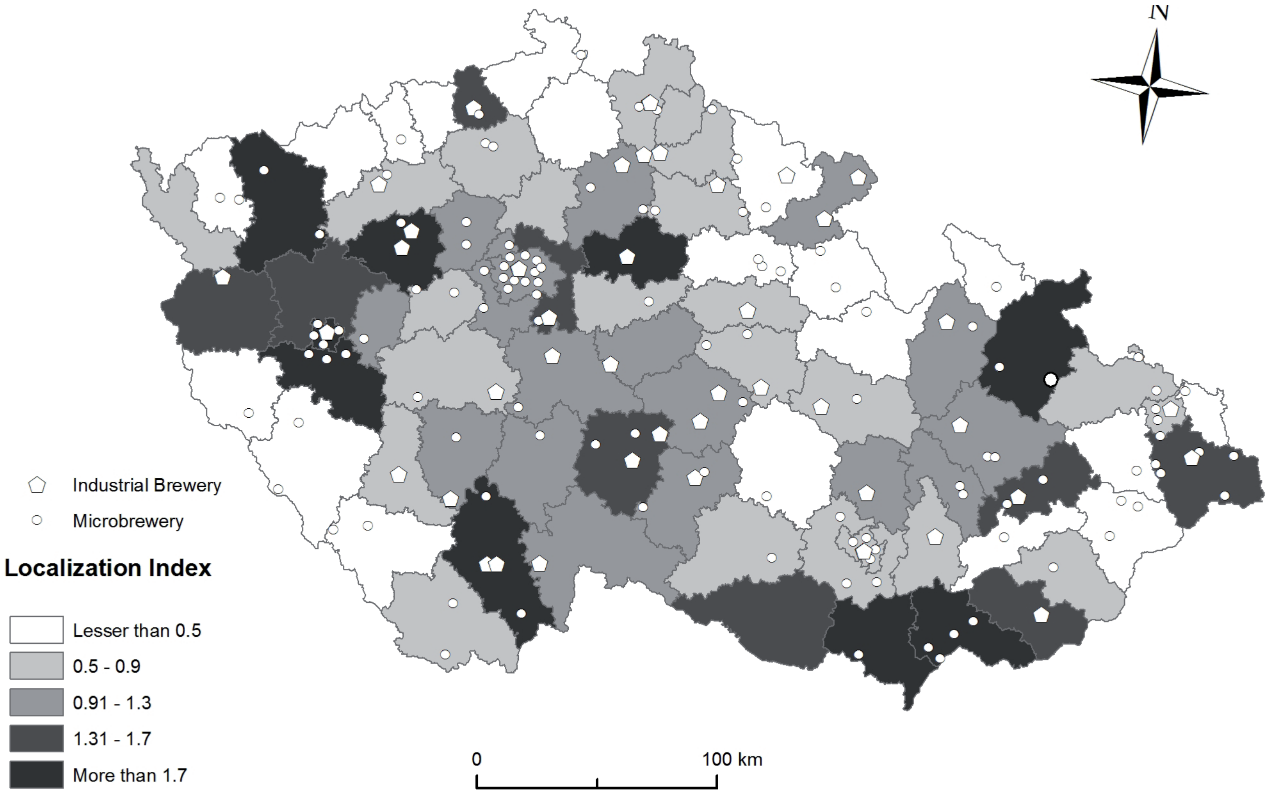

Fig. 2 Czech breweries and the localization of CZ-NACE 11 in 2011.
Note: Values of the localization index (LI) for the manufacture of beverages (CZ-NACE 11) calculated for districts of Czechia

$$LI = \frac{xi}{yi} : \frac{x}{y}$$

xi – number of employees of manufacturing of beverages in region *i*
yi – population of region *i*
x – number of employees of manufacturing of beverages in all regions
y – population of all regions

Pavlík and Kühnl (1982)
Source: czso.cz, pivovary.info, author.

brewing company in Czechia, which controls seven breweries in Bohemia and Moravia, and is now owned (from September 2015) by Chinese CEFC. This transaction was not included in my original research as well as in results and conclusions of this article.

The majority of remaining brewing companies and single breweries are Czech-owned. Several breweries and microbreweries in Czechia are also owned by Russian, British and Japanese capital. Overall, more than 72% of the beer production in Czechia was produced in breweries that were completely or partly owned by foreign capital in 2012.

In the next step, we evaluate the geographical structure of the Czech brewing industry by employment. Since the official employment data for the brewing industry (CZ-NACE 11.05) is unavailable, we had to rely on more general data for the manufacture of beverages as a whole.

As of 2013, the spatial distribution of breweries was quite uniform in Czechia (Figure 1), reflecting the historic need to supply the population uniformly in each region and be close to the market. Consequently, there are no areas of brewing industry concentrations with the exceptions of large population concentrations around the Prague, Pilsen, and Ostrava metropolitan areas. There are no industrial breweries in border areas near Bavaria, Lower Austria, and Silesia, although some of these regions had a strong position in the brewing industry in 19th century (Likovský 2005). This is mainly because these regions became peripheral during the centrally planned economy (1948–1989) in Czechoslovakia and this situation was further reinforced during the economic transformation in Czechia in the 1990s (Likovský 2008, Kratochvíle 2005).

We have to be careful when interpreting the localization index (LI) in Figure 2 since it shows the localization not only of the brewing industry but the production of beverages as a whole, including distilling, rectifying and blending of spirits; production of soft drinks; production of mineral waters; manufacture of wine from grapes and even the production of malt. These sectors together employed more than 13,000 workers. Only three districts achieved the highest LI values thanks to breweries: Plzeň-city, České Budějovice and Rakovník. In all other cases, high LI levels reflected other beverage industries, such as soft drinks and the production of mineral waters in the Karlovy Vary district, mineral waters and malt (Soufflet) in the Nymburk district, Kofola soft drinks in the Bruntál district and the distilling, rectifying and blending of spirits in Krnov. Furthermore, the production of wines from grapes distorts LI levels in Southern Moravia. At the same time, the LI values do not reach 0.5 or lower in any district where an industrial brewery is located. This underlines the importance of the brewing industry in the beverage industry, which, together with the manufacture of food products (CZ-NACE 10), accounts for less than 3% of Czech GDP.

3.2 Changes in the geographical structure of the brewing industry in Czechia

Since 1989, only one industrial brewery that is still in operation has been established in Czechia (Chotěboř). It shows that the processes of concentration and consolidation of the brewing industry into fewer large companies have played much more important role than the establishment of new industrial breweries after 1990. This concentration process results from the "regionally differentiated closures of breweries" (Ulrich 2006: 70) (see also Table 4).

Tab. 4 Closed breweries between 1990 and 2012.

Year	Brewery
1991	Jablonec nad Nisou
1994	Studená, Cheb
1996	Břeclav, Golčův Jeníkov, Domažlice
1997	Děčín, Vsetín, Jevíčko, Jarošov, Praha-Holešovice
1998	Most-Sedlec
1999	Hradec Králové, Karlovy Vary, Prostějov, Lanškroun
2000	Olomouc, Uherský Ostroh
2001	Brumov-Bylnice
2002	Svitavy, Litoměřice
2005	Opava
2006	Praha-Braník
2009	Kutná Hora, Znojmo
2010	Louny
2011	Krásné Březno

Source: pivovary.info

Four interrelated processes have been responsible for the restructuring of the Czech brewing industry since 1990: the post-1990 economic transformation, the break-up of Czechoslovakia, the entry of foreign capital, and the development of microbreweries. First, the former centralized organizational structure of the Czech brewing industry disintegrated during privatizations and restitutions in the 1990s. Some of newly independent breweries could not compete, which lead to decreases in their output and eventual bankruptcies. For example, Pivovary Louny used to operate ten breweries before 1990 but only four of them still produce beer today (Vratislavice nad Nisou, Svijany, Velké Březno and Žatec). Plzeňské Pivovary was negatively affected by the abolition of the zoning of production and was forced to close down breweries in Cheb, Domažlice and Karlovy Vary. Consequently, the Karlovy Vary region remained the only Czech region without an industrial brewery. (Kratochvíle 2005)

Second, the break-up of Czechoslovakia has mostly affected the Zlín region (Kovařík 2003) because its breweries largely depended on the Slovak market. After the loss of the Slovak market following the break-up, only the Uherský Brod industrial brewery survived in this region of Czechia. Third, the entry of foreign TNCs and related inflows of FDI further contributed to the consolidation and concentration of the Czech brewing industry. This process and its impacts are analyzed below. Finally, the rise of microbreweries has also significantly influenced the geographical structure of the Czech brewing industry as hundreds of microbreweries were established after 1990 and more than 190 of them have survived. The greatest growth was registered between 2011 and 2013 when 100 microbreweries were established. As of September 2015, there are more than 280 microbreweries (pividky.cz), which suggests that the de-concentration process continues. (See Pulec 2014 for details.)

3.3 The impact of FDI inflows in the Czech brewing industry

The Czech brewing industry was affected by several domestic and international mergers or acquisitions. Three foreign brewing groups owned by SABMiller, Molson Coors Brewing Company and Heineken have played the most important role (Table 5).

Table 5 indicates that foreign owners conduct similar changes in their Czech breweries after their takeover but there are important exceptions. For example, British BASS, which owned 30% of the Radegast brewery did not introduce any significant changes before selling its share to the Japanese investment group Nomura. There is a lack of information Nomura's activities in the Pilsner Urquell – Radegast – Velké Popovice Group and only two outcomes from the Nomura tenure could be identified: the personal changes on the CEO position and the decision to close the Karlovy Vary brewery, which was carried out after the takeover by SAB in 1999.

SABMiller is the largest investor in the Czech brewing industry having invested more than 14 billion Czech crowns between 1999 and 2008 mostly to strengthen the international position of Pilsner Urquell on the Canadian, U.S., Israeli, Vietnamese, South Korean, Brazilian, Macedonian and Taiwanese markets and to introduce Pilsner Urquell in new markets in South Africa, Albania, Montenegro, Argentina, Azerbaijan and Cyprus. SABMiller also invested in new production technologies, such as cylindro-conical tanks that reduce energy, water and heat consumption, and in the expansion of production capacity.

Tab. 5 The effects of TNCs influencing the Czech brewing industry.

	Plzeňský Prazdroj (Pilsner Urquell)			Pivovary Staropramen				group of breweries today owned by Heineken		
	BASS 1995–1999	Nomura 1998–1999	SABMiller 1999–2015	BASS 1993–2000	AB InBev 2000–2009	CVC Cap. Part. 2009–2012	MCBC 2012–	Binding Gruppe* 1994–2007	BBAG 1994–2003	Heineken 2003–
a)	X	–	+	+	+	+	–	+	+	+
b)	X	–	+	–	+	+	–	+	+	+
c)	X	–	+	+	+	–	–	+	+	+
d)	X	–	+	+	+	+	–	+	+	+
e)	X	+	+	+	+	x	x	+	+	+
f)	X	+	+	+	+	x	x	x	x	+

Note: a) access to foreign capital, b) introduction of new marketing or business strategies, c) introduction of new technologies or know-how, d) access to foreign markets and distribution networks, e) personal changes in the top management f) concentration of production by the closing of the breweries; "+" yes, "x" no, "–" not proved

* later Radeberger Gruppe

Source: author's interviews, pivni.info, pivovary info, Kratochvíle (2005).

No breweries were closed, except for the Karlovy Vary brewery mentioned above.

The remaining foreign investors have followed similar strategies as SABMiller, although differences exist based on the original reasons for takeovers of Czech breweries. While SABMiller selected the Pilsner Urquell brand as its flagship brand, other brewing corporations typically buy Czech breweries mostly in order to access the Czech market. Staropramen is the only exception as its products obtained the flagship role early on when the Staropramen breweries belonged to the StarBev group, owned by CVC Capital Partners, and they have kept this position after being bought by the Molson Coors Brewing Company.

Other effects of foreign TNCs in the Czech brewing industry include: building of expedition halls, setting the modern production technologies, and creating better logistic systems and distribution networks. The majority of foreign investors also invest in the marketing of Czech brands, which is typically conducted by domestic marketing firms because of their familiarity with the domestic market. Licensing production, in which the particular brand of beer is produced outside of its traditional place of production, represents one of the most important business strategies of brewing TNCs. Examples of the license production of Czech beer include Staropramen, Radegast or Starobrno in Lithuania, Hungary, Poland, Serbia and Slovakia. In most cases, these brands are produced in breweries owned by respective TNCs.

Foreign owners of Czech breweries determine the brand portfolio. For example, German Binding Gruppe (part of Dr. Oetker TNC) has not allowed the Krušovice brewery to produce cheap brands of beer. SABMiller, AB InBev, and Heineken appoint their own top managers in Czech brewing companies while lower managerial positions are left to Czech managers whose advantage is their good knowledge of the Czech market. TNCs operating on the Czech market can potentially displace Czech suppliers from their positions in value chains although the lack of data makes it impossible to find the evidence of this behavior.

Selective closures of Czech breweries are perhaps the most important negative effect of foreign ownership (Table 4). For example, Heineken has already closed four breweries and Interbrew has closed the Braník brewery in Prague. Since 2006 all closures of Czech breweries were based on the decisions made by TNCs. By selectively closing breweries, TNCs further the concentration processes in the Czech brewing industry. At the same time, the economic success of foreign controlled Czech breweries has been supported by corporate strategies based on profit-seeking behavior of their foreign owners. However, the potential outflow of profits abroad in the form of dividends can eventually exceed the value of invested capital (Dicken 2011).

4. The integration of Czech-based breweries into GPNs

Companies within the class of economic activities CZ-NACE 11.05 and producing more than 10,000 hl of beer every year were classified into four groups based on the following criteria: i) the inclusion in a brewing TNC ii), integration in a GPN through supplying relationships, and iii) integration in a GPN through customer relationships (Tables 6 and 7). The data was collected through

Tab. 6 The firms by integration into GPNs.

Category	Number of Companies
1 – fully integrated foreign-owned breweries	3
2 – mostly integrated domestic breweries	9
3 – partly integrated domestic breweries	6
4 – unintegrated domestic microbreweries	0
unclassified firms	9

Source: author

Tab. 7 The evaluation of integration of Czech brewing companies into GPN structures in 2013.

	Ownership	Suppliers			Customers	Export	Category
		Hops	Malt	Packages			
Plzeňský Prazdroj							
Radegast (Nošovice)	SABMiller	–	+**	+	+	+	1
Pivovar Velké Popovice							
Staropramen	Molson Coors Brew. Co.	–	+	+	+	+	1
Ostravar							
Královský pivovar Krušovice							
Starobrno	Heineken	–	+	+	+	+	1
Pivovar Velké Březno							
Budějovický Budvar	state ownership	x	+	+	+	+	2
Pivovar Protivín							
Pivovar Černá Hora							
Pivovar Rychtář (Hlinsko)							
Pivovar Klášter	Pivovary Lobkowicz	–	+**	+	+	+	2
Pivovar Vysoký Chlumec							
Pivovar Jihlava							
Pivovar Uherský Brod							
Pivovar Svijany							
Pivovar Rohozec	LIF Group	+**	+**	+	+	+	2
Pivovar Primátor (Náchod)							
Pivovar Holba (Hanušovice)							
Pivovar Litovel	PMS Přerov	–	+	+	+	+	2
Pivovar Zubr (Přerov)							
Rodinný pivovar Bernard	Duvel Moortgat + Czech owners	–	+**	+	+	+	2
Pivovar Samson (Čes. Bud.)	Czech owner	–	–**	+	+	+	?
Pivovar Nymburk	Czech owner	x	+**	+	+	+	2
Pivovar Krakonoš (Trutnov)	Czech owner	x	–	+	+	+	?
Chodovar (Chodová Planá)	Czech owner	x	x**	+	+	+	3
Měšťanský pivovar Polička	Czech owner	x	x	+	+	x	3
Měšťanský pivovar Havlíčkův Brod	Czech owners	–	–**	+	+	+	?
Pivovar Bakalář (Rakovník)	Russian owner	–	–	+	+	+	?
Pivovar Vratislavice nad Nisou	Czech owners	x	x**	+	+	+	3
Pivovar Regent (Třeboň)	Czech owner	–	–	+	+	+	?
Pivovar Pernštejn (Pardubice)	Czech owner	+	x	+	+	+	2
Měšťanský pivovar Strakonice	municipal ownership	x	x	+	+	+	3
Městský pivovar Nová Paka	Czech owners	–	x**	+	+	+	?
Pivovar Poutník Pelhřimov	cooperative own.	x	x	+	+	+	3
Žatecký pivovar	British owner	x	–	+	+	+	?
Pivovar Ferdinand (Benešov)	Czech owner	x	+**	+	+	+	2
Pivovar Vyškov	Czech owner	–	–	+	+	+	?
Pivovar Kácov	Czech owner	+	+	+	+	x	2
Pivovar Broumov	Czech owners	x	x**	+	+	+	3
Pivovar Chotěboř	?	–	–	+	+	+	?

Note: "+" yes, "x" no, "–" not proved, "?" uncategorized, ** these firms possess their own production capacities in this part of supply chain

Source: Pulec (2014).

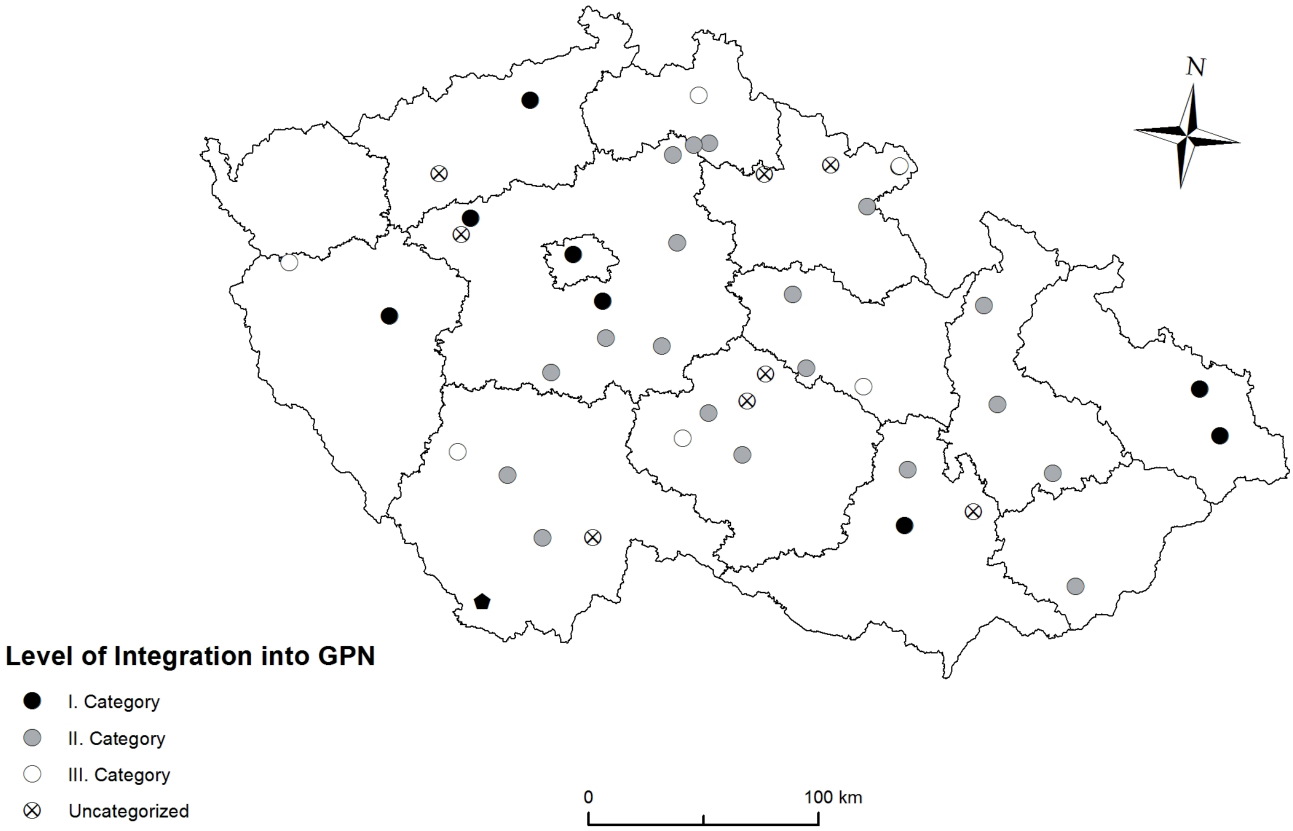

Fig. 3 The spatial differentiation of Czech breweries by their integration into GPNs.
Source: author

a survey of 42 industrial breweries, 28 supplying companies and 7 transnational retail corporations operating in Czechia and it yielded 33 returned questionnaires.

Data about supplying linkages and customer relations has been difficult to obtain. The three most important supply relationships in the beer industry include the supply of hops, the manufacture and supply of malt and the supply of packaging materials. The data about the supply of hops is most fragmented because brewing companies do not like to publish this information. Most of them claimed to use Czech hops in the traditional beer production, although 80% of hops are imported according to the Czech Hop Growers Union. I was unable to identify any TNC engaged in the production of hops in Czechia. In the manufacture of malt, more than half of malt production is carried out by malt-houses in Prostějov, Hodonice, Nymburk, Kroměříž and Litovel, which are owned by French Soufflet. In the area of packaging materials, three groups of suppliers were analyzed: glass packaging, plastic packaging, and metal packaging. The glass packaging is dominated by the U.S.-based O-I Manufacturing and Swiss-based Vetropack. Two important TNCs also dominate metal packaging: German Schäfer-Werke and Czech Imexa. Finally, Czech firms Petainer and Alfa Plastik play an important role in the plastic packaging.

The cooperation of breweries with transnational retailers is important for the beer distribution in Czechia because they control the Czech retail industry. I have only considered retailers operating in Czechia. The basic idea of the classification above is the fact that if any supplier or customer of a particular brewery is owned by a TNC, this brewery is part of its GPN. In some cases, a brewery is involved in multiple GPNs at the same time. Some breweries cannot be classified because of the lack of data. The spatial differentiation of the Czech breweries by the integration into GPNs is presented in Figure 3.

Four types of Czech-based breweries can be recognized based on their integration into GPNs:

Fully integrated foreign-owned breweries (I. Category)

Fully integrated foreign-owned breweries include large brand-name breweries owned by foreign TNCs, such as Pilsner Urquell, Staropramen Breweries and the group of breweries owned by Heineken. These foreign TNCs rank among the biggest brewing companies in the world. Their Czech breweries are strategically distributed in Czechia, fulfilling different roles in corporate business strategies and being responsible for regionally and structurally different segments of the Czech market. Firms fully integrated into GPNs account for 20% of industrial breweries (incorporated into three brewing companies) and occupy top places in the beer production in Czechia. Most of these breweries are located in Prague, regional centers and their close vicinity. Thanks to their importance, these breweries are supplied by the biggest foreign-owned suppliers and they distribute their beer through transnational retail corporations.

Mostly integrated domestic breweries (II. Category)

Mostly integrated domestic breweries account for the largest number of firms and they primarily include small and medium-size[5] breweries or brewing groups that are not owned by TNCs. Being usually located in regional centers or smaller cities, most of them function as regional breweries. However, they have a relatively strong position in the Czech (or foreign) market thanks to their integration into larger brewing groups and their cooperation with big foreign suppliers. Their beer is sold through transnational retail corporations. State-owned Budweiser Budvar has a specific position in this category. In terms of its size and importance, it is similar to firms classified in the first category because it is also linked to the global brewing market and it cooperates with Carlsberg (Materna 2011). However, since it is not foreign-owned, it lacks some of the business strategies and coordination that are typical for foreign-owned firms, such as top management positions occupied by foreigners, the regulation of product portfolio by a parent company, and the modernization and the purchase of modern technologies financed by foreign capital.

Partly integrated domestic breweries (III. Category)

Only six small regional industrial breweries that are located in peripheral areas of Czechia are classified into this category. These firms are specific because, except for the supply of packaging, they do not interact with companies owned by TNCs and their customer relationships are regionally based.

Unintegrated domestic microbreweries (IV. Category)

There are almost two hundred domestic microbreweries not integrated into GPNs. They use raw materials exclusively from domestic firms and domestic sources and they sell only to local pubs and restaurants. However, we can only speculate about the degree of their integration since these small breweries were not analyzed in detail.

Czech breweries can achieve a relative autonomy through the increasing level of vertical integration, which is a common strategy pursued by foreign brewing companies. Some Czech breweries own malt-houses and hop-gardens and even operate their own production lines of plastic packaging (Table 7).

5. Conclusion

By drawing on the GPN perspective, this article analyzed the Czech brewing industry, its integration in transnational production networks through FDI and how this integration affected its geographical structure. The geographical structure of the Czech brewing industry was analyzed through three main criteria: the ownership, volume of production and employment. I have identified the contradictory processes of concentration and de-concentration of brewing activities in Czechia. The concentration processes have predominantly been represented by the ever-decreasing number of industrial breweries for three main reasons: the liberalization, privatization and restructuring of the Czech economy after 1990, the break-up of Czechoslovakia in 1993 and the optimization of production networks by TNCs.

At the same time, the processes of de-concentration have been reflected in the significant increase in the number of microbreweries (by 100% in the period of 2011–2013). These tiny firms cannot compete with big industrial breweries in production volumes, but their competitive advantage lies in satisfying various tastes and customer preferences. By September 2015, there were more than 280 microbreweries located in Czechia and more are expected to start production soon (pividky.cz).

Foreign investors affected the Czech brewing industry in many different ways by investing in new production technologies and their modernization, allowing access of Czech-based breweries to international distribution networks, and by managing operations of Czech-based breweries. In the process, TNCs have concentrated the beer production into a smaller number of breweries. Foreign investors differ in the amount of invested capital, which depends on the length of their ownership and its original intent. For example, as a "flagship" brand of SABMiller, Pilsner Urquell has received several times higher investments than other foreign-owned breweries in Czechia. Recent developments, such as the capital investment into the Pivovary Lobkowicz Group by Chinese CEFC and the takeover of SABMiller (the owner of Pilsner Urquell) by Anheuser-Busch InBev will affect the Czech brewing industry.

I have identified four types of integration of Czech breweries into GPNs: fully integrated foreign-owned breweries; mostly integrated domestic breweries, partially integrated domestic breweries and un-integrated domestic microbreweries. These four types of firms differ not only in their size but also in their localization patterns with fully integrated foreign-owned breweries being most spatially concentrated in the largest Czech cities while un-integrated domestic microbreweries are most geographically dispersed.

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5 The production of small industrial breweries doesn't exceed 200,000 hl of beer per year and the production of middle-size breweries is located within 200–500 thousands hl of beer per year.

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Heineken: http://www.heinekenceskarepublika.cz

Pividky.cz: http://www.pividky.cz/mapa.phpPivni.info: http://pivni.info

Pivovary.info: http://pivovary.info
SABMiller: http://www.sabmiller.com
United Nations Conference of Trade and Development: http://unctad.org

RESUMÉ

Zapojení českého pivovarnického průmyslu do globálních výrobních sítí

Český pivovarnický průmysl prošel během transformace české ekonomiky mnoha změnami. Při hodnocení současné geografické struktury tohoto průmyslového odvětví byl identifikován protichůdný proces koncentrace a dekoncentrace pivovarnických aktivit zastoupený jednak stále klesajícím počtem průmyslových pivovarů a na druhé straně stále narůstajícím počtem tzv. minipivovarů. S tímto procesem úzce souvisí působení zahraničních NNS. Většina těchto společností od 90. let vykazuje obdobný přístup k českým pivovarnickým podnikům a aplikaci podobných strategií. Liší se však především v množství investovaných prostředků. Významně pak do územního rozmístění pivovarů v Česku zasahují jejich rušením v rámci optimalizace výroby a ušetření nákladů. Právě míra zapojení českých pivovarnických podniků do nadnárodních výrobních sítí zahraničních pivovarnických společností velmi úzce souvisí s procesy, jakými tyto zahraniční společnosti mohou české pivovary ovlivňovat. Na základě analýzy dodavatelsko-odběratelských vztahů byly identifikovány čtyři kategorie zapojení českých pivovarů do globálních výrobních sítí. Základní myšlenka tohoto rozdělení je taková, že pokud je dodavatel nebo odběratel pivovaru součástí nějaké NNS, je tento pivovar na území Česka součástí produkční sítě této NNS. Druhým klíčovým bodem je zahraniční vlastnictví českých podniků.

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THE TOPOGRAPHICAL CHANGES CREATED BY THE LANDSCAPE DESIGN ACTIVITIES. CASE STUDY OF THE CZERNIN PARKS, BOHEMIA

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ABSTRACT

Landscape is considered a specific type of heritage, and cultural landscapes provide an interface between nature and culture, the tangible and intangible, and biological and cultural diversity. They represent a closely woven network of relationships and the essence of cultural and personal identity. The most valuable cultural landscapes are designed landscapes or landscape parks. This paper focuses on landscaping activities associated with park foundation and management, especially those involving terrain changes and the remodeling of the natural topography. Terrain changes in landscape parks are typically meant to be hidden from viewers and to mimic natural lines and shapes. The paper focuses on determining to what degree the natural topography was used and changed, as well as what impact it had on the form and creation of the parks. Terrain changes should differ according to the natural topography, the landscape design activities, and contemporary landscape trends. Archival sources, including written documents, maps, and pictures, were considered viable sources. Four model areas were chosen for a detailed analysis of landscaping and design activities and their impact on the terrain: landscape parks around manor houses in Krásný Dvůr, Jemčina, Petrohrad, and Chudenice.

Keywords: landscape parks, terrain modeling, Czernin, Bohemia

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1. Introduction

Landscape and its natural and cultural value have long been of interest to researchers and have figured prominently among the considerations shaping planning policies. Landscape itself is considered a specific type of heritage (Kučera et al. 2008a; Kučera et al. 2008b; Lowenthal 2005). Cultural landscapes provide an interface between nature and culture, the tangible and intangible, and biological and cultural diversity. They represent a closely woven network of relationship and the essence of cultural and personal identity (Rössler 2006). The World Heritage Committee (UNESCO) established three categories of cultural landscapes, one of which was clearly defined landscapes designed and created intentionally by humans. This category includes garden and parkland landscapes constructed for aesthetic reasons. Such landscapes are often (but not always) associated with monumental buildings and ensembles (Rössler 2006). However, most studies of landscape value generally refer to an integrity criterion that encompasses coherence, harmony, visual balance, undisturbed functional entities, continuity over time, and the fit of land use to the landscape's natural characteristics (Gullino, Larcher 2013). Specifically, in landscape parks, attention is concentrated on dendrological value and veteran trees (Pejchal 2011; Pejchal, Šimek 2012; Nutt et al. 2013).

Though there is a large body of grey literature, few papers on the value of landscape parks have been published in Europe (Kümmerling, Müller 2012). Both within and outside of the Czech Republic, several approaches to historical parks and gardens are apparent. First, some papers focus on the composition of the garden or park and its components. This approach attempts to identify hidden compositional values and is often associated with park reconstruction (Kulišťáková et al. 2014; Kulišťáková, Sedláček 2013; Flekalová, Kulišťáková 2014; Nordh et al. 2009). Another strand of research is focused on plant species, the introduction of plants to new areas, rare plants or plants important for their shape (Abendroth et al. 2012; Nutt et al. 2013; Pejchal 2011; Pejchal, Šimek 2012). Historical parks and gardens and the manor houses to which they are attached are important components of tourism, and the attractiveness of the landscape is essential for tourism development (Navrátil et al. 2015; Kučera et al. 2013; Kozak 2013; Balcarová, Kulišťáková 2012). However, parks and gardens are also important for biodiversity in cities and in intensively managed landscapes, whether agricultural and forest. Endangered species may find refuge in such areas, and remnants of natural or seminatural biotopes could be incorporated into parks and be protected thereby (Lõhmus, Liira 2013; Liira et al. 2012; Jonsell 2012; Šantrůčková et al. 2015; Kümmerling, Müller 2012).

Landscape parks are specific areas, where the influences of natural conditions and intentional human intervention intersect closely. It is typical of such parks that they tried to fuse these human modifications with nature, and

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unknowing visitors often cannot even recognize this. This fact contributes to the pleasant impression given by landscape parks, but it also carries the risk of underestimating intentional terrain changes. However, there could not have been one unified concept of ideal landscape parks during their long history. Today in the Czech Republic, there are several hundred landscape parks of which several have significance on the European level. The natural environment contributes to the appearance of landscape parks significantly through various forms of relief. At the same time topography is not taken passively to be a base for establishing parks, but it is actively modified at great cost and effort. Other steps in the creation of parks were closely connected to land forming, such as the design and modification of water features, vegetation planting and modeling, and the compositional arrangement of the park (Lang 1974).

The landscape style was developed on the British Isles in the 18th century, during the second half of which this style began to spread to continental Europe. Its perception in France and in the German-speaking lands was important for further development as European landscape parks were enriched with peculiar elements there. This free landscape style remained popular in Europe throughout the entire 19th century with certain changes, considering its long existence. There was a concurrence of several influences that mutually intertwined and affected individual architects with various intensities in different time periods (Newton 1971).

The perception of the landscape as a whole and its aesthetic qualities became established in the 17th and 18th centuries. This conception resonated with infant Romanticism and contributed to the further expansion of the landscape park fashion, which was supposed to embody ideal, uncorrupted nature. Three aesthetic categories were discussed in particular in connection with early landscape parks – beauty, the sublime, and above all the picturesque. The picturesque expressed the quality of the landscape; the overall effect and perception of landscape/parks/gardens was emphasized. Individual components and objects were evaluated based on their working within the whole (Clark 1980). Another important impulse for the development of landscape parks was 17th and 18th century painting. The landscape park itself was conceived as a painting; gardens were created as three-dimensional pictures, where mutual relationships between individual features played a critical role (Kuča 1974).

Two attitudes towards life markedly appeared in art – Classicism and Romanticism. These seemingly opposing movements coincided at the turn of the 19th century and naturally influenced each other, which was noticeable in garden art. Classicism influenced parks on the one hand with the construction of buildings that reflected Classical and Palladian ideals, and on the other hand influenced the overall formation of parks. Harmonic relationships between materials, spaces and that which binds them were characteristic for Classicist park design. The park, not to say the entire landscape, was arranged with the help of centers and axes. The Romantics returned to spiritual experience, cultivated rural landscapes were also admired. With a return to spiritual values there was a related renewed interest in Christianity and the Gothic style, which was understood to be the most organic form of expressing desires and ideas. However, there was also interest in the traditions of pre-Christian Europe, and exotic lands. Under the influence of Romanticism landscape parks were modeled to be like wild nature (Hallbaum 1927).

Landscape parks, using natural, and less frequently, architectural features, were built to be intentionally irregular. Hilly terrain was sought after as it allowed for a moment of surprise to be introduced and also gave parks vantage points. Water could not be missing from the park. Stands of vegetation and meadows were created to be irregular; kidney-shaped forms were favorites. Especially large meadows were made to stand out with solitary tress or bushes, or groups of trees. Much attention was focused on the lay-out of paths, since as artificial creations they were not based on natural features. Paths were supposed to wrap around bends; circular paths leading visitors through the most important parts of the park were favorites (Clark 1980). The seemingly natural curves of landscape parks and their individual features (such as topography, water, and paths) were often the result of marked hard work. Complicated land forming was the rule, rather than the exception. As needed, valleys in parks were deepened and artificial hills were created. There were big changes in water features. Not only were ponds established for example, but stream channels were adjusted, or were dammed to create cascades, or new stream channels were dug. Work with vegetation, which formed park spaces and axes, were also very important. The dynamic features of vegetation were utilized and supported by planting various tree species, resulting in various foliage structures, textures, and colors (Hallbaum 1927). Follies were supposed to enhance views and contribute to creating certain desired moods of which they were symbols.

This paper focuses on landscaping activities associated with park foundation and management, especially those involving terrain changes and remodeling of the terrain's natural topography. Terrain changes in landscape gardens were typically meant to be hidden from viewers, and they often mimicked natural lines and shapes. This paper focuses on determining the degree to which the natural topography was used and changed and what impact it had on the form and creation of the parks. We assume that the natural topography played an important role in the park design. Furthermore, terrain changes are assumed to differ according to the natural topography, the landscape design activities, and the fashion prevailing during the time period the park was created. Several types of archival sources (written documents, maps, pictures) were consulted.

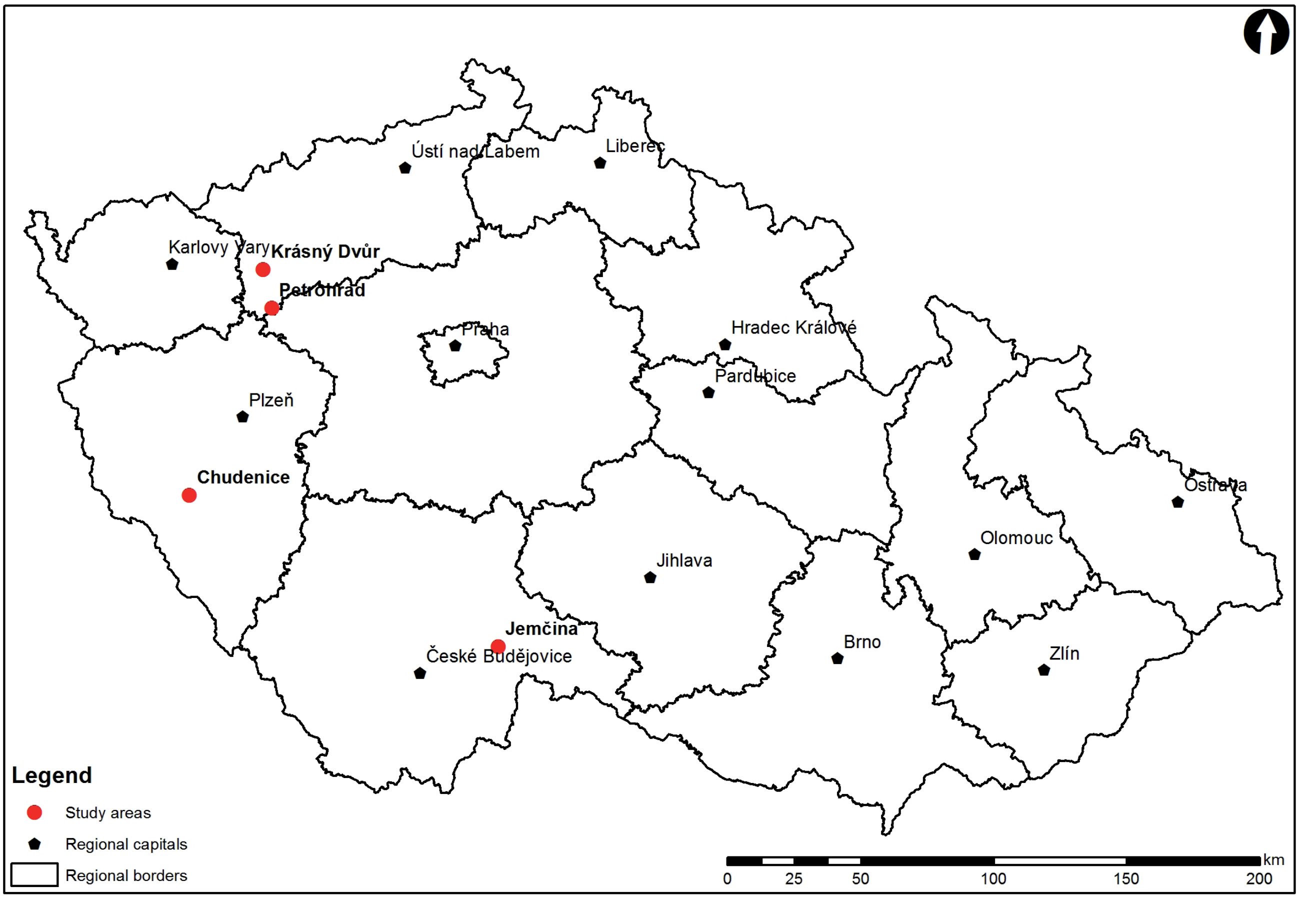

Fig. 1 The study areas.

2. Materials and Methods

2.1 Study areas

Four model areas were chosen for a detailed analysis of landscaping and design activities and their impact on terrain modeling: landscape parks in villages Krásný Dvůr and Petrohrad, small town Chudenice and around game manor house Jemčina (Fig. 1). Each of these parks was founded and owned by the same landlord, Johann Rudolph Czernin, and his son, Eugen Karl Czernin, during the end of the 18th century and the first half of the 19th century (Šantrůčková 2014). The oldest park, Krásný Dvůr, was built in the 1780s by J. R. Czernin, L. Födisch and G. Wachtel in the flat, rural landscape of the Mostecká Basin (Mostecká pánev) 300 m above sea level. The local climate is hot (average year temperature is 7.5–8 °C) with little precipitation (450 mm per year). The park is located in a deep valley of the Leska Stream (Leskovský potok) and covers 96 ha. This park was highly prestigious and expensive, and many of the original brick follies are still extant. The flat parts of the park are occupied by meadows, often with follies or ponds, and the slopes are covered by woods. The whole area is Nature monument Krásný Dvůr for protection saproxylic beetles.

Jemčina is a large game park that occupies 2400 ha, which include Holná pond. This park was founded in approximately 1790 by J. R. Czernin and G. Wachtel on the flat, marshy, wooded edge of the Třeboňská Basin (Třeboňská pánev), 430 m above sea level. The local climate is moderate (average year temperature is 7–7.5 °C), and the area receives 650 mm of precipitation per year. Landscaping was less intensive in Jemčina because it was primarily used as a game park. The most intensively landscaped section was that which surrounded the hunting castle. Roads and paths were also intensively cared for in the wooded part of the park. The follies, however, were rare and wooden and have completely disappeared. Jemčina is a part of Protected landscape area Třeboňsko.

A small Baroque garden, an orchard, and a small game park were built in Petrohrad during the first half of the 18th century. These areas were transformed into a landscape park in the 1790s by J. R. Czernin and A. Födisch and remained such until the 1840s. Petrohrad lies in a hilly landscape among the granite boulders of the Rakovnická Hilly land (Rakovnická pahorkatina), 400 m above sea level. The local climate is moderate (average year temperature is 7 °C), and the area receives 500 mm of precipitation per year. The park's area is 300 ha, but it is difficult to delimit because the park flows continuously into the surrounding landscape. The park is composed

Tab. 1 Types of terrain changes resulting from landscaping in the parks.

Space characteristic	Landform characteristic	Landform specification	Brief description
Area changes	Artificially undulating areas		Primarily park grasslands that were leveled and then "naturally" modeled
	Leveled areas	Original leveled areas	Leveled when the park was built. Used as a base for buildings, follies, a courtyard, and a plant nursery.
		Playgrounds	New playgrounds with regular shapes constructed primarily in the 20th century for tennis, football, etc.
	Terraces		Slopes formed like "staircases" with a wide base.
	Depressions	Depressions of ponds	Wet depressions on the river or water channel.
		Dry depressions	Depressions that have never been used as ponds.
	Artificial hills		Small manmade hills.
Linear changes	Embankments	Embankments	Huge embankments, often near a road.
		Banks	Small embankments, e.g., near water channels or in front of visually problematic areas.
		Dams	Massive but short embankments, mainly near ponds.
	Trenches	Artificial canals	Manmade water channels.
		Modified flows	Natural creeks that were remodeled by man.
		Ha-ha trenches	Dry trenches that protect the park from animals but do not interrupt the visual connection between the park and the landscape.
	Shapes on the terrain level	Ways	Regularly managed networks of roads, ways, and paths.
		Walls	Primarily stone or brick walls used to buttress slopes.
Point changes			Small terrain changes near banks and other small follies.

of four large park meadows with scattered trees and the wooded Castle Hill (Zámecký vrch). Northern part of the area is Nature monument Petrohrad for protection saproxylic beetles.

The last park, located in Chudenice, was founded in the 1790s, but the 130 ha area was primarily developed from the 1820s to the 1850s by E. K. Czernin and J. C. Blumenstängl. This park is also situated in a hilly landscape approximately 500 m above sea level in Švihovská Highland (Švihovská vrchovina). The local climate is moderate (average year temperature is 6.8 °C), and the area receives 650 mm of precipitation per year. The largest area in the central part of the park is forested, but meadows are found at the park's southern and western edges. Chudenice is also historically important for introducing overseas plant species to Bohemia and a part called American garden is protected as National nature monument.

2.2 Data analysis

Landscaping history must be reconstructed from various sources that are scattered across many documents and institutions, including archives, museums, galleries, and libraries. However, reconstructing design activities from archival sources is accompanied by problems resulting from the variable quality and reliability of the historical information provided in the documents and their interpretation. Descriptions of a particular park in written documents, maps, and pictures were subject to observer bias, both deliberate and accidental, making comparison across time and space difficult (Foster 1992; Endfield, O'Hara 1999; Šantrůčková et al. 2015; Black et al. 1998). Abundant archival data are available for the studied parks because they were exceptional areas on each estate and the landlord was keenly interested in their development and maintenance (Šantrůčková 2014).

Landscape parks and gardens are special areas that are often well documented in archival sources because their foundation and cultivation was the center of landlords' interest. However, old maps are relatively well known and the most frequently used resources and are often used for studying both landscape changes (Skaloš et al. 2011; Gustavsson et al. 2007; Van Eetevelde, Antrop 2009) and designed landscape composition and structure (Flekalová, Kulišťáková 2014; Kulišťáková et al. 2014) because they are the most accessible sources. Map language is universal across time and space, and maps can be analyzed using geographical information systems (GIS). Maps from the 19th century onwards were usually accompanied by geodetic measurements and accurate spatial information. Therefore, the scanned copies of these maps can be georeferenced. Maps made at different time points can be visualized and compared.

Written documents and old pictures comprise the second, less frequently used group of sources. Nevertheless, they are under-utilized because their study is time consuming and requires the ability to read and interpret old documents (Nestor, Mann 1998; Šantrůčková 2014). These sources are extremely scattered, narrative,

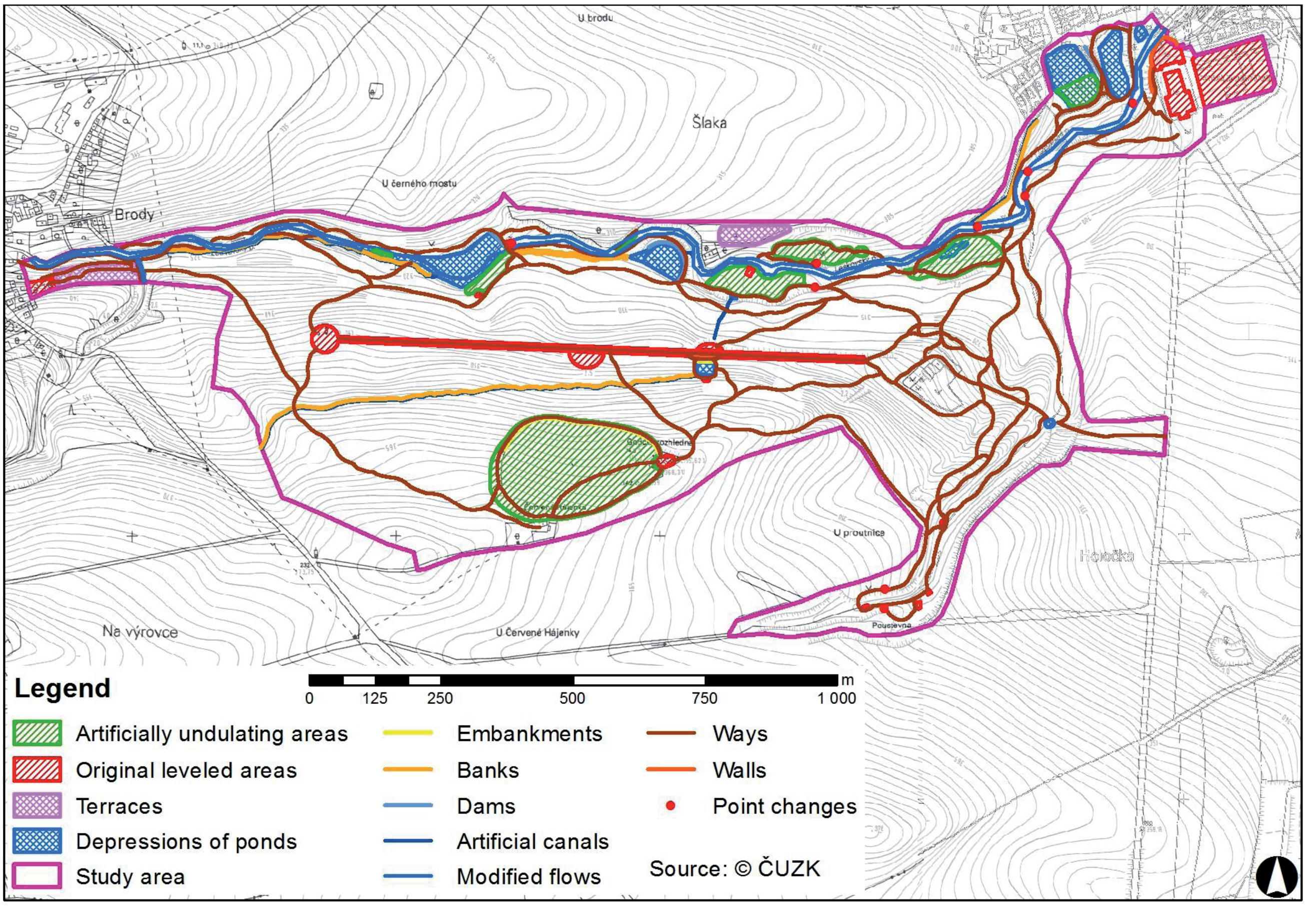

Fig. 2 Landform in the landscape park in Krásný Dvůr.

and individual, and many of them are not easily legible. However, they offer unique information about the landscaping process, terrain modeling, and plants used (Black et al. 1998; Endfield, O'Hara 1999; Nestor, Mann 1998). Common historiographical methods (textual analysis, inner and outer critics) were applied to analyze the written sources (Black, Macraild 2007), from which information about the design activities and terrain modification were obtained for each model area. The archival sources allowed us to identify, on historical and modern maps, the areas, lines, and structures that indicate terrain modeling (Table 1). All of the information and the current state of the terrain created by landscaping were confirmed by a terrain survey of the model areas.

3. Results

Terrain changes in the model areas were identified through a terrain survey and drawn on the maps on a 1:5,000 scale. They were assessed based on both the time and manner of their implementation and their current state. The area and linear changes proved to be the best preserved and the most varied (Table 2 and 3). Point changes, however, were difficult to identify. The terrain changes that were implemented respected the natural topography.

3.1 Landscape park in Krásný Dvůr

The establishment of the park in Krásný Dvůr was a highly prestigious event. The naturally broken terrain was not only perfectly used but subtly complemented. The terrain was deliberately manipulated to merge with the surroundings as quickly as possible, and though these changes are now immediately obvious, a layman would not recognize them. Krásný Dvůr is a typical picturesque park in which the natural interacts with the artificial terrain to evoke romantic images and create the illusion of a unified whole rather than a set of separate parts. Unlike the garden structures, the terrain changes are more permanent and erode slowly. Although some of the buildings have not survived, it is easy to detect their past locations because of clues in the terrain (Figure 2). Krásný Dvůr predominantly used artificial undulations on 0.07 km^2 to define individual representative areas of the park, which were usually complemented by a visually distinctive folly. One of the highlights of Krásný Dvůr is the high-volume Leska Stream, which runs through the entire landscape park. The bed in park (2.3 km) was laid with stones to create rapids, the banks were reinforced and curves were added to change the stream's route. Further changes included the building of paths; their total length is 15.7 km.

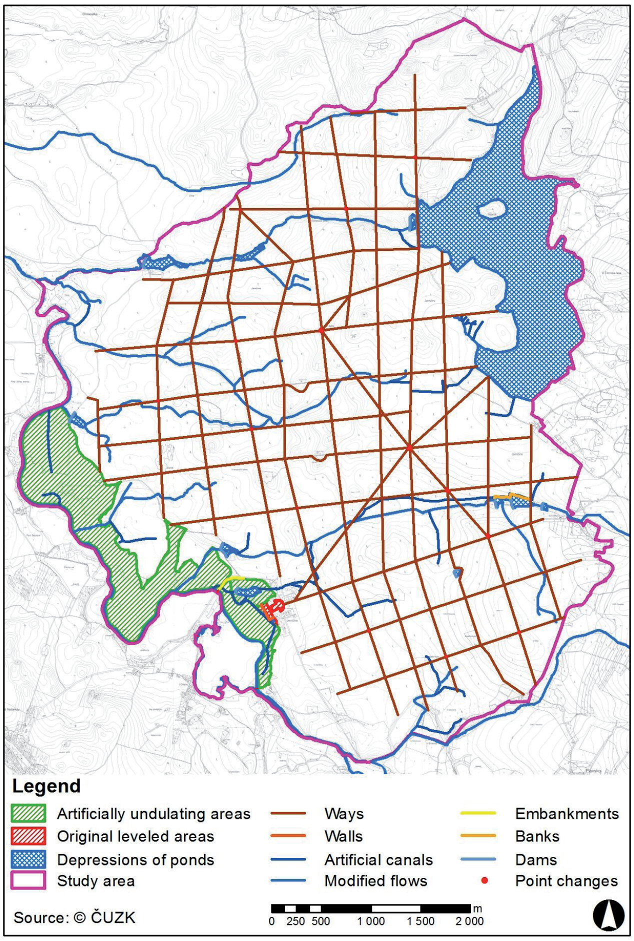

Fig. 3 Landform in the game park in Jemčina.

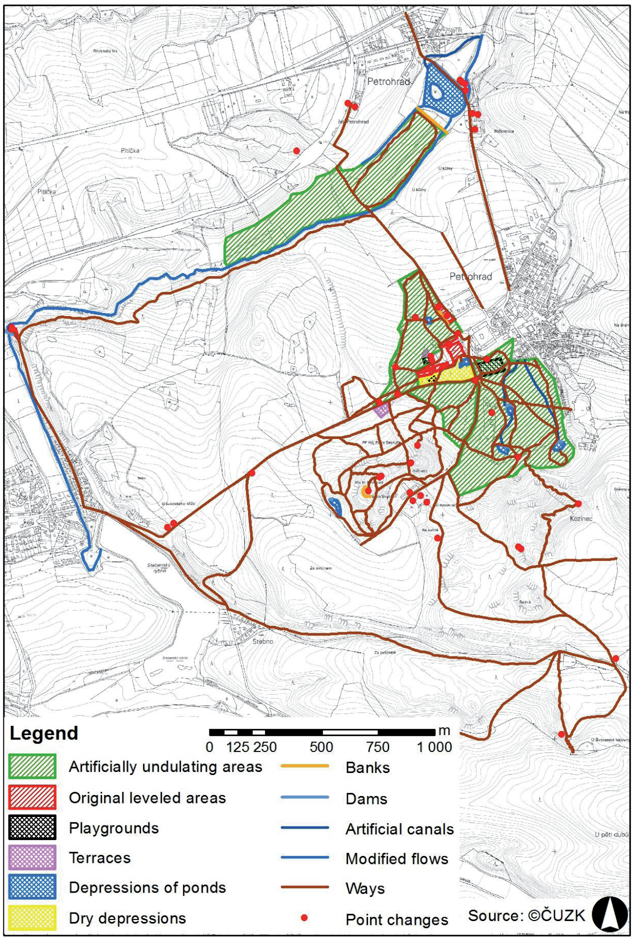

Fig. 4 Landform in the landscape park in Petrohrad.

3.2 Game park in Jemčina

The game-park in Jemčina was primarily used for hunting. To pursue game on horseback with dogs, it was necessary to maintain an easily penetrable terrain that provided a broad view of the landscape. It was most important to accommodate the rapid movement of the riders. Therefore, a flat area near Jemčina was chosen for the park, and the main changes to the terrain included creating a dense network of paths and ways and draining the wet areas. The mass of the Jemčina woods was divided regularly by a chiefly rectangular network of forest breaks with ways (total length 90.5 km) whose main direction was determined by a set of three ways that ran through the woods from the northeastern face of the castle. An aesthetic dimension was added by the inclusion of granite boulders, ponds and streams, which broke up the dense forest mass. The Jemčina castle is located on an important river terrace above the flat and wet flood plain of the Nežárka River. This meadow is several tens of meters wide. The most significant terrain changes were made in the immediate vicinity of the castle to meet the high standards of the mansion and its surroundings. The areas called the honour court and a viewing terrace were leveled, total area is 0.04 km^2. In addition, a park meadow (1.7 km^2) beneath the castle, the surroundings between Jemčina Pond and the manor farm were undulated and accompanied by ways and groups of trees (Figure 3).

3.3 Landscape park in Petrohrad

The park in Petrohrad was designed to give the manor house a pleasant and representative backdrop. The park primarily comprises open spaces, especially meadows in which groups of trees or single trees were grown. The undulating areas are therefore closely massed on 0.5 km^2. Establishing meadows required much effort, especially in the south of the park on the steep slopes of the Zámecký and Kozí Hills. Because the soil is stony there, it was necessary to remove the stones before installing a new plantation, and the surface needed to be undulated again. However, diverse and picturesque rock formations in the valley of the Podvinecký Stream, on Zámecký Hill and Kozí Hill and in the game park complemented the scenery or served as viewpoints. They were welcome as an enlivening element for walks in the garden meadows and provided overlooks. Terrain changes in the Petrohrad park also included the planting of trees, creating networks of paths (31.3 km), constructing buildings and creating water elements. The water elements were typically small ponds made in naturally damp places; however, even these required terrain alterations and their total area is 0.03 km² (Figure 4).

3.4 Landscape park in Chudenice

Chudenice landscape park is situated on the Žďár ridge, which provides a wide view of the surroundings. The landscape is picturesque and hilly. In Chudenice, a decorative tree and fruit tree nursery played a much more important role than in the other Czernin parks. The tree nurseries influenced the appearance of the modified areas, which were (where needed) leveled, terraced or undulated after being planned. The largest terrain changes in Chudenice were associated with the construction of the Lázeň manor house and the surrounding buildings and with the construction and demolition of St. Wolfgang's Church. The areas in the vicinity of these two buildings underwent the most significant alterations. Large buildings in the garden were scarce, so it was not necessary to make any other demanding terrain changes. The largest area is occupied by artificially undulating meadows (0.3 km²). It was also important to build ways and paths (16.5 km), which in the undulating terrain required much care, including terrain changes. Changes were also made to the water drainage systems, especially in Karolína's and Jaromír's meadows, and small ponds were created (Figure 5).

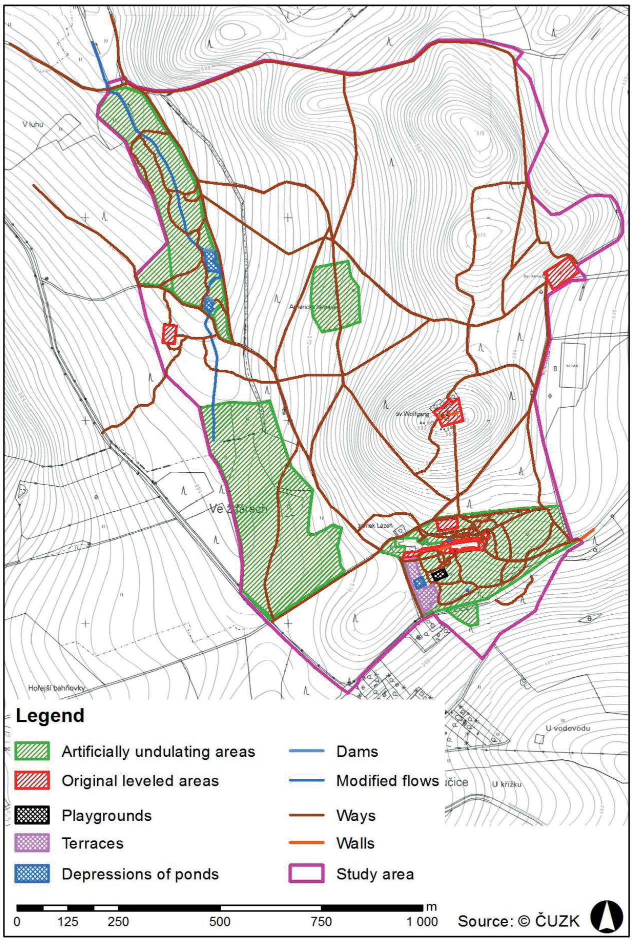

Fig. 5 Landform in the landscape park in Chudenice.

Tab. 2 Areal landforms in the model parks.

Areal landforms	Area (m²) in Krásný Dvůr	Area (m²) in Jemčina	Area (m²) in Petrohrad	Area (m²) in Chudenice
Artificially undulating areas	72,234	1,670,942	531,163	261,110
Original leveled areas	36,057	37,684	10,819	11,959
Playgrounds	x	x	7,372	556
Terraces	9,390	x	2,771	4,286
Depressions of ponds	27,124	2,414,640	29,808	2,277
Dry depressions	x	x	14,526	x
Artificial hills	x	x	x	x

Tab. 3 Linear landforms in the model parks.

Linear landforms	Length (m) in Krásný Dvůr	Length (m) in Jemčina	Length (m) in Petrohrad	Length (m) in Chudenice
Embankments	371	301	x	x
Banks	2,117	400	336	x
Dams	339	1,453	395	47
Artificial canals	2,039	12,909	1,119	x
Modified flows	2,292	31,667	4,404	410
Ha-ha trenches	x	x	x	x
Ways	15,660	90,464	31,253	16,537
Walls	189	224	x	149

4. Discussion

Archival sources were key to conducting a detailed study of landscaping activities. Historical and current maps document the state of the landscape, the presence of design elements and their exact locations. Terrain modeling is closely associated with the composition of the landscape parks, and both can be visualized on maps (Kulišťáková, Sedláček 2013; Flekalová, Kulišťáková 2014). Nevertheless, written sources are necessary for understanding the landscaping process, its timing, which alterations were planned and which actually executed, and the technical details of the design activities (Nestor, Mann 1998; Endfield, O'Hara 1999).

Landscape parks deliberately made use of the local topography, and its configuration was of key importance to the outcome of the landscaping. The topography influenced the appearance of the park in two ways. First, it played an important role in the selection of the park's location. Terrain changes are expensive; therefore, the parks' locations were selected to minimize these costs.

However, even the most suitable terrain was not left unchanged. The existing conditions of the parks were, therefore, actively created. This confirms the hypothesis that terrain changes differ based on the natural topography, the function of the landscape change and the time at which the changes were made. Therefore, the three assumptions explained above are closely intertwined. The analysis showed that the function of the landscaping was a fundamental factor at the time of the selection and in the terrain changes made. Another factor was the land available to the developer from which he could then select a place suitable for the establishment of a park. Financial limitations were also a consideration.

4.1 Terrain changes according the function

Significant changes made to all of the studied areas and that are common in other built landscapes include artificially undulating areas. The method used to prepare the undulated areas was similar in all of the parks (1.7 km^2 in Jemčina, 0.5 km^2 in Petrohrad, 0.3 km^2 in Chudenice, 0.07 km^2 in Krásný Dvůr). The location was first made into a plane and then molded into the shape of a mildly undulating area. These undulating areas substantially reflected the original shape of the terrain: in flat, broad, flood-plains they are almost even; on slopes they mimic the topography, but their surface is rougher. Where the land was not fertile, the area being modified was covered with soil of higher quality. Nevertheless, at present, the areas look natural, and the challenges associated with the artificial modifications are visible primarily in the archival documents.

Ponds were either created simultaneously with the landscaping for the purpose of the park or pre-existing water features were incorporated into the park (2.4 km^2 in Jemčina, 0.03 km^2 in Petrohrad, 0.03 km^2 in Krásný Dvůr, 0.002 km^2 in Chudenice). To make new ponds, it was necessary to create a basin, and the excavated soil was used to construct dams. Similar methods were used in each location and differed only based on the size and shape of the pond and the robustness of the dam. In two cases (Jemčina and Petrohrad), an artificial island was made to rise above the pond basin.

Unlike with these features, the anthropogenic origins of the original leveled areas are apparent (0.04 km^2 in Jemčina, 0.04 km^2 in Krásný Dvůr, 0.01 km^2 in Chudenice, 0.01 km^2 in Petrohrad). However, these areas are not large. They were typically situated at the back of buildings because of the need to create a flat plane or to create a foundation for a structure. Often the leveled area exceeded the area of the building, emphasizing its role and relevance as a human artistic element. Some leveled areas were made only for practical purposes, such as to facilitate the management of vegetable gardens or tree nurseries.

In all of the gardens, a network of paths represented a substantial part of the terrain changes (90.5 km in Jemčina, 31.3 km in Petrohrad, 16.5 km in Chudenice, 15.7 km in Krásný Dvůr). The design of the network visibly reflected the configuration of the terrain. Usually these ways passed directly beneath surfaces with elevated edges. In wet areas, the ways were constructed raise slightly above the surrounding terrain. More landscaping work was needed to create paths on slopes: the surfaces of the paths needed to be leveled so that they did not slope down. Therefore, the foundations of the paths built on the slopes needed to be leveled in advance by digging out the upper part of the slope and moving the excavated soil to the lower part of the slope. Through this process, a terrace step was produced on which the path ran, slightly submerged in the step. Most of the ways were also slightly sloped and accompanied by one or two trenches.

4.2 Terrain changes and the natural topography

The methods used to make the terrain changes differed based on the differences in the natural topography, though this was not true for all types of changes. This difference is most striking with regard to differences in function. The natural topography influenced the appearance of the parks because the natural configuration of the terrain was used to the maximum degree, especially during the layout of individual sections, the overall composition of the parks and the laying out of the viewpoints and dominant features. However, the creators of the landscape parks did not reject relatively large terrain changes if these changes were not eye-catching and did not detract from the impression of a natural landscape.

The most outstanding divergence is the absence of terraces on the flat terrain of Jemčina. Other gardens used terraces, especially for orchards, gardens or vineyards (0.009 km^2 in Krásný Dvůr, 0.004 km^2 in Chudenice, 0.003 km^2 in Petrohrad). Their function was not only practical – terraces made it easier to cultivate the land – but also aesthetic. Similarly, drainage canals were only created in wet areas. Slopes were reinforced and steepened where needed; retaining walls were used (224 m in Jemčina, 189 m in Krásný Dvůr, 149 m in Chudenice).

The streambeds were altered to support or even create curves. Where needed, banks were reinforced to prevent them from being washed away and disrupting the river course. Boulders and small weirs were introduced into the streams to make the flow more dynamic (31.7 km in Jemčina, 4.4 km in Petrohrad, 2.3 km in Krásný Dvůr, 0.4 km in Chudenice). The artificial canals (12.9 km in Jemčina, 2 km in Krásný Dvůr, 1.1 km in Petrohrad) also resemble natural shapes but are usually straighter than the modified flows. Artificial canals were built to copy the stream through the addition of curves and grass banks. In some cases, the canals are accompanied by banks that separate them from the stream or slope and prevent inundation (2.1 km in Krásný Dvůr, 0.4 km in Jemčina).

Artificially made hills were used in flat terrain to enliven the scenery and introduce a dominant element. They were accompanied by major plantings and/or follies. An artificial hill could have a grotto, which would otherwise have been difficult to construct in a flat terrain. Some artificial hills, however, also had a practical function of protecting plantings against a high water table. Other rare structures included ha-ha trenches. Ha-has were relatively deep and distinctive terrain features. The wall of a ha-ha adjacent to the garden is steep and paved, while the other wall slopes gently and is covered with grass. The trench is visible only at a close distance, and it therefore does not disrupt the view and creates the illusion of open space. At the same time, it prevents wild and domestic animals from entering the park. Ha-has were used more often in flat terrain. None of these structures were built in the model areas.

4.3 Terrain changes after the main period of landscaping

Only minor differences between the terrain changes based on time of origin were found. The types of terrain changes made were similar throughout the period from the end of the 18th century until the end of the 19th century. Moreover, the methods used for their implementation were based on the terrain conditions, and the technology used remained the same. Differences were not visible until the 20th century, when the recreational function of the parks began to be emphasized. Completely new elements were introduced to the existing parks. These consisted chiefly of playgrounds (0.007 km^2 in Petrohrad, 0.0006 km^2 in Chudenice), which began to be built in the first half of the 20th century and which required the introduction of regular-shaped, leveled and consolidated areas.

Focusing on the mutual interaction between the influence of nature and human interventions and activities during the creation of the parks offers insights that improve our understanding of the current relevance and state of landscape parks. Understanding the relevance of topography and the sensitivity of the changes made to it can reveal how to best care for and maintain the parks and how their modern use should be limited to prevent irreversible damage to the gardens.

5. Conclusion

The study of landscaping and terrain changes is demanding because it requires detailed research of the literature; the context of the sources, including their critique and interpretation; and detailed terrain surveys. The analysis of the historical maps using GIS is also indispensable. Landscape parks are specific sites in which the influence of natural conditions is integrated with deliberate human interventions. What is unique about them is that people strove to integrate these human changes into the natural topography, and a layman often fails to recognize these changes. This contributes to a pleasant impression of the landscape park, but there is also a risk that the deliberate changes to the terrain will be underestimated. In fact, the protection of parks often emphasizes the protection of the park's composition, valuable trees, and/or places that are botanically or zoologically valuable. Topography and configuration of the terrain are usually not considered elements that need to be protected. Nevertheless, insensitive changes to a landscape park, e.g., by creating a golf course, may, despite preserving the composition and precious organisms, constitute a complete degradation of the park. Terrain changes are a more permanent part of landscaping, though even these suffer from degradation and lose their outstanding and characteristic features if left unattended. Nevertheless, they can be easily identified, even when the composition is difficult to recognize and the trees have aged considerably.

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RESUMÉ

Terénní úpravy v krajinářských parcích.
Případová studie z černínských parků v Čechách

Krajinářské parky a v širším smyslu komponované krajiny jsou specifickou součástí kulturní krajiny a významným kulturním dědictvím. Českým i zahraničním krajinářským parkům je věnována řada titulů, jež detailně popisují jednotlivé objekty. Zaměřují se především na kompozici zahrad a parků a na významné dřeviny. Parky jsou rovněž zkoumány jako významné komponenty cestovního ruchu či v souvislosti s ochranou přírody. Při studiu historického vývoje zahrad a parků jsou nejčastěji využívány staré mapy, které jsou poměrně jednoduše přístupné. Ostatní typy pramenů, zejména prameny písemné a obrazové, jsou využívány podstatně méně často. Příspěvek na základě detailního studia všech typů pramenů a terénního výzkumu charakterizuje terénní úpravy, jež byly prováděny v krajinářských parcích, což je téma, kterému zatím nebyla věnována systematická pozornost. Modelovými objekty jsou parky rodiny Černínů z Chudenic v Krásném Dvoře, Jemčině, Petrohradě a Chudenicích. V krajinářských parcích byly mnohdy prováděny poměrně značné terénní úpravy, které však měly evokovat přirozený terén. Prováděné terénní úpravy závisely na původní přírodní modelaci reliéfu. Byla snaha nákladné terénní úpravy minimalizovat, proto byl pro park vybírán pokud možno vhodný terén a úpravy se mu přizpůsobovaly. Každý z vymezených typů terénních úprav vyžadoval specifické terénní práce. Plošně nejrozsáhlejším typem byla tvorba zvlněných povrchů, téměř každá louka byla takto uměle upravena, byť louky velmi zdařile evokují přirozený terén. Dalšími častými terénními úpravami bylo budování cestní sítě, úprava koryt potoků, tvorba nových vodních příkopů a tvorba zarovnaných povrchů u budov a školek dřevin. Méně plošně rozsáhlé, ale časté byly hráze, náspy a valy. Terénní úpravy tvoří neoddělitelnou součást identity krajinářských parků a zasluhují tak stejnou ochranu jako kompoziční hodnoty či staré dřeviny.

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WHAT CAN A CITY DO FOR ITS IMMIGRANTS? THE STRATEGIES OF LOCAL GOVERNMENTS IN FRANCE

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ABSTRACT

As the proportion of immigrants among the inhabitants of today's cities is growing, they have to find and form new bonds and social relations once established in their new place of residence. Their integration into the majority society can be significantly facilitated by policies implemented in their favour by local governments. This paper evaluates and compares the practices in two different French regions: in the capital of Paris and in the towns of the rural region of Basse-Normandie. The research has shown that the attitude of town halls in the cities studied is significantly influenced by the size of the immigrant population, how long it has been in the city and its composition, as well as by the political persuasion of the city leaders. The most striking difference between national level policy and that implemented in daily practice was found in the city of Paris. In the region of Basse-Normandie there was also a statistically significant correlation between the helpful attitude of the city government to the immigrants and the activity of immigrants themselves, as shown by the number of local non-profit organizations founded by immigrants. The French experience can serve as a lesson and an inspiration for cities in other parts of world.

Keywords: integration of immigrants, local integration policy, France, Basse-Normandie, Paris

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1. Introduction

France is one of the European countries with the longest tradition of receiving immigrants and was long considered a model in terms of their integration (Freeman 1994; Pison 2010). The national government is always responsible for migration policy at the borders, but all migration ends up as a local government issue – and it is local councils that end up dealing with it (Travers 2015, in Casciani 2015). Which tools and measures do local authorities really use when supporting the integration of immigrants into mainstream society? The answer to this question will be looked at in this article, based on the analysis of the experience in two French regions: metropolitan Paris and the rural region of Basse-Normandie. These two regions are as distinct as possible in both the total number of immigrants living there (and their percentage in the total population of the region) and their socio-geographic characteristics.

2. The diversity of approaches to the concept of integration and the importance of the local dimension

The term *integration* is used by various researchers to describe both the process of integration itself and its results, even on different levels (individual-group-state).

At the level of the state, three main classical models can be distinguished. They differ in the conditions and possibilities which they give to the immigrants in the "new" country and in the im/possibility for them of being fully accepted in the society. *The Multicultural model* gives immigrants full rights and promotes their cultural differentness, which is considered to be valuable (Sweden, Canada). In the *differential exclusion model* (Germany, Austria) the immigrants are very quickly integrated into one or two domains of everyday life (most commonly in the labour market), but they are denied access to other ones (most usually to citizenship). *Assimilation*, applied in France, gives all rights to immigrants very quickly, but in exchange it is expected that they will give up their cultural distinctiveness and that they will in some degree "forget" where they come from. However, only few countries nowadays apply one of the above listed models in its pure form: states most commonly use a combination of the various approaches in different domains. This approximation of attitudes to immigrants gave birth to a model called *civic integration*, used in fact by the majority of western countries today (Baršová, Barša 2005; Lachmanová 2006).

At the level of individuals, integration is at the same time the *process* of integrating individuals (or groups) into the majority society, as well as the subsequent *outcome*. Integration as *process* means incorporating newcomers into an already existing society that has a certain structure. Heckmann and Schnapper (2003) defined four basic dimensions of the process of social integration: *structural* (gain of rights and access to memberships, roles

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Tab. 1 Main characteristics of the assimilationist model on the local level according to Alexander (2007).

Local policy		**Assimilationist**
Local authority attitudes toward labour migrants		Migrants permanent, but their otherness is temporary
Policy type and aims		Facilitate individual integration by assimilation into host society
Measures		Universalist (non-ethnic criteria); formal anti-discrimination mechanisms
Policy domain	***Issue area***	***Attitude of local government***
Legal-political	Civic status	Facilitate naturalization
	Consultative structures	Reject, or mixed (non-ethnic) advisory councils
	Migrant associations	Co-opt or exclude migrant associations; delegation to migrant associations is implicit
Socio-economic	Social services (health, welfare, etc.)	Equal access to all services (ignore ethnic-based needs)
	Labour market	Anti-discrimination policy; equal access to vocational training
	Schools	Spatially dispersed; support for teaching the language of the majority society
	Policing	Depends on areas; migrants can join
Cultural-religious	Religious institutions/public practices	Institutions (e.g. mosques, religious school) and religious practices are not supported
	Public awareness	Campaigns against racism and discrimination
Spatial	Housing	Equal access to social housing; marginalization of discrimination based on ethnic criteria in access to housing
	Urban development	Ethnic enclaves are seen as a problem – the policy of their abolition; policies of gentrification
	Symbolic use of space	Against clear and physical representation of differences (e.g. a mosque yes, but without a minaret)

Source: Alexander 2007, pp. 40–45.

and positions in the key institutions of the host society), *cultural, interactive* (personal participation of immigrants in relationships in the host society) and *identification* (the sense of belonging to the majority). This *process* is necessarily two-sided: for immigrants, it means learning about the new culture, the acquisition of rights and duties and gaining access to positions in society and to social status; while for the host society it means opening up institutions and ensuring equal opportunities for migrants. Seeing integration as the *resulting state* usually relies on the idea of immigrants occupying similar positions in the society as the members of the majority society. This makes possible to measure the success of particular integration policies, by comparing the values of selected indicators between the majority and immigrant populations.

However, the process of integration of immigrants into the host society always has a strong local (and especially urban) dimension. From the historical point of view, it was big cities with strong economies that had the most experience with integrating diverse and culturally enriching populations (Borkert et al. 2007), thus serving as "machines of integration". Therefore, "the integration of immigrants takes place at the local level" (Bosswick, Heckmann 2006, p. 17). The city administrations may act "only" to implement national integration policy or, on the contrary, they may have considerable autonomy and independence in both finance and opinion (Borkert et al. 2007). The processes and the structures working in a place are, of course, heavily influenced by policy at higher levels, i.e. counties/regions, states or even by supranational organizations such as European Union (OECD 2006). However, everyday practice in the implementation of laws and regulations at the local level always provides some space for municipalities' own reading. Everyday practice also includes other actors working in the locality, who add to local integration policy some of the aspects which the local government does not pay attention to. Most commonly, local authorities cooperate with non-governmental organizations (NGOs), which provide social and legal assistance to the immigrants, but this can also involve (for example) employers, trade unions or local labour offices. However, the attitudes and everyday practices of municipal councils and their administrations are the most important and they have a significant influence on the results of the process of integrating immigrants into the host society. The type of migration coming to a city defines the attitude of municipality to integration policy and determines whether integration is a key or marginal priority within the issues solved (Bosswick, Heckmann 2006).

Since integration is a two-way process, immigrants play an important role. Complete knowledge of all aspects of the local environment allows local leaders to easily identify specific problems that migrants may face. The powers of authorities give them the opportunity to undertake actions that will facilitate the life of immigrants (Drbohlav 2005), adjusted to the group concerned (refugees, economic migrants etc.) (OECD 2006). The interest of cities in creating a good and functional integration strategy is strongly motivated by the fact that if the integration does not work, the city will pay a high price, for example in the form of spatially segregated areas (Borkert et al. 2007).

A classification of policies implemented by local authorities within the above state models of integration was carried out by Alexander (2007). To the three main models at the national level (see above) he added a fourth one, *making no policy*. He did not however consider the model of civic integration: he ranked the two main components of this model (i.e. courses in the language and everyday culture of the majority society) among the elements of the model of local multicultural policy. He then assigned – for each of these four models of local integration policies – the main types of non/action of local governments in four key areas: legal-political, socio-economic, cultural-religious and spatial. The main characteristics of the assimilation model at the local level can be seen in Tab. 1. This shows how the policies of local governments in France should work if acting according to national policy. Given the fact that this is one of the few theoretical perspectives (if not the only one) that assigns to the traditional national models of integration specific characteristic of supposed behaviour of local governments (and hence makes it possible to compare them), we used it as a theoretical basis for our research.

3. Methodology

All the above inspired our research, conducted between 2007 and 2011 (Seidlová 2012). The research questions which we sought to answer were as follows:

1) Is there any difference in the approach of local governments to immigrants, even if they are acting within the same national model of integration of immigrants? Does this difference depend in some way on the proportion of immigrants in the total population of the city and/or on the composition of the immigrant population?

2) If there is a difference in the approach to immigrants, does it also depend on the type of socio-geographic environment, e.g. will be there any difference between a town in a rural region and a big metropolis?

3) How much do the local councils really know "their" immigrants and their specific needs?

4) At what moment does the local government start to be aware of the need to participate actively in the process of integrating immigrants? When do they start to deal with the integration of immigrants? What tools and measures do they use?

The hypotheses to be tested were then formulated as follows:

1) The way local councils implement national integration policy varies depending on the context in which they act: the higher the proportion of immigrants in the total population of their city, the greater is the awareness of the need to deal with immigrant integration.

2) The process of integration of immigrants achieves better results in those places where there is a higher concentration of immigrants.

3) Better knowledge of local conditions allows local governments to better formulate specific projects which aim to promote the integration of immigrants into the host society.

4) The tools and measures used by local governments in rural and metropolitan areas are quite similar; the only difference is the extent.

With the following clarifications:

ad 1) awareness meant in the sense of the knowledge that something exists, and verified within semi-structured interviews and hence set on a three-level scale according to the understood need to deal with immigrants in the city/city district;

ad 3) the local officials have a better knowledge of local conditions than state officials would have.

In order to confirm their validity or non-validity, it was necessary to select two regions in the chosen country (i.e. France), which vary in *the proportion of immigrants in the total population of the region* and in *the proportion of immigrants in the region out of the total number of immigrants* in France. We looked for both extremes: for the regions with the lowest and the highest values of these shares, under the assumption that cities in such regions will also meet the desired dichotomy *"city in rural area – metropolis"*. After analysing the available secondary data, the regions of Île-de-France and of Basse-Normandie appeared as most appropriate. The region of Île-de-France had to be narrowed to one city, so the choice of its capital, *Paris*, where in 1999 24.1% of all immigrants in the region lived was obvious (INSEE 2006). Almost half (41.0%) of immigrants in the region of Basse-Normandie lived in only seven cities: *Caen, Hérouville-Saint-Clair, Cherbourg-Octeville, Flers, Alençon, Argentan* and *Lisieux*. These seven cities and 14 friendly city districts out of the total 20 in Paris (see below) were further explored.

Besides the analysis of secondary data and participative observation, semi-structured interviews were used to gather information. We interviewed 39 representatives of cities/city districts and representatives of NGOs on 22 questions, divided into three main areas: *The relationship to national immigration policy, the migration situation in the municipality* and *the role of municipal government in the integration of immigrants*. The composition of respondents was as follows: 15 representatives of NGOs (8 with national scope, 7 local to Basse-Normandie); 15 representatives of districts of Paris and of the city of Paris (only 14 persons in 14 districts out of 20 agreed to be interviewed: in the 1st, 2nd, 3rd, 5th, 8th, 10th, 11th, 13th, 14th, 15th, 16th, 17th, 18th and 19th districts, and 1 person from the Paris Town Hall); 9 representatives of the seven studied cities in Basse-Normandie, i.e. Caen, Hérouville-Saint-Clair, Cherbourg-Octeville, Flers, Alençon, Argentan and Lisieux (in Hérouville-Saint-Clair and in Flers the main representative of the city invited one of their colleagues to join us). The representatives of municipalities (cities/city districts) were elected officials, most commonly deputy mayors, and were responsible for the integration of immigrants, social cohesion etc. (the title and responsibilities of the role varied from town to town and this became one of the factors which we studied).

The attitude and the un/friendliness (or un/helpfulness or un/quality) towards immigrants of each of the town halls studied – as well as the comparison between them – was then evaluated using our own methodology (Seidlová 2012). This comparison consisted of five steps, including links to other data (i.e. not only the data acquired from semi-structured interviews):

Firstly we described the immigrant population of each city/city district using secondary data sources. The first ranking was hence created: the city/city district with the highest proportion of immigrants ranked first.

Secondly we evaluated the factors that could potentially affect the form of local integration policy, with the choice of these factors based on existing theories and concepts of migration and migration policy. The institutional theory, looking for the influence which institutions and their leaders could have on the continuity of international migration and (in brief) stating at the same time that once institutions established it is impossible to stop migration (Massey et al. 1993), was the most inspiring, added to the considerable powers of French mayors towards the immigrants (see below). Only the following data were available in comparable quality for all the cities/city districts studied:

1) Political affiliation of mayors and their possible migrant origin. The political affiliation, i.e. if a mayor belongs to right-wing or left-wing party, was chosen even if due to the voting system in France (based on a huge list of candidates) political affiliation itself does not usually play such a significant role on the local level. However, we can still presume that elected left-wing mayors will be more welcoming and friendly to immigrants than their right-wing counterparts. We took the *Socialist Party* as the left-wing party; the *Union for a Popular Movement* and the *National Centre of Independents and Peasants* as right-wing parties, and the *Europe Ecology Greens* and *Democratic Movement* as more or less centre parties;

2) Possible migrant origin of others members of the city/city district council;

3) The areas that deputy mayors were responsible for;

4a) For Basse-Normandie: the existence of the city's own strategy addressing the issues of integration of immigrants; the presence and activities of nongovernmental organizations (NGOs) of both national and local scope) and by whom they were founded (majority society – immigrants);

4b) For Paris: the presence of an advisory body composed of immigrants from third countries (i.e. non-members of EU) – despite the fact that there should be such body in every district, it has been set up only in a few.

The ranking for each of these factors (i.e. 1, 2, 3, 4a, 4b) for the surveyed cities/city districts was then averaged, giving the second final ranking by other prerequisites for the implementation of "integration-friendly" policy.

The third step evaluated the data acquired from semi-structured interviews in terms of the policy tools used (number, nature). The nature of the tools and their un/friendliness (un/helpfulness) towards immigrants were judged according to Alexander's scale (2007): the most accommodating, immigrant friendly and helpful local integration policy is a multicultural one, assimilation is less responsive, discriminatory policy is less friendly and the last and least friendly is no policy (or *ad hoc* policy). This gave us the third ranking of the cities/city districts by their actual integration policy.

In the *fourth step*, the rankings of the cities/city districts were compared within the two researched regions using Spearman's rank correlation coefficient.

Finally, the results for Paris and Basse-Normandie region as a whole were compared.

4. Basic characteristics of studied territories

First of all, it must be pointed out that as our research was conducted between 2007 and 2011, the input data were those from the 1999 census, the most recent one available at the beginning of our research (INSEE 2011a). In French statistics, the most important division of inhabitants is according to their citizenship. A distinction is made between French citizens (French) and citizens of another state (foreigners). An immigrant is then a person born outside France with other than French citizenship and currently living in France. The difference and interference of terms used can be clearly seen from Fig. 1 below.

So, in *Paris* in 1999 there were 386,398 immigrants, who constituted 18.2% of all city residents. There were also 305,784 foreigners living there in the same year, making up 14.4% of all inhabitants (INSEE 2006). Among the city districts, foreigners represented more than 20% of inhabitants in districts 2 (21.5%) and 10 (21.2%), and districts 18 (19.1%), 3 (18.3%) and 19 (17.2%) also approached this level. At the other end of the scale, with percentages of around 10%, were districts no. 12 (9.8%), 15 (11.0%) and 5 (11.3%). So, the districts in the northern part of the city, on the right bank of the Seine (the "business" area of the city) had a larger proportion of foreigners in the total population as compared with districts in the southern part of the town, on the left bank of the Seine (the "intellectual" part of the city). Most immigrants in Paris came from Algeria (38,691 persons, i.e. 10.0% of all immigrants), Portugal (34,549 persons, i.e.

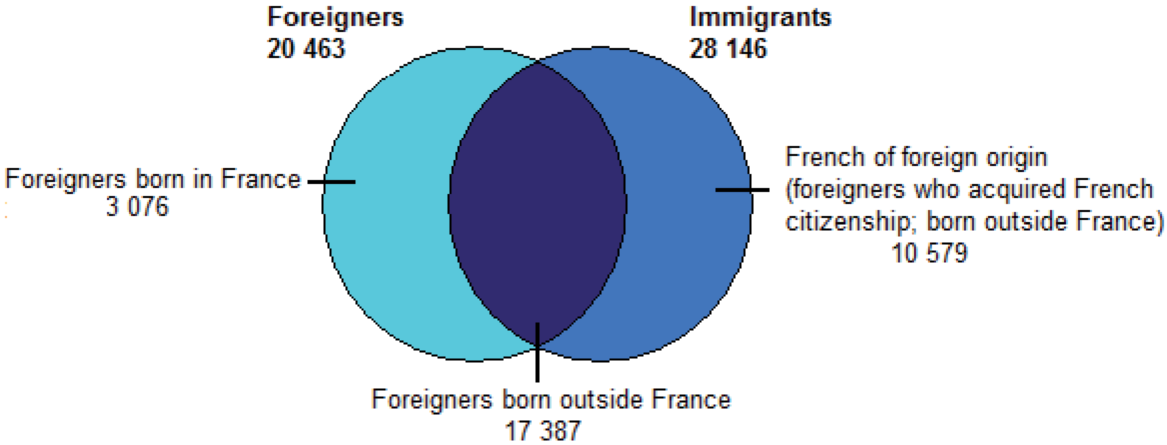

Fig. 1 Immigrants and foreigners in the region of Basse-Normandie in 1999. Source: INSEE 2006

8.9%) and Morocco (31,598 persons, i.e. 8.2%), Tunisia (29,343 persons, i.e. 7.6%) and Spain (17,197 persons, i.e. 4.5%): thus 39.2% of all immigrants in the city originated from these five countries (INSEE 2004).

In *Basse-Normandie*, situated in the northwest of France, there were a total of 28,146 immigrants in 1999 (see Fig. 1), making up 1.98% of all inhabitants of the region. Immigrants who were also foreigners born abroad came to 17,387, making up 1.22% of all inhabitants of the region. More than half of the immigrants in the region lived in the department of Calvados (52.5%; i.e. 14,774 persons), the other half were distributed quite evenly between two other departments of the region (Orne: 26.9%, i.e. 7,579 persons; Manche: 20.6%, i.e. 5,793 persons). Almost half of all immigrants (41.0%) in the region of Basse-Normandie lived in 7 cities: Caen, Hérouville-Saint-Clair, Cherbourg-Octeville, Flers, Alençon, Argentan and Lisieux. The largest in terms of numbers was the immigrant population in Caen, the administrative centre of the region (4,727 persons, i.e. 16.8% of immigrants in the region), followed by Hérouville-Saint-Clair (1,892 persons, i.e. 6.7%) and Alençon (1,648 persons, i.e. 5.9%). The cities with the largest percentage of immigrants in the population of the whole city were Hérouville-Saint-Clair (7.9% of the total population), Flers (6.2%) and Alençon (5.7%). So based on the significant presence of immigrants in them, these cities were selected as those whose local integration policies we would study. Almost half (45.3%) of the immigrants in the region came from five countries: Morocco (10.0%), Portugal (9.6%), Turkey (8.9%), Great Britain (8.5%) and Algeria (8.3%) (Blazevic 2005; INSEE 2006; Seidlová 2010; Seidlová 2012).

So how is the diversity of the immigrant population in the two regions studied reflected in the practice of their local integration policy? Are there also other factors that affect this policy? And what used to be the role of local governments in relation to immigrants from the historical point of view? When did the local councils start to be involved in this issue?

5. The interest of municipalities in immigrants on their territory: from the regulations set by higher levels of administration to their own activity

While there are attempts to increase the role of regions and departments in the integration of immigrants (the first such programmes date back to the 1990s), the main tasks have always been allocated to the municipalities.

The role of municipalities (towns) in relation to immigrants was shaped from the very beginning of immigration to France by regulations passed down from higher levels of administration – by the laws on the entry and residence of foreigners in France. These laws transferred to the municipalities responsibilities associated with registration, record keeping and supervision of foreigners (Seidlová 2012). Since 1888 the municipalities have to hold a special register of foreign residents, which list their number, family situation and profession (Pottier 1999). As early as 1913 the Prefect of the Seine-et-Oise department stated that right, correct and complex implementation of immigration laws relies primarily on mayors. The sudden arrival of foreign workers and associated administrative tasks surprised mayors, who had to play multiple roles at one and the same time: firstly, they had to inform those who were giving work to foreigners about their rights and obligations. Secondly, the mayors also had to defend the interests of such employers to other institutions or to assist them if they wanted to keep the situation of foreign worker illegal. On the other hand, the mayors also had to inform foreigners about their rights. Then, as guardians of order, the mayors were also asked to supervise and control the foreigners, by submitting periodic reports on the number of foreigners living in the village (town) and their employment to the prefecture of the department. Residence permits, as well as work permits for a specific place and work, were issued by police authorities, but the municipalities have been significantly involved in the process of preparing applications since 1920. The mayor had to carry out a preliminary investigation of a foreigner applying for a work/residence permit, assessing their francophone feelings, earnings, behaviour, morals and social contacts: this order corresponds precisely to the importance of the criteria considered. Among them, only the earnings were entirely objective, the others being fully dependent on the personal assessment of the mayor. The mayor then recommended (or not) (un)suitable candidates to the prefecture, which then awarded (or not) the desired permit. The prefecture also asked the mayors for their opinion if a foreigner was at risk of expulsion. In addition, the mayors had to deal with various applications from consuls requesting information about their nationals (Hubscher 2005).

The principles set in the early days of immigration control in France are, in general, still valid today. Municipalities also have a significant role in the integration of immigrants: the specific tools used will be introduced in the next section of this article. So even today, for example, an applicant for family reunification has to meet a number of conditions (length of residence, income, accommodation etc.) in order to be allowed to bring in members of his or her family. The application is then examined by the prefect of the department for a period of six months. Within this time, many different parties are asked for their views on the application, including the mayor of the municipality where the immigrant already resides or wants to settle. The municipal officials verify the income of the applicant and investigate the foreigner's accommodation – if the foreigner doesn't agree with this, the accommodation is automatically evaluated as unsuitable. This assessment has to be objective – the mayor cannot issue an adverse opinion based for example on the view that there are already many foreigners living in the area. The prefect may also require the mayor's opinion on a foreigner's "adherence" to the basic values of the French Republic or on the level of a foreigner's integration into the majority society. If the mayor does not respond within two months, he is considered to have agreed to the application (GISTI 2008; SP 2011; Seidlová 2012).

6. Tools and measures used by local integration policies

The above mentioned study (Seidlová 2012) examined in detail the practice of 22 town halls from different cities/cities districts. To show these practices in detail would however be beyond the possible extent of this article. So the findings obtained were summarized and divided into three major groups, according to the target population. The tools and measures presented are the ones which are really and actively in use by local councils and their integration policies in the surveyed cities/cities districts in Paris and in the region of Basse-Normandie. Information about them was acquired during semi-structured interviews with city officials. The research confirmed the validity of the hypotheses defined above, i.e. that *the tools and measures used by local governments in rural and metropolitan areas are quite similar; the only difference is the extent.* The number of tools and measures used by a particular city/city district can be derived indirectly from the final ranking of the particular city/city district as concerns real and implemented policy (see below Tab. 2 and Tab. 3). However, in the list which follows, we identify cases when a particular tool is used only in Paris or only in the towns in the Basse-Normandie region.

The first group of tools and measures are those that *target primarily the immigrant population,* ranked from the most commonly used ones to those less used in the cities/city districts surveyed:

- *Public declaration of support for diversity* or, in other words, a statement by the city leaders about fostering an open and multicultural society. For example, the town of Hérouville-Saint-Clair in the region of Basse-Normandie openly declares its support for local multicultural policy in the words of the deputy mayor responsible for the integration of foreigners, Mr. Simeoni Kouéta-Noussithe: *"Hérouville is a window open to the world. Our differences should be our pride. Our diversity is the sign of tolerant and friendly city."* (Seidlová 2012, p. 177). This openness is then also translated into the number of activities that city does for its immigrants;
- *An Advisory Body of the City composed of representatives of immigrants from third countries* (i.e. non-EU countries) which allows immigrants to express their points of views, wishes and needs;
- *Promotion of the right of foreigners to vote in local elections* motivates foreigners to participate actively in public life;
- *Support for non-profit organizations (NGOs) which help immigrants*, whether financially or materially or in the form of help with the organisation of multicultural events. Only in the towns in the region Basse-Normandie were such NGOs concentrated in 1–2 places (houses) in the city, which facilitated the access of immigrants to this kind of services;
- *Courses*
  - *Language courses,* i.e. the French courses provided by town halls for free or for a symbolic fee (e.g. in Paris for 40 euros per school year) and held in the evening;
  - *Literacy courses* for immigrants who come either from a culture which uses a different alphabet or who are even completely illiterate;
  - *"Everyday life" courses*, informing immigrants about how institutions are functioning etc.;
- *Preparatory classes in schools for children of immigrants* in Flers in the region of Basse-Normandie: their main aim is to teach French to children of immigrants;
- *"Parenthood" for foreigners including interventions at the prefecture* is a specific tool provided by French legislation. It means that the elected members of

municipal councils can intervene at prefectures (police offices) in favour of a particular immigrant through letters, personal meetings or by accompanying him to the meetings at the prefecture – and this intervention is really effective in many cases;

- *Organization of ceremonies at the town hall to celebrate the acquisition of French citizenship* in order to stress the importance and gravity of the moment when an immigrant becomes a French citizen;
- *Advisory places targeting their activity at traditionally marginalized groups of immigrants*, i.e. at women (only in the region of Basse-Normandie) and at seniors (only in Paris):
  - Two *"Clue for women"* were functioning in the city of Cherbourg-Octeville as places where women could come and learn French or ask for a French speaking assistant to help them in dealing with everyday issues in the town (doctor, post office, school, etc.);
  - "*Social cafes*" are aimed at older migrants so that they can meet each other in a relaxed atmosphere, attend educational or cultural programs or solve their particular problems (access to social benefits, pension, etc.) with the help of a social worker who works in this cafe;
- *Banners with the requirements of various social movements that defend the rights of foreigners*, displayed on the building of the town hall or other public institutions, a new tradition since about 2005 (only in Paris);
- *A grant scheme "Developing partnerships between Paris and the South"* is a special tool of Paris City Hall used since 2006 and hence used only in Paris. It gives financial support to selected development projects that aim both to implement a development project in a country of the global South and to integrate the immigrants coming from outside of the EU and living in Paris;
- *Restoration of common residences for foreign workers* takes place only in Paris, where there are 45 collective hostels for foreign workers mostly built in the 1970s. Besides improving the technical state of buildings and the quality of housing, rooms for providing specialized services for immigrants (such as legal, social and medical assistance or courses of literacy or of French) are also built;
- *Using the possibility of the mayor's right to examine the bride and groom* in order to detect marriage fraud is an instrument that is really not favourable to immigrants, but since some town halls in Paris use it, it has to be included here too (Seidlová 2012).

The second group of tools, *targeted primarily at the majority society*, is not so large in number, but it is the most visible to all, as these tools support projects that increase the awareness of the majority about the diversity of cultures present in the town. These may be of three types:

- *Multicultural festivals* that show elements of other cultures to the city's inhabitants, most commonly through performances by traditional music groups or by tasting typical foods;
- *Lectures, conferences, exhibitions, theatre and film performances* showing the country of origin of immigrants, their life in France or the life of immigrants in general;
- *Specialized libraries*, where one can borrow books related to migration issues (Seidlová 2012).

Last but not least come the third group of tools and measures *targeting all city residents* and promoting social cohesion in the city. These tools help all disadvantaged groups of inhabitants or promote the active participation of citizens in public life (Seidlová 2012). Among the very concrete tools we can mention for example:

- *Promoting equal access to all rights and all the services provided by the City:* in the case of immigrants this means that in Paris, for example, all major information booklets (about access to social housing, about services for seniors, about services for children under the age of 6, etc.) are translated into the most commonly spoken languages of the immigrant community (Arabic, Spanish, Turkish, Russian and English);
- *An Advisory Body of the City/District Council intended for all inhabitants* of the city/city district;
- *Financial and material support for NGOs* that provide legal and social assistance for free to all citizens;
- *Retraining courses held in the evening* and aiming to boost the success of unemployed citizens on the labour market (only in Paris);
- *Teams for school success for children from disadvantaged backgrounds* work in Hérouville-Saint-Clair in the Basse-Normandie region and help all disadvantaged families dealing with problems in school attendance (tutoring), family relationships, culture and health;
- Formulation of the *city's own social cohesion policy*;
- *Partnerships and cooperation with cities abroad,* which can be more formal (just a signed partnership) or more friendly cooperation on projects providing real results;
- *A special section in the local magazine* which presents two successful people who grew up in the city, at least one of whom is always of immigrant origin (only in the Basse-Normandie region);
- *A competition for lawyers for the best speech defending human rights* held in Caen in the Basse-Normandie region since 1989 is not *a priori* a tool of local integration policies, but on the other hand it shows the long-term human-rights-friendly approach of the city hall (Seidlová 2012).

As we can see from the above set list of tools and measures used in all three categories, the cities/city districts surveyed used many different tools and measures that aim to facilitate the life of immigrants and their

Tab. 2 Ranking of the districts of Paris according to the input assumptions about the nature of implemented local integration policy and by its actual form.

District	The ranking of the district in Paris by the percentage of immigrants in the total population of the district	The ranking of the district in Paris by the number of immigrants	The ranking of the district in Paris by other prerequisites for the implementation of integration-friendly policy*	The ranking of the district in Paris by policy implemented in reality**
2nd district	1	13	12	9
10th district	2	8	5	4
18th district	3	1	2	1
3rd district	4	12	11	5
19th district	5	2	4	2
11th district	6	4	1	6
8th district	7	11	14	11
16th district	8	5	10	12
1st district	9	14	7	14
17th district	10	6	8	3
14th district	11	9	3	8
13th district	12	7	9	7
5th district	13	10	13	10
15th district	14	3	6	13

Source: own survey 2008, as in Seidlová 2012

NB: * according to the criteria: Political affiliation of the mayor (right/left-wing party); Number of members of the city district council – of them those of possible migrant origin (% of total); Deputy mayor in charge of integration of immigrants; Existence of an advisory body of the city district council composed of immigrants from non-EU countries. ** i.e. ranking according to the "degree of multiculturalism" of implemented policy.

integration into the major society. However, the level of activity of local councils and the level of their friendliness (helpfulness) towards immigrants was very different in the monitored group. So the question now is: on which factors does this difference depend?

7. Factors influencing the helpfulness and friendliness of local integration policy

Due to the differences in the types of local governments compared (single cities in contrast to city districts), as already mentioned in the section on methodology, in each of surveyed regions slightly different factors that can affect the level of friendliness of local integration policy were examined. However, the results for the two examined regions may be concluded as follows:

As concerns the simple order (ranking) of the districts of *Paris* by the monitored indicators, the relationship between the percentage of immigrants in the total population of the district and the quality of implemented policy was fully confirmed only in one case (in district no. 11) and partially in two other districts (nos. 3 and 15) (i.e. the difference in ranking was "one" at a maximum). On the other hand, the relationship between the absolute number of immigrants living in the district and the non-friendliness of local integration policy was fully confirmed in six districts (numbers 18, 19, 8, 1, 13 and 5) and with a small deviation also in district no. 14, i.e. in a total of seven districts out of 14, so in exactly half of cases (see Tab. 2). The effect of other assumptions (i.e. of the political affiliation of mayor (right/left-wing party); the possible migrant origin of other members of the city/city district council; the deputy mayor in charge of integration of immigrants; the existence of an advisory body of the city district council composed of immigrants from non-EU countries) on the quality of implemented policy was not found at a significant level; playing a slightly bigger role only in the 10th and 16th districts. The mutual dependence between other assumptions for implementing a friendly policy and the number/percentage of immigrants in a given district was, however, entirely confirmed in the 5th district and partially in districts 2, 18, 3 and 19, i.e. in four cases in total.

Testing by Spearman's rank correlation coefficient, searching for correlations between the final ranking of a district according to the policy implemented in reality and all other rankings one by one showed a positive correlation in only one case at the chosen significance level (0.05): with the political affiliation of the mayor (right/left-wing party). The value of $r_{sp} = 0.7198$ was the only one of all detected values greater than the critical value of r_{sp} for chosen significance level and number of monitored subjects, i.e. 0.5341 (Tvrdík 2008).

It can be therefore concluded that in the studied metropolis, i.e. Paris, where the percentage of immigrants

Tab. 3 Ranking of cities in the region of Basse-Normandie according to the input assumptions about the nature of implemented local integration policy and by its actual form.

Town	The ranking of the city in region by the percentage of immigrants in the total population of the city	The ranking of the city in region by other prerequisites for the implementation of integration-friendly policy*	The ranking of the city in region by policy implemented in reality**
Hérouville-Saint-Clair	1	1	1
Flers	2	6	3
(town)	3	4	5
Caen	4	3	2
Argentan	5	5	7
Lisieux	6	7	6
Cherbourg-Octeville	7	2	4

Source: own survey 2008, as in Seidlová 2012

NB: * according to the sum of rankings according to the criteria: Political affiliation of mayor (right/left-wing party); Possible migrant origin of mayor; Number of members of the city council of possible migrant origin (% of total); Deputy mayor in charge of integration of immigrants; NGOs with national scope – number of branches; NGOs with local scope in the fields of human or migrant rights or humanitarian aid – number; NGOs with local scope – founded by immigrants – number. ** i.e. according to the resulting classification according to Alexander, where ad hoc policy was considered to be the least friendly to immigrants and multicultural policy as the most helpful and friendly; then the cities were ordered by the number of tools and measures used.

in the population varied from 11.0% (district no. 5) to 21.5% (district no. 2) in the studied districts, the most important factor in implementing a specified policy is the political affiliation of the district's mayor (right/left-wing party) and the other factors considered do not play such a significant role as we expected.

In the case of cities in the *Basse-Normandie* region, the relationship between the percentage of immigrants in the total population and the quality of implemented policy was confirmed only in two cases: in Hérouville-Saint-Clair and in Lisieux. The cities of Caen and of Cherbourg-Octeville in fact implemented relatively "better" policies than those expected according to the percentage of immigrants in their total populations while, on the other hand, the towns of Flers, Alençon and Argentan implemented "worse" policies (see Tab. 3). These differences may be explained mostly by other considered factors, such as the political affiliation of mayors (right/left-wing party); the possible migrant origin of members of the city council; the presence and activities of nongovernmental organizations (NGOs) in the fields of human or migrant rights or humanitarian aid; the promotion of culture of foreign communities and other factors.

Testing using Spearman's rank correlation coefficient, to search for correlations between the final ranking of a city in the region of Basse-Normandie according to the policy implemented in reality and all other rankings one by one showed a positive correlation in two cases at the chosen significance level (0.05): with the number of immigrants living the city and with the number of NGOs with a local scope founded by immigrants. Only in these two cases was the value of $r_{sp} = 0.821$ of all detected values greater than the critical value of r_{sp} for the chosen significance level and the number of monitored subjects, i.e. 0.745 (Tvrdík 2008).

It can therefore be concluded that in the rural region the activity and initiatives of immigrants themselves are the most important factors for the implementation of migrant-friendly policies, while the activity and initiatives of immigrants are likely to be greater when more immigrants live in the city. Dependence on other observed factors probably also exists, even if these other factors may not play such an important role as the two mentioned above; however, due to the small number of cities studied it was not possible to prove this statistically.

8. Conclusion

We have seen that not all surveyed cities and city districts use the tools and the measures that can help immigrants with their integration into the majority society to the same degree. In some cases we even found an inverse relationship between the percentage of immigrants in the total population of the studied city/city district and the number of tools used by local governments. This discrepancy was most striking when comparing the conurbation of Caen and Hérouville-Saint-Clair in the region of Basse-Normandie with the 1st district of Paris: the percentage of immigrants was 4.3% and 7.9% respectively compared to 13.7%, but among the studied cities, the cities of Caen and Hérouville-Saint-Clair were among the most active in the field of local integration policies, while the 1st district of Paris could even be described as hostile to immigrants (Seidlová 2012). The explanation for this contradiction can be found both in the activity of people from the local council, depending on their political affiliation to a right-wing or left-wing party (for Paris), and in the activity of the immigrants themselves (in the case of cities in the region of Basse-Normandie):

In the metropolitan area studied, i.e. in the city of Paris, the most important factor for the implementation of "immigrant-friendly" policy was the political affiliation of the mayor of a city district (left-wing party). Other considered factors – including a high percentage of immigrants in the population of the district, which ranged from 11.0% to 21.5% in our studied districts – did not play such a significant role as we had expected at the beginning of our research.

On the other hand, in the rural region of Basse-Normandie, the most important factors for the implementation of "immigrant-friendly" policy were the activity and the initiatives of immigrants themselves. At the same time, these activities and initiatives are likely to be higher if there is a greater number of immigrants living in the city. Other observed factors could also interfere in the nature of adopted policy, but they probably do not play such an important role as the two factors mentioned above, even if – due to the small number of studied cities – we cannot prove this statistically (Seidlová 2012).

The results of this analysis of the attitude of French cities towards immigrants, studying cities with both high and low percentages of immigrants in the total population, can be used as inspiration for concrete and specific tools of local integration policies in cities and towns in other countries of world. Even if the current composition of the immigrant population in each country is the result of that country's specific migration history, the basic principles of successful integration of immigrants into the majority society remain the same.

The specific tools and measures that are implemented should therefore respect the situation in the concrete city, town or region. Furthermore, they should also reflect the fact that local governments are not the only players in the field of integration of immigrants in an area, as the successful implementation of a chosen strategy is always the result of cooperation between a number of parties. The involvement of NGOs working with immigrants – founded by members of the majority society or by immigrants themselves – seems to be the absolute minimum. More appropriate is cooperation with other practitioners and representatives of local/regional offices of all possible state institutions when creating or implementing the chosen local integration policy. It is also desirable to include in this strategy from the outset the mechanisms through which feedback on the applied measures and tools will be collected from foreigners living in that place. This feedback is the only tool which makes it possible to see if the adopted strategy is working well and if not, to allow flexible changes according to the suggestions of immigrants.

Generally speaking, we should recommend that city administrations think in advance when drawing up a local plan about the possible arrival of large numbers of immigrant workers in the city and prevent their possible concentration, doing this by an even distribution of possible places for hostels for foreign workers or for social housing throughout the city and its boroughs. If, for example, a new factory is due to open within the city and if it seems that likely there will not be enough local inhabitants to staff this factory, the arrival of foreigner workers is more than probable and the local council should not hesitate to cooperate with the new employer. The local council should also participate in providing the accommodation for immigrants as well as in setting up new places to provide specialized services for them. At the same time, it is also important to inform local residents about the new and emerging situation.

If there are immigrants already living in the city, it is essential to carry out a thorough analysis of them (number, origin, age distribution, etc.) before beginning to prepare or adopt any strategy and actions in their favour. If the city lacks the capacity to provide immigrant-specific services (like legal or social counselling, language courses, etc.), it is advisable to set up a mechanism that will support local NGOs in doing so (or to collaborate with a NGO of national scope and help it set up a new branch in the city). Translating leaflets about the services provided by the city and the website of the city into the most commonly spoken languages of communities living in the city then ensures that immigrants are better informed about everyday issues and prevents them using the services of questionable mediator agencies.

And last but not least, every city council should continue to bear in mind the needs of people from the majority population, in order to prevent their feeling that the council is so immersed in combating discrimination and promoting diversity issues that it forgets the needs of other disadvantaged populations of its city.

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RESUMÉ

Co mohou města dělat pro imigranty? Strategie místních samospráv ve Francii

Mezi obyvateli současných měst mají čím dál větší podíl imigranti. V jejich začleňování do většinové společnosti jim přitom významným způsobem mohou pomoci politiky prováděné místními samosprávami. Byly vybrány dva regiony, které splňovaly požadavky jak z hlediska rozdílné velikosti podílu imigrantů na celkovém počtu obyvatel v nich žijících, tak z hlediska odlišnosti typu prostředí: velkoměsto Paříž (resp. 14 jejích obvodů) a sedm měst ve venkovském regionu Basse-Normandie (Caen, Hérouville-Saint-Clair, Cherbourg-Octeville, Flers, Alençon, Argentan a Lisieux). Ve vlastním výzkumu, realizovaném v letech 2007–2011, byly mimo sekundární analýzy dat a pramenů uplatněny mj. metody polostrukturovaných rozhovorů (se zástupci neziskových organizací a se zástupci obcí) a autorkou sestavený postup komparace lokálních integračních politik. Výzkum prokázal, že radnice zkoumaných měst/obvodů v praxi aplikují řadu opatření, která dle definice Alexandera (2007) spadají do modelu lokální multikulturní politiky. Postoj jednotlivých měst/obvodů k imigrantům byl výrazným způsobem ovlivňován nejen velikostí populace imigrantů, délkou jejího usazení ve městě a jejím složením (země původu, typ migrace apod.), ale také politickým přesvědčením vedení města. Dále se prokázalo, že samosprávy levicového smýšlení umí i v době panujících restriktivních zákonů přistupovat k imigrantům vstřícněji než samosprávy pravicové, což prakticky činily např. nevyužíváním všech možností, které jim tyto zákony dávají. V regionu Basse-Normandie se mimo závislosti prováděné politiky na celkovém počtu imigrantů žijících ve městě statisticky prokázala i závislost mezi vstřícností lokální politiky a iniciativou samotných imigrantů, vyjádřenou počtem místních neziskových organizací, které imigranti založili. Z pohledu konkrétních používaných nástrojů mohou být francouzské zkušenosti inspirativní i pro samosprávy v ostatních zemích světa.

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CHERNOZEM. FROM CONCEPT TO CLASSIFICATION: A REVIEW

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ABSTRACT

In this paper, we put together the most important facts that lead to the research on chernozem. Thanks to the work of V. V. Dokuchaev (1846–1903), chernozem stands at the forefront of pedology. In 1883, Dokuchaev introduced the first concept of chernozem: he defined chernozem as a steppe soil with pedogenesis dominated by a dry continental climate and steppe vegetation, with calcareous parent material. Chernozem is a soil well known for its high agronomical potential; therefore the perception of chernozem as something extraordinary valuable goes back far into history. Our review presents the key factors of the pedogenesis of chernozem by explaining the causes of the high stability of its organic matter and the role of vegetation and fauna in this process. Moreover, it shows that chernozem can have many aspects due to various (a) textures, (b) chemical compositions, (c) influence of water, (d) fauna, or (e) anthropogenic factors. We examine the position of chernozem in numerous national and international soil classifications over time. We have found out that chernozem had been classified, according to its properties, as a "steppe soil", as a "calcic soil" or as an "isohumic soil".

Keywords: chernozem, history of research, soil classification, Central Europe, literature review

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1. Introduction

Chernozem is an iconic soil. Because chernozem is a symbol of fertility, it has always been a centre of high interest for agronomists and pedologists. However, the perception of chernozem has varied over time and differs depending on pedological schools of thought and geographical location. The main objective of the presented work is to give a complete overview of the meaning of the term "chernozem" in pedology. Since V. V. Dokuchaev defined chernozem as a zonal soil formed under steppe and dry continental climates on loess parent material, the concept has been developed and reviewed.

In this paper, we present the main characteristics and features of chernozem. These are consequences of the soil formation processes, including long maturation of soil organic matter, steppe vegetation and intensive faunal activity. At the same time, we emphasize that behind the model definition of chernozem there is a wide range of soils included in the concept. We have therefore reviewed numerous soil classifications to see their perception on global and regional scales, with a special focus on the Czech national soil classification.

2. Chernozem: a long story of research interest

The term chernozem is derived from the ordinary Russian words chornyi – black and zemlja – soil. It means simply "black soil". The black colour is linked to its richness in organic matter. According to historical sources, the regions covered by black organic soils have always been described as fertile (Krupenikov et al. 2011). In literature, the "chernozem" was probably mentioned for the first time in 1645 by Salmon Gubert (Reintam 2001). At that time, the word "chernozem" was commonly used by farmers to designate black steppe soils (Boulaine 1989; Akonin 1771 in Kubiena 1953). In scientific literature, the term chernozem was used for the first time by the Russian scientist M. Lomonosov in 1765 (Krupenikov et al. 2011). Lomonosov used the term chernozem for both: the soil itself and the form of humus (Krupenikov et al. 2011). He believed that chernozems formed after the decomposition of plant and animal matter. Subsequently, various theories were constructed during the 18th and 19th centuries – theories that today have only a historical value (Prokhorov 1969–1978; Boulaine 1989; Krupenikov et al. 2011).

Great expansions of chernozems have always been a benefit for the concerned regions. In their report on a mission to Russia for the Geological Society of London in 1840, English geologists referred to chernozem by comparing its value to that of the coal mines in England (Boulaine 2005).

This context opened up a new era for research, triggered by the work of V. V. Dokuchaev (1846–1903). Indeed, the extensive research work on chernozems is directly responsible for the creation of a new science: pedology. This research work was the result of a request from the Free Economic Society of Russia. The aim of this

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research was to find out why some soils are fertile and the others are less so, for taxation purposes (Johnson and Schaetzl 2015). It was necessary to clarify the concept of chernozem. For a long period of time the agricultural land market had been distorted by speculators and swindlers who sold any kind of black soils, such as peat, rendzinas or vertisols, under the name of chernozem. The buyer, who thought he was buying fertile soil, was left with swamp or stony, dry land (Boulaine 1989). Dokuchaev spent several years on fieldwork in southern Russia. He studied and mapped the soils (Boulaine 1989; Hartemink et al. 2013). His thesis "The Russian Chernozem" was presented in 1883 in the University of Geognosy and Mineralogy in Saint Petersburg (Figure 1).

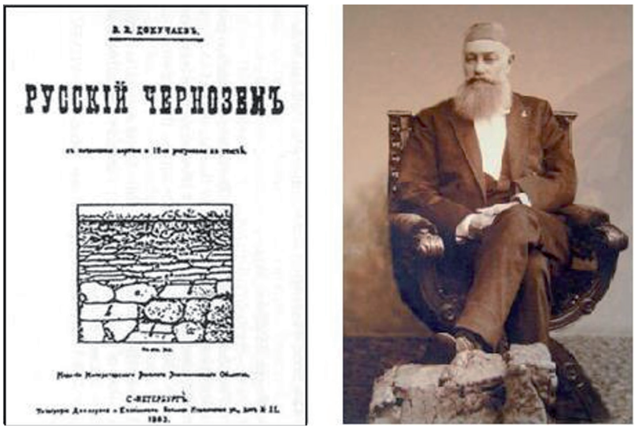

Fig. 1 The flyleaf of the thesis by Dokuchaev (1883) and a portrait of the author (taken from European Commission, 2005).

As part of his work, Dokuchaev (1883) developed in detail the holistic concept of pedology (Boulaine 1984). He described soil as a natural body, just like those of plants and animals (Boulaine 1989). Soil became the key component of biosphere and the best mirror of properties and of the history of surface areas (Pedro 1984). Dokuchaev (1883) formulated the concept of the soil profile and clarified the concept of genetic horizons as he observed them in the field. He identified five factors of pedogenesis: bedrock, climate, biological action, relief and time (Yaalon 1997; Boulaine 1984; Monnier 1966). Although he was a geologist, or because he was a geologist, he was able to show that the horizons are not strata. The presence of vast virgin, uncultivated areas allowed him to look at soil in its full complexity. He studied the topsoil, which is in the focus of agronomists (Monnier 1966).

Dokuchaev (1883) developed a theory that the organic matter of chernozems originated in terrestrial plants (Ruprekht, quoted by Prokhorov 1969–1978). He concluded that the formation of chernozems is related to the interaction between steppe vegetation, continental climate, topography and calcareous parent material. The richness in organic matter of chernozems is a consequence of the interactions between these factors. As these are zonal, the chernozem itself is also zonal. Thanks to his research on chernozems, Dokuchaev is the author of the theory of zonal distribution of soils on a global scale: each major bioclimatic region (currently called biome) is characterized by a dominant soil type. The formation of such dominant soil type is related to the action of climate and vegetation. This soil is called zonal soil (Boulaine 1989).

Therefore, chernozem has a fundamental role in pedology. It was the first soil that was properly studied and that received wide publicity. At the Paris World's Fair of 1900, Dokuchaev brought and displayed a block of several cubic metres of chernozem, which was admired by French farmers (Boulaine 2005). A part of this chernozem monolith is still kept in the French National Institute for Agricultural Research (INRA) in Grignon and Orleans. It was recently presented at the occasion of the 9th Journées nationales de l'Étude des sols in 2007. There are institutes of soil research named after V. V. Dokuchaev in Russia: the Dokuchaev Research and Development Institute of Agriculture of the Central Chernozem Zone in Voronezh and the V. V. Dokuchaev Soil Science Institute in Moscow. A museum dedicated to chernozem and a research station are located 20 km south of Kursk in Russia at the V. V. Alekhin Central Chernozem Biosphere State Reserve.

In 1880, E. W. Hilgard (1833–1916), an American pedologist and a contemporary scientist of Dokuchaev, edited the "Report on Cotton Production of the United States Census Report of 1880", which describes the soil regions of the USA (Boulaine 1989). He also commented on the zonal distribution of soils. In 1892, he published a report on the relationship between climate and soil. Hilgard classified the calcareous and non-calcareous soils. He gave a leading role in the storage of humus – especially in grassland soils – to the carbonate content, which was reassessed later by European authors who then opposed Dokuchaev (Boulaine 1989). Indeed, for Dokuchaev, it was the climate and herbaceous vegetation and not the carbonates that explained the richness of chernozems in the organic matter.

3. What is chernozem: definition and properties

Since Dokuchaev's studies on Russian chernozem, the given definition has been considered to be a reference group of soils with specific characteristics (Eckmeier et al. 2007). Chernozem is defined as a dark brown or black soil because of its richness in well-humified organic matter. The thickness of the organic layer is at least 40 cm. The base saturation, particularly in Ca^{2+} and Mg^{2+}, is high, while the pH is around 7; the aggregate structure is stable and the bioturbation is well expressed (Altermann et al. 2005; Němeček et al. 2001; Duchaufour 1977; Legros 2007). Chernozem develops on calcareous parent material, usually loess. Its formation is conditioned by bioclimatic factors: cold continental climate and dry steppe vegetation (Dokuchaev 1883; Duchaufour 1977; FAO/ISRIC/ISSS 1998). Chernozem is very fertile and valued for its high agricultural potential (Figure 2).

Fig. 2 A typical landscape of Eastern Ukraine of today in the region of Sumy. Chernozems are intensively exploited for agriculture. In the valley, there is a remnant of a steppe. Photo: B. Vysloužilová.

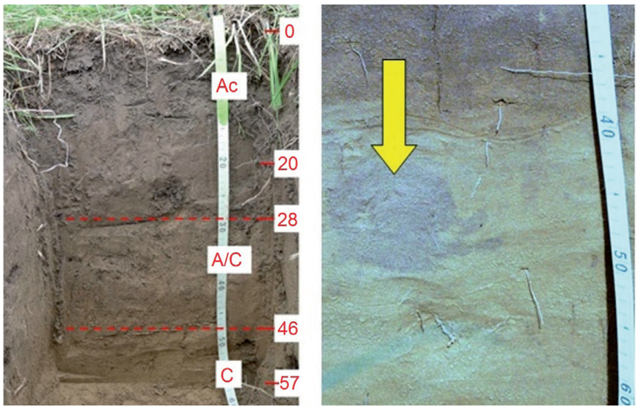

Fig. 3 Left: A modal chernozem profile in Gödölö Hills, Hungary. Right: Krotovina, marked with an arrow, a characteristic item for chernozem, remains of rodent burrows. In Bugac Puszta, Hungary. Photos: D. Schwartz.

A modal chernozem is presented in Figure 3. The A–C profile is characterized by a very thick topsoil horizon A. The organic matter content decreases slightly with depth (Kuntze et al. 1983, Duchaufour 1977). This phenomenon is defined as isohumism. The essential process of evolution of this organic matter is a long maturation of various humic compounds, called melanization (Mathieu 2009, Němeček et al. 1990). The transitional horizon between the topsoil and the subsoil is marked by abundant traces of macrofaunal activity, called *krotovinas*. Krotovinas are circular or linear forms (depending on the direction of the cut), which are old rodent burrows filled with soil (Parfenova and Yarilova 1967, Pietch 2013). A circular krotovina is clearly visible in Figure 3 (right). There are krotovinas in chernozem because rodents are very numerous in steppe regions. The bottom of the transitional horizon is a calcareous C horizon. In the C horizon carbonate is present in the form of white spots, usually called pseudomycelia (Mathieu 2009). They have a finely fascicular shape that follows the contours of the ancient rootlets where calcium precipitated. Accumulations may also take various forms (Khokhlova et al. 2001, Becze-Deák et al. 1997). The hardened concretions and nodules are called loess dolls (Duchaufour 1977, Barta 2014, Baize and Girard 2008).

The structure of chernozem is characterized by the formation of irregular crumbs. These aggregates are very stable and about the size of a grain of wheat. In cultivated chernozems, this structure is often destroyed at the ploughing horizon, where it becomes compacted (Duchaufour 1977; Głąb and Kulig 2008). The granular structure is conserved in the lower part of the A horizon, where the soil is not affected by ploughing. Moreover, the chernozem is predominantly a loamy soil (Chlpík et al. 2003; Eckmeier et al. 2007; Gorbunov 1974). The clay content in Russian chernozem varies between 15% and 20%. The nitrogen-rich plant debris is source of humus. The C/N ratio of chernozem is about 10 (Duchaufour 1977).

The most recent version of the WRB (IUSS Working group WRB 2014) defines chernozem as a soil with a chernic horizon. According to the WRB (IUSS Working group WRB 2014), the chernic horizon is considered as a diagnostic horizon. The chernic horizon is a relatively thick, well-structured blackish surface horizon, with a base saturation, a high biological activity and with a moderate to high content of organic carbon. Chernozem has a calcic horizon or a layer with protocalcic properties that starts in 50 cm below the lower limit of the mollic horizon. A calcic horizon or a layer with protocalcic properties can be eventually found above a cemented or indurated layer. The mollic horizon is defined as a structured surface horizon, dark in colour, with a high saturation base and moderate organic matter content. Consequently, a chernic horizon meets the criteria of a mollic horizon. The mollic horizon may be extended below the chernic horizon. The base saturation of the soil surface to the calcic horizon or to the layer with protocalcic properties is 50 percent or more, or when there are high concentrations of carbonates throughout the profile.

The definitions of the WRB (1998, 2006, 2014) are derived from the description of zonal chernozems that served as a reference for all chernozems. It can be difficult to assign soils called chernozems in the Central European classifications to the WRB (Nestroy 2007; Altermann et al. 2005; Zádorová and Penížek 2011). The Soil Taxonomic classification system of the Czech Republic (Němeček et al. 2011) describes chernozem as a soil with a chernic horizon (Ac) (30 to 60 cm thick) and an adsorbent complex of saturated and organic material content between 2% and 4.5%. The particle size distribution varies from sandy to clay. The parent material may be sandy loess, loess or marl. The main difference between the definition of chernozem given by the WRB (FAO/ISRIC/ISSS 2006) reference system and the Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2011) is the absence of criteria on the position of the calcic horizon in the profile and on the concentration of carbonates in the 50 cm below the lower limit of the mollic horizon (Zádorová and Penížek 2011). Zádorová and Penížek (2011) compared a soil population classified as chernozems under the Czech system with the WRB (FAO/ISRIC/IUSS 2006) system: 91% of the Czech chernozems fitted to the classification in the WRB 2006 system.

In general, the chernic Ac horizon is characterized by (a) ≥ 30 cm thick, dark colour (value and chroma ≤ 3.5 wet), (b) saturated or subsaturated adsorbent complex mainly of calcium, (c) base saturation rate ≥ 60%, (d) pH ranging from 6 to 8.3, and (e) intense polymerization of humic acids. Humic acids prevail over fulvic acids (humic acids/ fulvic acids ≥ 1.5). The humic acids are well stabilized (Němeček et al. 2001).

According to Němeček et al. (2001) again, the typical chernozem is characterized by Ac horizons: A/Ck – K – Ck under natural steppe vegetation and Ap – Ac – Ck under cultivated land. The A/Ck horizon is a transition between the chernic Ac horizon and the parent substrate. The K horizon is characterized by the accumulation of pedogenic $CaCO_3$ with a thickness of at least 15 cm. The $CaCO_3$ content is ≥ 15%. The difference between the $CaCO_3$ content of the K horizon and the horizon located just above is at least 5%. Accumulations of $CaCO_3$ are the size of clays or silts in the form of fine calcite (lublinite). Conversely, $CaCO_3$ is present as coarse crystals in the loess (Němeček et al. 2001). The Ck horizon is the horizon of carbonate alteration. There are secondary calcite accumulation traits, in the form of veins, nodules (Figure 4), or pseudo-mycelia. The Ap horizon is equal to the plough horizon.

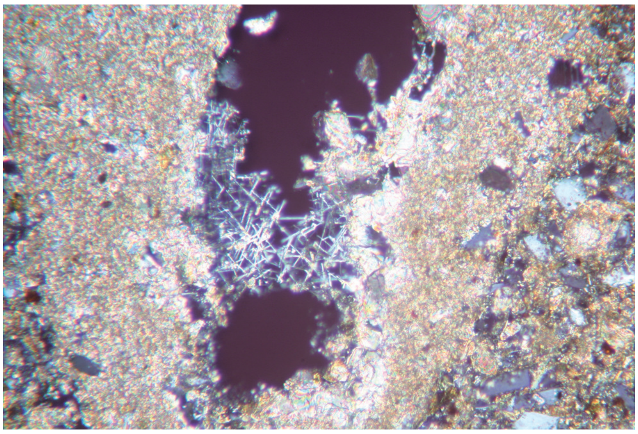

Fig. 4 The needle form of calcite in the calcic horizon in chernozem. The polarised light magnified 20×. The site of Hrušov, Czech Republic. Photo: A. Gebhardt.

4. Key pedogenesis factors

4.1 High stability of soil organic matter (SOM)

The main pedogenesis features of chernozems are the long maturation of soil organic matter (SOM) and the formation of weathering complex (Duchaufour 1977). The SOM is an essential functional component of the soil (Kögel-Knabner 2002). It comes almost entirely from the decomposition of plants and from the production of organic substances exuded by roots, but it is also partly composed of microbial mass (Guggenberger 2005). The SOM enters the soil through the root network or litter.

The humification and mineralization processes are controlled by the continental-type climate (Duchaufour 1977; Němeček et al. 1990; Kuntze et al. 1983; Phokhrov et al. 1969 to 1978; Fischer-Zujkov 2000). Seasonal climate fluctuations lead to the development of a specific soil climate. The best conditions for humification occur in spring and early summer, when soil moisture increases significantly due to the snow melting. The impregnation of water into the partially frozen ground causes temporary aerobic conditions, which are favourable to the accumulation and preservation of the water-soluble compounds produced in large quantities by the roots of steppe grasses. During the summer – the dry season – the humification process weakens. Indeed, in the dry season, as during the cold season, the activity of microorganisms is slowed (Bridges 1970).

The seasonal alternations result in the formation of molecules of high molecular weight, characterized by polymerization (condensed aromatic rings) and by high stability of the SOM revealed through a high mean residence time (MRT). The stability of humic acids in chernozems is recorded through the radiocarbon dating that gives the apparent "age" of the SOM. In general, the SOM is heterochronous – it is composed of fractions of different ages, ranging from days to millennia (Scharpenseel and Pietig 1970; Gregorich et al. 1994). In fact, the measurements of "age" through 14C show the life expectancy of the SOM: its average lifespan between an input through the decomposition of the fresh SOM and an output of the soil through mineralization. This result is called mean residence time (MRT) and it corresponds to the non-arithmetic mean of the ages of the SOM fractions (von Lützow et al. 2007). There is a strong MRT gradient with depth in chernozems. The average SOM decrease is 486.2 years for 10 cm of depth (Vysloužilová 2014). Němeček (1981) estimated this value for chernozems as 473 years for 10 cm of depth. When we compare this value with the data about other soil types in literature (Guillet 1979; Schwartz 1991; Scharpenseel and Pietig 1971; Ertlen 2009), we see that the MRT gradient for chernozems is among the highest values.

4.2 The role of vegetation and fauna

The characteristic steppe vegetation on chernozems offers special conditions for biochemical degradation (Phokhrov et al. 1969 to 1978; FAO/ISRIC/ISSS 1998 Fuller 2010; USDA 1999). The 70% to 80% of the plant biomass exists in the form of roots. The above-ground part of a plant does not provide much SOM as it decays, or is grazed, mowed or burned. Most of the SOM comes either from the decomposition of roots or root exudates.

Tab. 1 The soil classifications of the world and their principles. The main criterion used for the classification of "chernozem".

Soil classification		**Chernozem**	
Name and Author	**Principle**	**Name of Chernozem**	**Main classification criterion**
Soil Classification (Dokuchaev 1900; Russia)	Geographic and genetic	Chernozem	Steppe soil
Soil Classification (Vilenskiy 1927 in Segalen 1978; USSR)	Geographic, climate zonality	Chernozem (black soil)	Steppe soil
Soil Classification (6th International Congress of Soil Science (Ivanova 1956; USSR)	Bioclimatic	Chernozemic soils of steppes	Steppe soil
General Scheme of Soil Classification (Gerasimov and Ivanova 1958 in Segalen 1978; USSR)	Bioclimatic	Chernozem	Steppe soil
Soil Classification of the USSR (Tiurin 1965 in Segalen 1978; USSR)	Bioclimatic	Chernozem	Steppe soil
Systematic List of the Soils of the USSR (Rozov et Ivanova 1967)	Ecologic, genetic (bioclimatic)	Chernozem	Steppe soil
Historic and Genetic Classification of Soil of the Soil Map at a Scale of 1:5,000,000 (Kovda et al. 1967; USSR)	Tertiary and quaternary history of soils	Typical Chernozem	Steppe soil
Soil Classification (Volobuyev 1964; USSR)	Organic and mineral	Chernozem	Calcic soil
Categories of soils (Marbut 1927; USA)	Organic and mineral	Chernozem	Calcic soil
Soil Classification in the USA Based on their Characteristics (Baldwin et al. 1938; USA)	Morphologic and analytic characters of soils	Chernozem	Calcic soil
Higher Categories of Soil Classification (Thorp et al. 1949; USA)	Climatic (zonal soils) Mineral, hydric (interzonal soils)	Chernozem	Steppe soil
Soil Classification Project (Aubert and Duchaufour 1956; France)	Pedogenetic and morphologic	Chernozem	Calcic soil
Classification (Aubert 1965; France)	Pedogenetic and morphologic	Chernozem	Isohumic soil
Classification CPCS (1967; France)	Pedogenetic and morphologic	Chernozem	Isohumic soil
Référentiel Pédologique (Baize and Girard 2008; France)	Pedogenetic and morphologic	Chernosol	Reference group
Soil Taxonomy 1999, USA (USDA)	Objective	Order: Mollisols Suborders: Ustolls, Udolls, Xerolls	Isohumic soil
World Reference Base for Soil Resources IUSS Working group WRB 2014., 2014	Soil properties and morphogenetic processes	Chernozem	Reference group

The development of the root system to a great depth explains the thick organic impregnation of chernozems. The development of the root system is largely related to climatic conditions, with seasonal droughts requiring exploration of a large volume of soil by the plant.

The first study about the role of animals for the pedogenesis was already lead by Darwin in 1881 (Johnson and Schaetzl 2015). He described the way how soil animals like moles, susliks, marmots or worms work and aerate the soil (Figure 5). Their activities contribute to uniform the distribution of humus and to intensify the weathering of bedrock (Johnson and Schaetzl 2015). The activity of wildlife also enables a deepening of the chernic horizon (Altermann et al. 2005). The migration of clays is very low (Duchaufour 1977) because of the faunal activities and because of the high calcium content. The earthworms are important regulators of the SOM dynamics in the soil (Hong et al. 2011). Some species dig their burrows deep to protect themselves against drought and cold winters (Baize and Girard 2008). They contribute in this way to the redistribution of calcium in the soil profile (Lambkin et al. 2011). The witnesses of this biological activity are vertical earthworm galleries and krotovinas.

There is a decarbonisation of the material in environments with a high biological activity due to the very high CO_2 production. Calcium is dissolved in bicarbonate form because of the high pressure of CO_2. Consequently, calcium precipitates at the base of the profile, where the CO_2 pressure decreases. Then, a Cca horizon is formed (C carbonated) (Duchaufour 1977).

5. Classification

Chernozem is a major type of soil. Its name has remained stable since the first scientific descriptions, but its position in global and national classifications varies depending on the selected classification criteria.

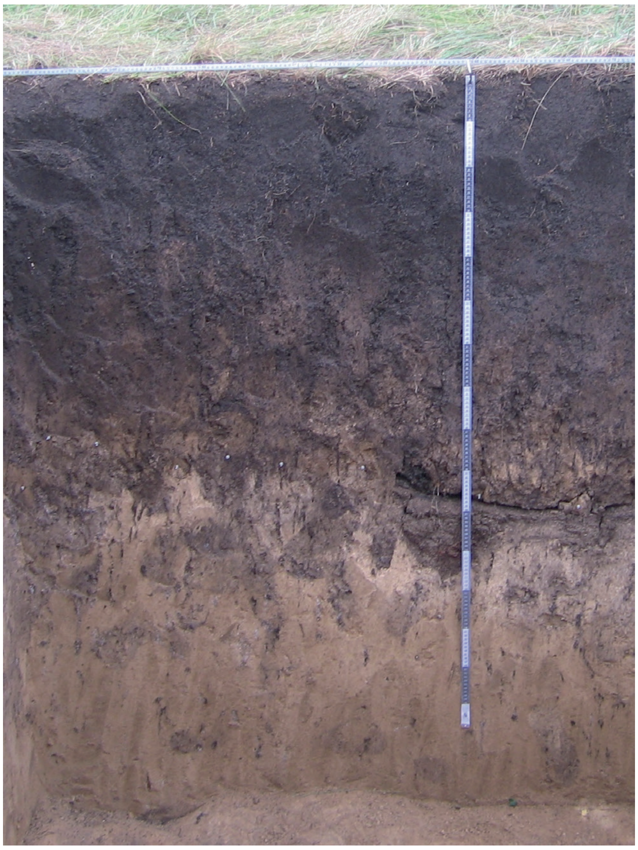

Fig. 5 Chernozem with a high biological activity marked by the vermic qualifier. Southern Russia, the region of Kursk. Photo: B. Vysloužilová.

Němeček et al. (1990) estimate that three national classifications have had a major influence on global soil classification: the Russian classification based on genetic-geographic principles, the French classification encompassing all soils in the world and based on morphogenetic principles, and the American classification based on a complex diagnosis. The World Reference Soil classification of the FAO/ UNESCO, which served as the basis for the global soil map (FAO and UNESCO 1972) is the only globally recognized classification. In each of these classifications, chernozem finds place depending on various criteria (explained below), but these criteria are not entirely disconnected from each other. The positions attributed to chernozem in various classifications are listed in the following table.

5.1 Chernozem: a "steppe soil"

The classification of soils created by Dokuchaev and presented in 1900 at the World's Fair in Paris (Pedro 1984) is based on geographic and genetic principles. There are three soil classes: Class A of normal soils (vegetal, zonal), Class B of transitional soils (intrazonal) and Class C of abnormal soils (azonal). Chernozems are part of Class A, where external phenomena (climatic and biological) are involved in soil formation. Chernozems are classed in Category IV: steppe soils. The classification of chernozems as steppe soils has persisted in subsequent Russian classifications. The climate is taken into account as a zonation factor through the thermal and moisture regimes (Vilenskiy 1927; Ivanova 1956; Gerasimov and Ivanova 1958; Tiurin 1965; Rozov and Ivanova 1967; Kovda et al. 1967; all quoted in Segalen 1978). The principle of zonation also appears in the American classification proposed by Thorp et al. (1949), which adopts the division into zonal, intrazonal and azonal soils from Dokuchaev (1900). The group of steppe soils is often shared with kastanozems (Ivanova 1956; Gerasimov and Ivanova 1958 quoted in Segalen 1978; Tiurin 1965; Rozov and Ivanova 1967). The classification by Kovda et al. (1967) groups chernozems with other arid to humid sub-boreal soils: humified alluvial soils, brunizems, light grey forest soils, grey forest soils and dark grey forest soils. Thorp et al. (1949) categorise chernozems with other semi-arid dark soils, sub-humid and wet meadows: chestnut soils and chestnut reddish soils, grassland soils and grassland reddish soils.

5.2 Chernozem: a "calcic soil"

Another point of view is a classification based on the organo-mineral characteristics. Thus, in some classifications, chernozem is classified according to its high calcium content. The calcium content as a classification criterion was used for the first time by the American soil scientist Marbut in 1927. In his classification, chernozem is a part of the group called pedocals (soils rich in calcium) that are present in mid-latitudes. This group also includes brown soils and grey soils. Baldwin (1938), in his classification of the soils of the USA, retains the concept of pedocals and categorises chernozems with chestnut soils, reddish brown soils, prairie soils and reddish grassland soils in the class of dark zonal soils of semi-arid, sub-humid and humid grasslands. The calcium content is used in the classification by Volobuyev (1964) where chernozem forms with sierozems and chestnut soils a group of steppe soils saturated with calcium. Aubert and Duchaufour (1956) introduced the concept of the evolution´s degree of the soil profile and the physicochemical nature of its evolution in their classification. The chernozem is placed in the calci-morphed AC profile class; it belongs to the subclass of steppe soils with chestnut soils and red brown soil, brown soil and red soil and soil crust.

5.3 Chernozem: an "isohumic soil"

Chernozems are remarkable for their high organic matter content. Aubert (1965) introduced the term isohumic soil in the soil classification in order to describe soils with relatively constant organic matter content over a large thickness (Segalen 1978). Chernozems share the class of isohumic soils with brunizems, brown soils, brown isohumic soils, brown soils and chestnut subtropical soils, sierozems and isohumic soils of pseudo-steppes. The concept of isohumic soils persists in the French classification established by the Commission of Pedology and Soil Mapping (CPCS 1967), which takes into account the physical, chemical and morphogenetic properties of soils. The CPCS sorts chernozems in the class of isohumic soils with a very cold soil climate together with chestnut soils and brown isohumic soils. Duchaufour (1970 in Segalen 1978) adapted this classification; three soil types form an isohumic soil group with a saturated complex. The USA soil classification from 1975 (the Soil Taxonomy) is based on the principle of detailed diagnostics of horizons in terms of their properties, and not of the environmental processes. A new terminology was created. The Soil Taxonomy introduced a term that encompasses active layer soils with thick topsoil, richness in organic matter and fertility. Mollisols are one of the major groups of the Soil Taxonomy, in which chernozems are integrated. In this way, they lost their traditional name. The second edition of the Soil Taxonomy (1999) keeps this system of classification. Soils with characteristics of chermozem can be found in different groups, especially udolls (IUSS Working group WRB 2014).

The WRB 2014 (IUSS Working group WRB 2014) world soil classification – created on the basis of soil properties and morphogenetic processes – made chernozems one of the 32 reference groups. Unlike in other classifications, they are clearly separated from kastanozems and phaeozems, which are separated reference groups on the same hierarchical level.

5.4 Chernozem in the European national classifications

Chernozem also appears in the national soil classifications of Central European countries (Table 2). The German classification from Kubiena and Mückenhausen from 1980 (Kuntze et al. 1983) Die Systematik der Böden Mitteleuropas places chernozem (Tschernosem) in the class of terrestrial soils (= well-drained soils), within the subclass of steppe soils. The Czech classification Taxonomický klasifikační systém půd ČR (Němeček et al. 2011) contains a reference class of černosol that includes two soils: černozem (chernozem) and černice (= gleyic chernozem according to the WRB 2006; Zádorová and Penížek 2011). The Slovak classification (Sobocká et al. 2000) Morfogenetický klasifikačný pôd systém Slovenska defines 10 groups of soils. The chernozem (černozem) forms, together with smonica (vertisols) and čiernice (chernozem gleyic), a group of Mollic soils. The Austrian classification Systematik der Böden Österreichs defines a class of terrestrial soils: raw humus soils with developed A–C, where there are chernozems (Tschernozem), trunk chernozems (Rumpf-Tschernosem) and brown chernozems (Brauner Tschernozem) (Nestroy et al. 2011). The Hungarian Soil Classification System (Szabolcs et al. 1966) defines a group of chernozems that includes five subtypes. The correlation between the chernozem defined by Szabolcs et al. (1966) and the WRB is not obvious: leached chernozems do not meet the criterion of colour and rather correspond to kastanozems, meadow chernozems correspond to chernozem gleyic, terrace chernozems meet mollic fluvisols (FAO/ISRIC/ISSS 2006; Micheli et al. 2006).

Tab. 2 Chernozem in Central European soil classifications.

Country	Name and Author	Name of chernozem
Czech Republic	Taxonomický klasifikační systém půd ČR (Němeček et al. 2011)	Černozem
Slovakia	Morfogenetický klasifikačný systém Slovenska (Sobocká et al. 2000)	Černozem
Germany	Die Systematik der Böden Mitteleuropas (Kubiena and Mückenhausen 1980 in Kuntze et al. 1983)	Tschernosem
Austria	Systematik der Böden Österreichs (Nestroy et al. 2011)	Tschernosem
Hungary	Genetikus Talajtérképek (Szabolcs et al. 1966)	Csernozjom

6. Variety of Chernozems

There are many subtypes of chernozems which are described with various qualifiers. The fundamental isohumic character of chermozems is preserved. There are also secondary features, which reflect the interference of basic and of physicochemical processes that are typical for another type of soil (Duchaufour 1977). We have compared the subtypes represented in the Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2001; Němeček et al. 2011) and the subtypes defined by the WRB (IUSS Working group WRB 2014). In some cases, we have picked out an equivalent or related subtype from another classification system.

The diversity of chernozems is underlined in the most recent classifications. The number of defined subtypes varies depending on the year of publication, the author and the geographical extension of the use of a classification system. The Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2001) identified six subtypes: modal, luvic, hydromorphic, arenic, pelic, and vertic. In the latest version of the Czech soil classification (Němeček et al. 2011), two additional subtypes appeared: carbonated and anthropic. The WRB of 1998 (FAO/ISRIC/ISSS 1998) defines only three subtypes of chernozem: calcic, cambic and argic. The WRB of 2006 (FAO/ISRIC/ISSS 2006) set several qualifiers. Some of them are expressed by following prefixes: voronic, vermic, technic, leptic, vertic, endofluvic, endosalic, gleyic, vitric, andic, stagnic, petrogypsic, gypsic, petroduric, duric, petrocalcic, calcic, luvic, haplic, anthric, glossic, tephric, sodic, pachic, oxyaquic, greyic, skeletic, arenic, siltic, clayic, and novic. These are used in a higher hierarchical level. The other qualifiers are expressed by suffixes that are used in a lower level: anthric, glossic, tephric, sodic, pachic, oxyaquic, greyic, skeletic, arenic, siltic, clayic, and novic.

The most recent WRB (IUSS Working group WRB 2014) defines 15 principal qualifiers for chernozems: petroduric/duric, petrogypsic/gypsic, petrocalcic/calcic, leptic, hortic, gleyic, fluvic, vertic, greyzemic, luvic, skeletic, haplic; and 25 supplementary qualifiers: andic, arenic, clayic, loamic, siltic, aric, cambic, colluvic, densic, fractic, hyperhumic, novic, oxyaquic, pachic, ruptic, endosalic, sodic, stagnic, technic, tephric, tonguic, transportic, turbic, vermic, vitric.

The correlation between the term chernozem (IUSS Working group WRB 2014) and the Soil Taxonomy (USDA 1999), used principally in the United States of America, is not obvious because these classification systems are constructed differently. A clear accordance is rather rare between these two classes. The USDA classification takes into account also the water regime and the soil temperature. There are varieties of chernozems included in some suborders of mollisols, like udolls, ustolls, rendolls or xerolls, depending on the soil temperature and on the moisture regime. At the same time, not all the soils classified in these suborders must correspond to a type of chernozem (IUSS Working group WRB 2014). Mollisol is a name for a very dark colored, base-rich, mineral soil of the steppe with a mollic epipedon. Below the mollic surface horizon, there can be a cambic, calcic, natric or argillic horizon. The presence of another horizon or a special feature is indicated by the prefix to the suborder name: natri-, calci-, argi-, pale-, duri-, verm-, hapl- (USDA 1999).

6.1 Description of principal subtypes

A typical chernozem of Central Europe (Němeček et al. 1990; Mathieu 2009) matches by its characteristics with calcic chernozems (FAO/ISRIC/ISSS 1998). The thickness of this chernozem is between 50 cm and 100 cm. There is a horizon with a concentration of secondary carbonates (calcic horizon). The $CaCO_3$ accumulations are in the size of clays or silts (Němeček et al. 2011). The Soil Taxonomy (USDA 1999) also admits the presence of a calcic horizon in mollisol with a mineral horizon, that is marked by a prefix calci- in the name of the soil.

When there are not carbonates concentrated in one layer but there are residues of carbonates in the whole profile, Němeček et al. (2011) defines it as carbonated chernozem. The origin of the carbonates is not specified. The WRB 2014 (IUSS Working group WRB 2014) does not apply a qualifier to refer to this feature. However, a subtype of chernozem with carbonates of a secondary origin along the whole profile is defined for example in German soil classification – *Kalktschernosem* (Altermann et al. 2005) – or in the French soil classification – *chernozem anacarbonaté* (Baize and Girard 2008).

There are two subtypes of chernozems which differ from the modal one by the textural composition. Vertic chernozem (IUSS Working group WRB 2014; Němeček et al. 2011; Duchaufour 1977) is characterized by its high content of swelling clays, which causes the formation of shrinkage cracks in droughts. It is located in lowlands, where fine clays were deposited by water in the periods of flooding (Duchaufour 1977). Němeček et al. (2001) say that vertic chernozem is very difficult to distinguish from pelic chernozem (Němeček et al. 2011). Arenic chernozem is characterized by a high content of fine sands (Němeček et al. 2011; IUSS Working group WRB 2014).

Luvic chernozem (IUSS Working group WRB 2014) is defined as chernozem with a Bt (argic) horizon with clay-humus coatings on the surfaces of aggregates and on the walls of macro-porosity (Baize and Girard 2008). The leaching process is clearly expressed, but the chernic horizon is always present (Figure 6). This is a transitional soil unit between chernozem and luvisol (or albeluvisol). Luvic chernozem in the WRB 2014 corresponds to luvic chernozem in Němeček et al. (2011). The suborders of mollisols with a horizon rich in clay below the mollic horizon are marked by the prefix argic-. The suborders of mollisols, in which the argic horizon is thick or deep, are marked by the prefix pale-. Glossic chernozem is characterized by the tonguic transition between the Ac chernic horizon and the Bt horizon (IUSS Working group 2014).

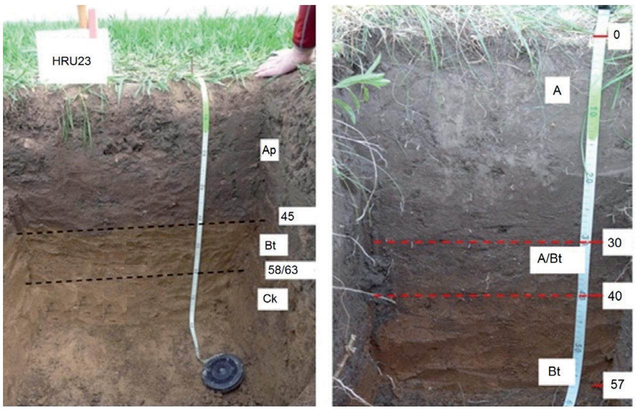

Fig. 6 Left: Luvic chernozem in Hrušov, Czech Republic. The A horizon is completely transformed by ploughing. Right: Luvic chernozem under the secondary steppe in Tard, Hungary. Photos: D. Schwartz.

Chernozem černická (hydromorphic) shows redoximorphic features in the first 60 cm of the profile (Němeček et al. 2001). The gleyic chernozem (IUSS Working group WRB 2014) shows signs of gleyic processes in the first meter of the profile depth. These two types of chernozem are formed in the areas influenced by the presence of a water table.

Cambic chernozem defined in the WRB 1998, 2006, 2014 is characterized by a structural horizon (Bw) between the A horizon and the C horizon (FAO, IUSS, ISRIC 1998, 2006; IUSS Working group 2014). The Bw horizon is characterized by a brownish colour and an absence of carbonates. In the Czech system, this horizon is called transitional A/Ck (Němeček et al. 2011). According to Altermann (2005), chernozem with a Bw horizon is also called decarbonated. There are clay coatings in a Bw horizon, but these are less important than in a Bt horizon.

This corresponds to chernozem with a structural horizon as defined by Baize and Girard (2008).

Němeček et al. (2011) introduce the subtype anthropic in the Czech soil classification. This subtype is defined as chernozem with an anthropic influence where the diagnostic horizons must be persevered, so it can be classified as chernozem. The anthropogenic factor was first introduced in the soil classification in the WRB 2006 (FAO, ISRIC, IUSS 2006). The most recent WRB 2014 differs the subtypes of aric, hortic and technic, which refer to the anthropic influence on the soil (FAO Working group WRB 2014).

7. Conclusion

This paper goes back to the beginnings of pedology as a modern science. The need of a scientific definition of chernozem lead V. V. Dokuchaev to his systematic research on this type of soil in the second half of the 19th century. However, the meaning of chernozem as something very precious and important goes much further into history. The common name for chernozem, that was originally used by people who worked on fields, penetrated amazingly into the scientific terminology around the world. The central concept of chernozem defined by Dokuchaev has been used and developed until now. Chernozem is a result of the process that has been going on for thousands of years. Chernozem is a thick soil of black colour, rich on organic matter, formed on calcareous parent material under specific conditions of the dry continental climate. Chernozem may have a large number of varieties, but the key factors of its pedogenesis are slow maturation and humification of the organic matter.

We have proved that the name of chernozem has a stable place in the soil classifications of different national and international systems. All of them refer to the main characteristics of chernozem: steppe environment, high organic matter content and carbonate content.

When we compare the definition of the central concept of chernozem and all the varieties of chernozem that there can be, we see how difficult it is to enclose the complexity of chernozem. Moreover, every soil classification sets artificial limits to the natural variety of any type of soil. We have to point out that the concept of chernozem is still being developed. Some recent studies show that chernozems could have even more nuances. The main character of chernozem can be resulting from some other pedogenesis cofactors like man and fire (Eckmeier et al. 2007), or chernozem is not necessarily only a product of a steppe environment (Vysloužilová et al. 2014).

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RESUMÉ

Černozem. Od pojmu ke klasifikaci: shrnutí

Černozem představovala vždy v historii díky vysokým zemědělským výnosům výjimečné bohatství. Proto se těšila odjakživa zájmu zemědělců, obchodníků a jako první půda se stala cílem podrobného vědeckého výzkumu. Díky práci V. V. Dokučajeva (1846–1903) se tak černozem octla u zrodu pedologie jako samostatné vědecké disciplíny. Článek pojednává o nejdůležitějších skutečnostech, které vedly k výzkumu černozemě, a také o jejích vlastnostech a způsobu klasifikace. V roce 1883 definoval V. V. Dokučajev ve své doktorské práci černozem jako půdu, kde hlavním půdotvorným faktorem je suché kontinentální klima, stepní vegetace a karbonátová mateční hornina. Definice černozemě se však postupně vyvíjela a byla upravována. Mezi hlavní půdotvorné procesy patří dlouhé vyzrávání organického materiálu, které způsobuje vysokou stabilitu půdní organické hmoty, a činnost vegetace a fauny. Černozem může mít mnoho podob v závislosti na rozdílné zrnitosti, chemickém složení, vlivu vody, fauny nebo činnosti člověka. Černozem má své stálé místo v národních i mezinárodních půdních klasifikacích. Nejčastěji bývá klasifikována mezi stepní půdy, karbonátové půdy nebo humózní půdy.

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ANTHROPOGENIC RIVER ALTERATIONS AND THEIR EFFECTS ON THE FLOOD SITUATIONS (BÍLINA RIVER CASE STUDY)

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ABSTRACT

This paper summarizes the results of research focused on the evaluation of anthropogenic impacts on the formation and process of the flood. The HEM-F methodology, partially modified and supplemented by identifying potential risk parts which during the floods could complicate the water convection, was applied on part of the Bílina River. During mapping were evaluated selected reaches of the Bílina River, and determined watercourse characteristics and the degree of anthropogenic river alterations. The conclusions of the research indicate that more than 50% of the river length shows no significant risk factors that could have influence on the development and flood events.

Keywords: flood, risk, HEM-F, Bílina River, river alteration

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1. Introduction

Floods and the related conditions of riverbeds, river banks or floodplain are actually a present theme. Recently several major floods have occurred in the Czech Republic during previous fifteen years. Among the most disastrous were the floods in 1997, 2002, 2009 and 2013. This issue about floods, their effect on landscape and society is actual in the Czech Republic, and is the main area of study for many authors (Brázdil et al. 2005; Brázdil, Kirchner 2007; Křížek 2008; Langhammer 2007b; Patera 2002; Šobr et al. 2008). The most emphasis is on the continuing occurrence of floods with historical and present anthropogenic river alterations (Kopp 2007; Langhammer, Vilímek 2008). The aim of research is to provide protection against the effects of flood events. As an example study results of analysis of relationships between stream direction and the geomorphological effects of floods in the case of the Blanice river basin in the Czech Republic on relationships between river alterations and the geomorphologic effects of floods in riverbeds and on floodplains (Langhammer 2010). The following text summarizes results of survey of anthropogenic activities in the landscape and riverbeds and the origin and course of the flood events (for full data of this research see Jelen 2015). The main objective is to analyze the kinds and grades alterations of floodplain, and evaluate positive or negative effects on floods. This evaluation also includes a methodology of field mapping of those riverbeds alterations. This methodology is based on already published and accepted methodologies of the Ministry of Environment specifically methodology HEM-F (Langhammer 2007a). However, differently of other existing methodologies, it is complemented by sub-elements. This concentrates on mapping a standstill state of the watercourse and identifying barriers to water flow and critical points that could be threatened if the water overflows the riverbed during a flood. The methodology has preventive character in compare with other methodologies (HEM (Langhammer 2007a), MUTON (Langhammer 2007b)) that focuses on mapping the effects of floods. The methodology was tested by mapping section of the Bílina River. This river was intentionally chosen because it is located in the Ústí nad Labem region, which is heavily influenced by anthropogenic activities. Studies have been conducted in the past (Dvořák, Matoušková 2008; Vlasák et al. 2004, Havlík et al. 1997 or Kyselka 2010), which confirmed the significant anthropogenic river alteration. The differences between author's approach and mentioned works will be present in other part of this text.

1.1 Flood formation and process

There are many factors which are influencing the occurrence of the floods. One of the main factors is the weather situation, exactly rainfall (Brázdil et al. 2005). River basin also has its specific properties that contribute to the retention or drainage of water (interception, detention, infiltration, river network volume and the volume of inundations) (Matějíček, Hladný 1999). In evaluating the factors influencing the course and consequences of floods should be considered not only the riverbed but the overall condition of the landscape. It should take into account the soil profile, terrain depression, vegetation and wildlife corridors. Retention and storage elements on the landscape can have a surface, line or composite character. All of these elements are called the water retention capacity of the landscape (Soukup, Hrádek 1999; Benitob et al. 2008). At present, a lot of money is spent after extreme floods and damage. The most important thing is prevention and the effective use of the landscape and the economic efficiency (compare the cost of flood protection measures and acquired effects). A thorough survey of individual catchment areas and identifying critical places could prevent or mitigate flood damage. Land use along rivers must be adapted to the needs of both industry and agriculture, as well as flood protection (Gilvear 1999). The state legislative should lead the way on preventive measures and financial support as well as research activities to analyze the areas that need flood protection measures.

One of the major interventions on the landscape is the change in land use in catchment area. The most significant changes are associated with intensive farming, which significantly interferes with the character of the landscape. The original natural vegetation (meadows and forests) on cultivated areas is transformed and they lost their natural retention capacity and this accelerates flooding. The retention capacity of forest areas is higher than agricultural areas (Langhammer 2007b). The importance of forests in the watershed has not always been appreciated as much as it is today. In the 1960s it was called "Forestry Hydrology" which began to look at the ecological links within the landscape structure of a basin and noted the importance of forest (Bonell 2002).

An important aspect of land use is the way of farming in a floodplain. If it is used incorrectly, in terms of flood control, significant damage can occur during floods. For example, when the land is transformed into an arable agricultural area the natural retention properties are lost and water erosion arises. Built-up parts of the floodplain sustain many times more material damage than areas left to develop naturally with natural vegetation. The mitigation or aggravation of the consequences of floods depends on the passage of the flood wave and its transformation on the way through the floodplain. If the floodplain is in good environmental condition it can slow down the runoff and reduce the speed of the wave. If these areas are revitalized it is important that the management of the watercourse and its floodplain are sensitively connected (Newson 1992). Revitalization should be taken as a single disturbance. It is a single river system interference which lead to near-natural condition of the floodplain. Rivers systems can respond very quickly to revitalization while gaining better resistance to other floods (Kopp 2007; Schumm 1994).

The studies of land use changes indicate that the positive aspect of flood prevention is a long-term decrease of arable land and increase of the forested areas in the headwater catchment areas, which contribute to the natural retention capacity of the landscape. The risk factor is the increase of built up areas (Bičík et al. 2008).

Urbanized and industrialized areas have lost most of their natural vegetation and thus their ability to retain water. Flood protection is ordinarily based on technical elements. Sewerage systems in urbanized areas have almost no retention capacity and the runoff is accelerated. Also, in the past, rivers were subjected to many anthropogenic alterations. Some of them could be described as highly insensitive to the natural environment (Langhammer 2007b). The developing mining industry was responsible for some of the major interventions into river network over the last two centuries. The most striking example is the mapped Bílina River, which due to mining brown coal in the Most basin had to be transformed several times and in some places the watercourses still flow through a conduit.

Floods also effect the actual condition of the riverbed and their degree of human influence. For increased capacity are the riverbeds countersunk. The extreme case is a flow through a conduit to passing through an industrialized area, urban area or under roads. The main objective of these measures is to let water flow through a built-up area as quickly as possible, which is only possible up to the capacity of the riverbed (or conduit). When the limits are exceeded, water overflows into the surroundings and damages property. Reinforcing the shore and bottom with artificial materials can reduce the roughness of the channel and increases the rate of flow velocity. Floods in those sections lead to an increase in the slope of the flood wave, a higher state of water levels at the peak and increased destructive power of the water flow (Langhammer 2007b).

2. Study area (description and characteristics of the Bílina River)

The Bílina River is a relevant watercourse in northwest Bohemia. It rises in the Ore Mountains on the eastern slopes of Kamenná hůrka, northwest of Jirkov. The total catchment area is 1,082.47 km^2, channel length 81.96 km. From the source, in Klínovecká uplands, the river flows across the Most region to Ústí nad Labem, where is the left tributary of the Elbe River. The Bílina River flows through one of the most industrialised areas of the country. The riverbed of the Bílina River has been adapted and transformed many times in the past and was one of the most polluted waterways in the area (Dvořák, Matoušková 2008). The original channel was changed mainly due to mining activities in the area of Most and the Bílina region. The natural hydrological regime only remains in parts of the stream before reaching the Jirkov waterworks (Štefáček 2008).

Among the interesting facts about the Bílina River is the three water conduit from the Ohře River into the Bílina River. They are called the "Podkrušnohorský přivaděč", Industrial water conduit and the Nechranice industrial Ohře–Bílina conduit. These systems are used to supply the area with water and protect local coal

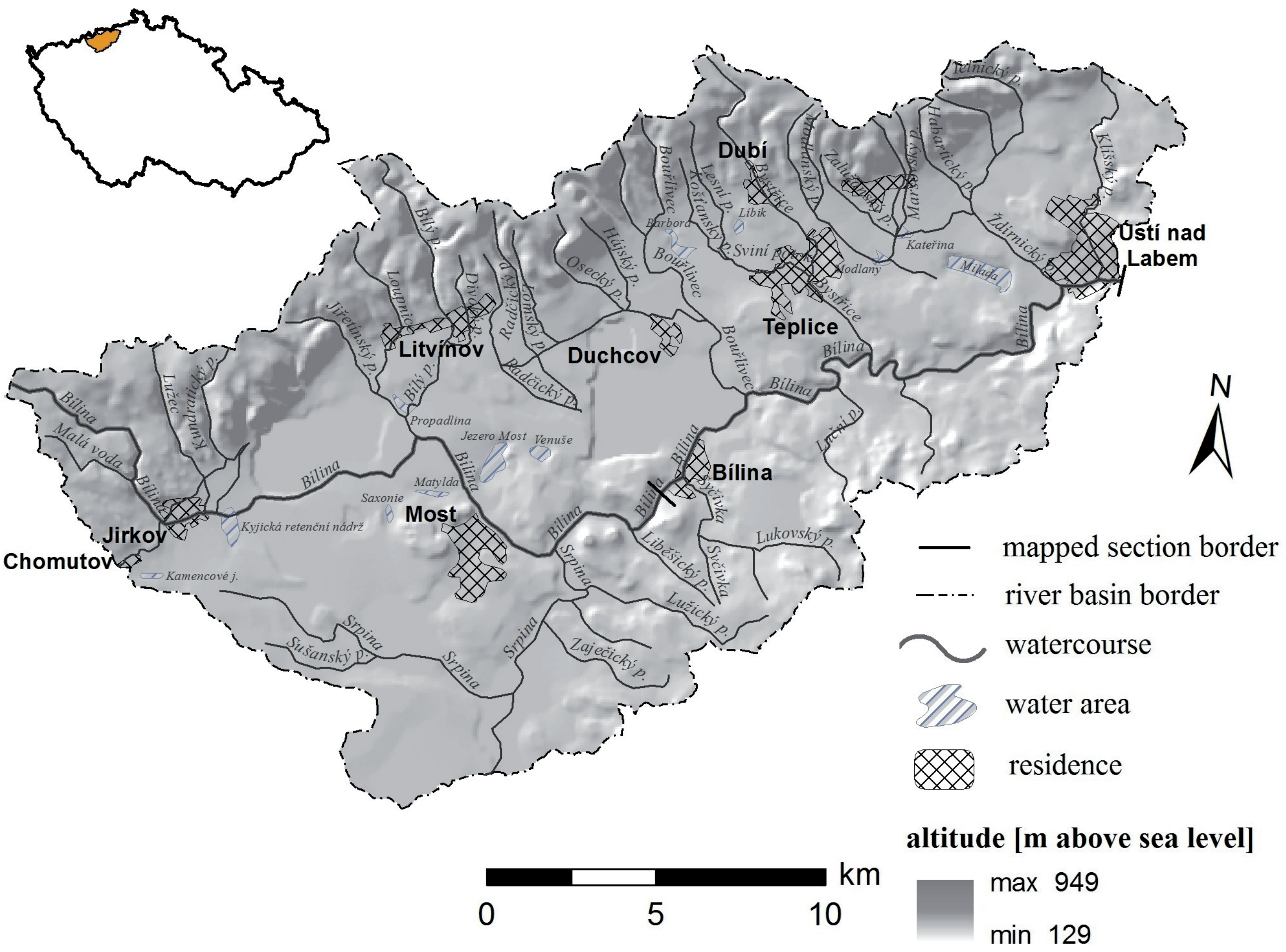

Fig. 1 The Bílina River basin.

mines from flooding. Water is also transferred through Počerady power station, which draws water from the Ohře River, and drain the waste water into the Srpina River, a tributary of the Bílina River. The system for transferring water from the Ohře basin to the Bílina basin is the largest in the Czech Republic. In the long term coal mining is expected to decline in the region and in a few decades the open mines should become flooded. The water for this purpose will be drawn primarily by the indicated penstock. For example, flooding the ČSA mine near the town of Most (the start is planned for 2020) should create the largest mining lake in the Czech brown coal districts, which will have an area of over 1,500 hectares (Simon et al. 2005). Another rarity is the Ervěnický corridor, with an up to 170 metres high embankment in places between Jirkov and Most. It is on part of the Bílina River where water is transferred to the conduit. The four steel pipes cover a distance of 3.5 kilometres with a total capacity of 10 m^3 sec^{-1}. There is also the road and railway line, linking the city of Chomutov and Most. The Bílina River's conduit will be the world's unique technical solution that will serve its purpose for over 25 years. As it is located at the dump, which is constantly falling (from the beginning to the laying of the hopper declines of several metres are expected), it was chosen instead of an open steel conduit channel (Hladný, Němec et al. 2006). In the future, after the mining pits are flooded and areas reclaimed the conduit will be removed and the river will return to its natural state of an open channel.

When assessing anthropogenic transformation, the rate of reduction of the length of the main stream is evaluated by comparing historical and contemporary maps. Over the past 80 years the Bílina watercourse has been reduced by nearly 3.9%. The most significant changes occurred in the area between the towns Most and Jirkov. The watercourse was increased between the discharge Ervěnický corridor and the Most corridor, where the Kopistská dump originated (Dvořák, Matoušková 2008).

The survey (May–October 2014) of the hydromorphological characteristics of the selected area using the established methodologies mapped 36.51 km of the Bílina River, between towns Ústí nad Labem and Bílina. The total length of the watercourse is 81.96 km therefore 44.55% of its length was mapped. The mapped section were divided into 36 sub-sections and marked by codes from BIL001 to BIL036. The average length of a section was 1014 metres, the shortest part was 300 m and the longest 3000 metres. The longer sections are mainly in the urban areas and municipalities (3000 metre section in Bílina town), and mostly have homogeneous characteristics. Conversely, the shorter sections are outside built-up areas where there are frequent changes in the characteristics.

3. Overview of the methodologies involved in mapping watercourses alterations

The state of watercourses can be viewed from many perspectives. There are many methodologies for evaluating rivers and their characteristics. This can include monitoring their chemical or ecological properties. Methodologies were created to solve the problems of taking and treating samples (the issue of sampling phytoplankton, fish, biota, macrophytes, etc.). When assessing the ecological status various biological, physical and chemical components should be evaluated; there is a sub-set of methodologies for each category. The list of accepted methodologies is administered by the Ministry of the Environment (MoE[1]).

In diferent countries were developed many methods of ecohydromorphological monitoring. Among the most important pertain LAWA – Field survey (LAWA, 2000) used in Germany. It is based on field survey, rated sections have a uniform length (50–500 m) depending on the width of the riverbed. A total of 25 parameters are evaluated in the 3 zones (watercourse, riparian zone, floodplain). Another German methodology is LAWA – Overview survey. It evaluate the function ability of the river ecosystems. The methodology is based on the use of existing maps and images. Field research has only supplementary character. In total 17 parameters in 3 zones are rated (Matoušková, 2008). Other method is Rivers Habitat Survey, which is used in Great Britain. Characteristics of riverbed, floodplain, riparian zone or green belt and land use around watercourse and anthropogenic transformation are evaluated. The length of the monitored parts is 500 m, evaluated are 25 parameters. This methodology is also used in Italy, Slovenia and New Zealand (Matoušková, 2008).

In the Czech Republic (Faculty of Science, Charles University in Prague) were created another methodologies. The first is EcoRivHab (Matoušková, 2003), which is based on field survey and the using of distance data. The method involves analyzing the hydromorphological characteristics of the watercourse, anthropogenic river alterations, the degree of flow dynamics, water quality and land use in the riparian zone. There are 31 parameters in the 3 zones (riverbed, green belts, riparian zone, floodplain) evaluated. Another methodology is mapping transformations of riverbed, floodplains and flood consequences – MUTON (Langhammer 2007b, 2008). The method was developed for evaluate river basin, riparian zones and geomorphological manifestations of floods. The main objective is not to evaluate ecological status of watercourses but determinate relationship with anthropogenic river alterations and floods consequences.

For this study the most important methodology is monitoring of the hydromorphological components of the landscape. This includes especially the hydrological regime, morphological continuity and flow conditions. The accepted method for evaluating them is HEM – Hydroecological monitoring (methodology for monitoring hydromorphological indicators of the ecological quality of watercourses). This methodology has its own sub-section HEM-F, and in addition to the attached section, is based on mapping the effects of floods (Langhammer 2007a).

3.1 Mapping the anthropogenic alterations of the Bílina River

The anthropogenic alterations and actual condition of riverbed of the Bílina River and its surroundings were mapped from May to October 2014. A methodology that builds on another existing methodology (HEM-F) used for mapping river network was created for the investigation and adjusted according to the needs of the field investigation. The presented methodology was used to determine the specific characteristics and level of anthropogenic riverbed alterations. Its aim is to obtain information of the intensity and character of adjustments of the river channel, its surroundings and floodplains that cannot be obtained from other sources (maps, photographs and satellite images) and continue to identify potentially critical sections that might have a negative effect on a flood, its course and consequences.

For the mapping was used a modified form of methodology HEM-F, from which were discharged mapping the effects of flooding and flood damages. The aim was to identify problematic reaches or sections and generally highlighting potentially endangered objects. The risk is seen as probably experiencing undesirable phenomenon that has negative impacts (e.g. on the lives and health of people, their property and the environment).

The mapping was carried out by a survey from the mouth to the spring, – upstream. The watercourse was divided into sub-sections of various lengths, each was homogeneous in some of the key parameters (naturalness of the floodplain, the use of floodplains, river alterations). Each sections were marked with a unique code and its boundaries, recorded by GPS coordinates and evaluated according to mapped indicators described below. These sections are the basic mapping units and the indicators in them are evaluated for each separate mapping. The aim is to evaluate the extent of anthropogenic adjustment of the riverbed and riparian zone, the observed phenomena are recorded on the field mapping forms, the surveyor selected one (or more) of the options, possibly accompanied by details. 16 indicators that describe the various characteristics of the watercourse and its surroundings, anthropogenic alterations and flood risks were inspect.

1 http://www.mzp.cz/cz/hodnoceni_stavu_vod

Tab. 1 Comparison of selected data of single mapping.

Mapped reach code (in terms of the present study)	River kilometer	Hydromorphological quality			
		Dvořák (2008)		Kyselka (2010)	Jelen (2015)
		EcoRivHab	LAWA-OS		
BIL001	0.00–0.45	5	5	5	5
BIL017–BIL019	14.28–15.53	4	3	3	2
BIL020	15.35–16.36	3	3	2	1
BIL021	16.36–17.31	3	3	2	1
BIL026	21.46–23.26	2	2	2	2

Note: During mapping hydromorphological characteristic is provided evaluation on a scale from 1 to 5 (1. High, 2. Good, 3. Moderate, 4. Poor, 5. Bad)

Tab. 2 Mapped indicators.

Identifiable information of the section	Morphometry of the river channel, riparian belt, green belt and floodplains	Watercourse alterations and the use of coastal areas and floodplains		Floodplain, the potential risks during floods
section code	the length of the reach (m)	watercourse trajectory	shore purity	floodplain condition
river name	the riverbed width and level	obstacles in the riverbed	riparian vegetation	potential risks during floods
date and time	the width of the floodplain (left + right bank)	depth of the channel	use of the riparian zone	notes
research worker name	the shape of the valley	the bottom structure	use of green belt	
		the bottom substrate	flow type	
		bottom purity	impact on the hydrological regime	

During the field survey have been measured empirical values. Basic features such as distance was determined using a laser rangefinder LEICA, limit points measured sections were recorded by using GPS machine GARMIN. Another data were obtained by direct observation of a qualified appraisal.

3.2 Comparison with already performed studies

In the Bílina River basin was already done a similar field survey. The most important might be considered a studies from Havlík et al. (1997a, 1997b), Vlasák et al. (2004), Dvořák (2008) and Kyselka (2010). Study from Vlasák et al. (2004) builds on earlier studies of river basin Bílina presented in the Havlík et al. (1997a, 1997b) works. There are any ecological studies in witch is on individual profiles computed water flow, evaluated the hydrological flow characteristics, water quality and pollution (including monitoring pollution producers). These studies are applied at intervals of several years, monitor and evaluate changes between measurements. In those studies are evaluated completely different flow characteristics and measurements are only in certain profiles, therefore these studies are not appropriated to compared the results with the submitted work. Dvořák (2008) and Kyselka (2010) concentrate on the evaluation of the Bílina riverbed ekomorfological condition by using different methodologies. Kyselka (2010) used methodology HEM but only on several reacehs of river. Selected reaches are called "priority sections" and they are distributed over all river length, but there are not connected. There are evaluated 31.99 km of watercourse. Dvořák (2008) applied EcoRivHab and LAWA – Overview Survey methods. Selected identical reaches from all of mapping are displayed in Table 1. It can be seen that in some reaches are the same values and in other reaches are better values of hydromorphological quality. Because it was used different methods, we can not say with certainty, that hydromorphological quality was improved or not. All sections which pass through the urban or industrial areas shows the worst results of hydromorphological quality. Unfortunately sections's comparison is quite confused because determining values depend on the researcher's experiences and knowledges.

4. Results

In the following text will be presented partial results of field survey of the Bílina River. For complete and detailed results see Jelen (2015).

4.1 Riverbed width and level

The morphometry of river the channel category is an important indicator of the breadth of the riverbed

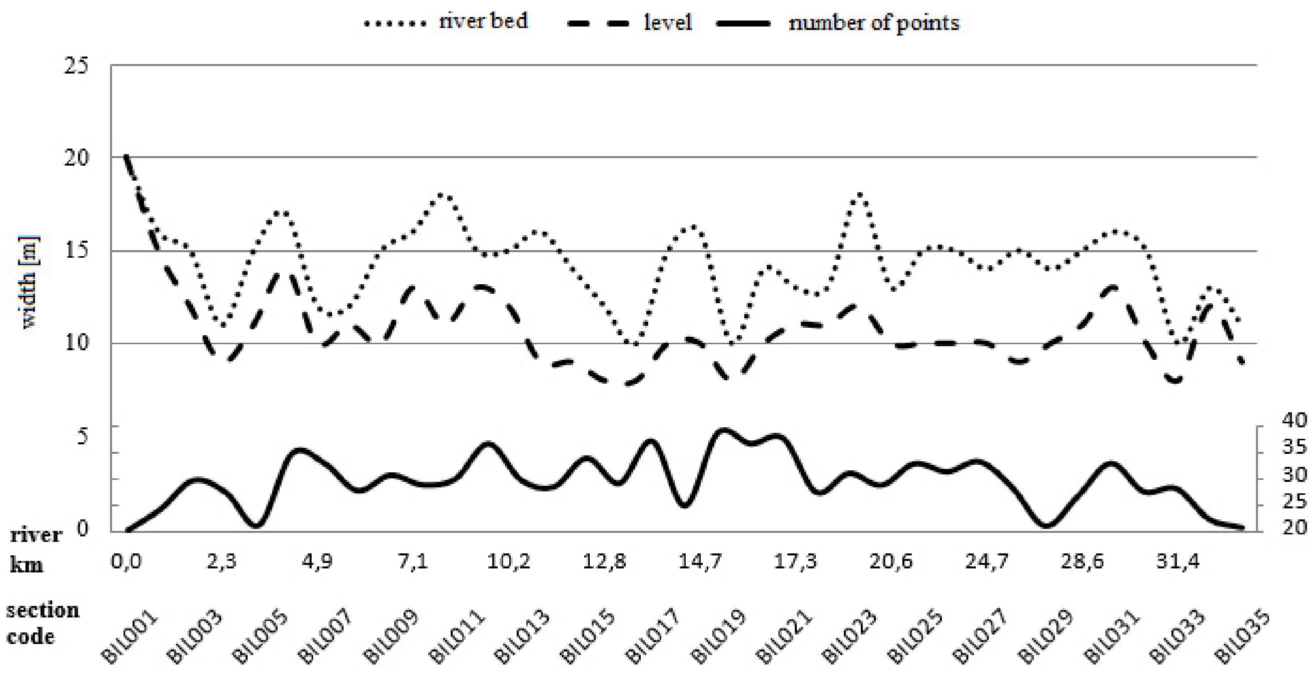

Fig. 2 The riverbed width and level in kilometres.
Note: The water level on 12 April 2014, when the segment was mapped, at the specific station Trmice (river km 3.80) was 1039 mm, with a flow of 3.81 $m^3 s^{-1}$. During the mapped period from May to October 2014, the level of this station ranged from 1000 mm (lowest status on September 5, 2014) to 1380 mm (highest status on September 20, 2014). The average water level was 1117 mm during the year.

levels and their differences (Figure 1). The figure shows that in areas with the highest degree of anthropogenic influences the riverbed (the urban areas) is the width of the channel and almost on the same level (see the first 1.5 km, which crosses the city of Ústí nad Labem). This means that the riverbed is mostly concreted or otherwise modified. The distance between the curve gradually increases as the river leaves the built-up area. When the water flow passes through less anthropogenically influenced areas, the variability of the riverbed width and level is high. In relatively natural sections the difference can be up to between 5–7 m. These are segments of higher ecological value, natural vegetation and with greater retention potential in cases of elevated water levels.

4.2 The width of the floodplain and flow path

The rate of anthropogenic influence riparian zone could be demonstrated on the floodplain condition. The average width of the floodplain on the left bank was 39 m and the right bank 49 m. These values are reasonable, to keep overflow water from river on the floodplain. But these values, are partially distorted by the fact that in some parts of the river there is none at all because it is an urban area. Because it is necessary to evaluate the individual sections separately. Therefore, the individual sections must be evaluated separately. Other indicators include the flow path and its type. Mapping the reaches of the Bílina River show two main indicators – meandering channel (39% river length) and artificially straightened flow (47% river length). Another occurring type is naturally direct flow which exceeds the limit of 10%. Outside built-up areas the river always meanders. In these parts a parallel with the different widths and channel levels can be found (Figure 1). On the other hand, direct sections are found where the river crosses an urban area or industrial areas, such as Ústí nad Labem. 17.1 kilometres are artificially straightened compared to 14.2 kilometres naturally meandering. This shows that the artificially straightened parts are less than half the total mapped area and more than a third is left in its natural state. The river flows through lots of small towns and villages between the large cities of Ústí nad Labem and Bílina. These are mainly rural settlements where the water flow is regulated only at the core urban area and does not require extensive regulation in the area where flood water could naturally spillover onto the surrounding countryside. There are no major dams or weirs on the mapped parts of the watercourse. The main sections are completely without barriers. One small culvert flow was found due to shift of communications over the watercourse and some low grades and two weirs 1 m high. Over the entire length of the mapped watercourse the longitudinal profile of the flow was very little affected by the construction of dams, weirs, etc. The section could be evaluated as part of the stream with a lower than average incidence of construction because of the unsuitability of the channel for building a large water project (dam type) and the uselessness of these buildings.

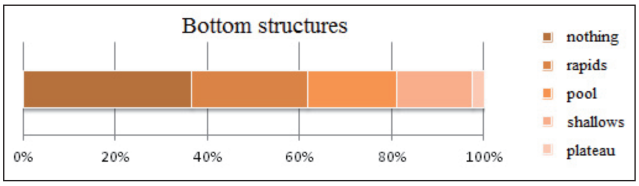

Fig. 3 Bottom structures in the study area.
Note: nothing mean that bottom structures can't be detect, other concepts include the bottom structures, respectively their flow velocity.

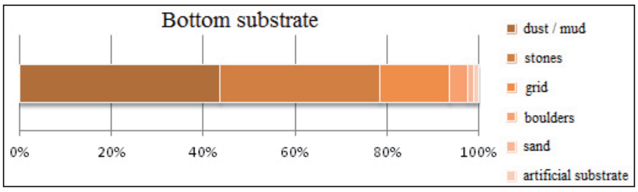

Fig. 4 Bottom substrate in the study area.
Note: bottom substrate is classified according to the grain size (size of the individual parts in millimetre). Dust/mud = 0.002–0.06; sand = 0.06–2; grid = 2–100; stones = 100–200; boulders = > 200, artificial substrate = pavement or concrete.

4.3 Channel depth variability

Other indicators are depth variability and depth of the channel. Where there is low depth variability there is low depth of channel. Depth variability is 60% artificially low, 34% low naturally and 6% in the middle. This corresponds to the partial adjustments of the river channel, but again only a slightly absolute majority, i.e. the remaining 40% is left to develop naturally. Higher values absent because this is the lower part of the medium size flow with a relatively small slope. High variability is found mainly in mountain streams or in meander reaches. The most frequent values of the channel recess are 1–2 m (58%), which is the average value corresponding to the type of watercourse. To help prevent floods it is common to artificially recess the channel to increase its capacity. These adjustments are made mainly in towns and villages, and are used as a substitute for levees. This protection element is only sufficient to limit the values when the volume of the riverbed is exceeded, then the water flows out of the riverbed. In some places this is complemented with, for example, mobile flood barriers (see section BIL001), the city centre of Ústí nad Labem, the site of the confluence of the Elbe and Bílina rivers.

4.4 Bottom structures

The bottom structures and bottom substrates are descriptive characteristics of the actual state of the bottom of the riverbed. The most common structure includes rapids, when it comes to shorter sections with higher speed, outside built-up areas where the bottom is covered with stones. To a lesser extent pools that appear in sections with a slow flow. The bottom substrate is mainly dust/mud, as approximately 50% of the mapped length

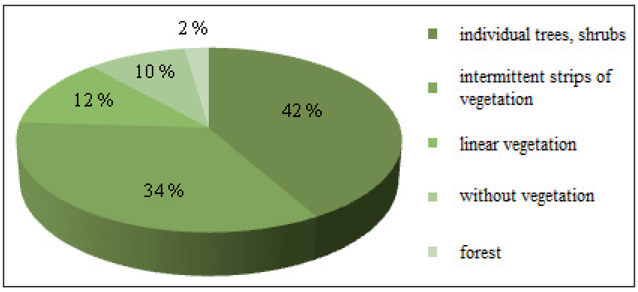

Fig. 5 Percentage types of green belt vegetation in the reporting period.

of the flow is outside the built-up area of vegetation and there is great potential for storing fine dust. In reaches where is stone bottom are the rapids. The rapids are also in reaches where were realized fortification of river banks. After several years stones sunk to the riverbed and create the stone bottom. Indicators mapped the anthropogenic interference with the channel bottom and the tidiness of the shore. More than half length of the river bottom is without alterations – in almost natural state. Unmodified bottom have different flow velocity. Concreted bottom increases the flow velocity through the area. The mapping of the bottom may be distorted by the inability to identify the adjustments due to the riverbed pollution or the water visibility. Alterations is closely related to the neatness of the bottom. For example, if the riverbed has a concrete bottom the banks will be concreted (the mapping indicates bottom casting of 6.01% and 6.69% for banks). Conversely, compared with a modified bottom, the bank is generally more regulated, but more than half of them were very close to the near-natural state (vegetation or stone fortifications). These measures do not prevent water soaking into the surrounding ground and acts favourably in a flood.

4.5 Bank vegetation and land use in the riparian belt

Other important factor is absorption of water into the environment, depend on the species composition of the bank vegetation as well as its quality and age. In the mapped area there are mainly individual trees, shrubs or intermittent bands of vegetation. These include especially self-seeded trees. In many sections the stands are not maintained and some may extend up to the watercourse. During floods floating material may become entrapped after hitting these branches or the branches themselves may be broken and act as a barrier in other areas downstream e.g. during the build up to pass under a bridge. This problem should be actively addressed in some sections where there is a high incidence of old trees, extending into the riverbed. In some places the vegetation is left entirely natural, which sometimes prevents continuity along the riverbed. The mapped area is intensively used in the industrial area of the Bohemian Highlands. Therefore, there has been no form of preserved natural forest

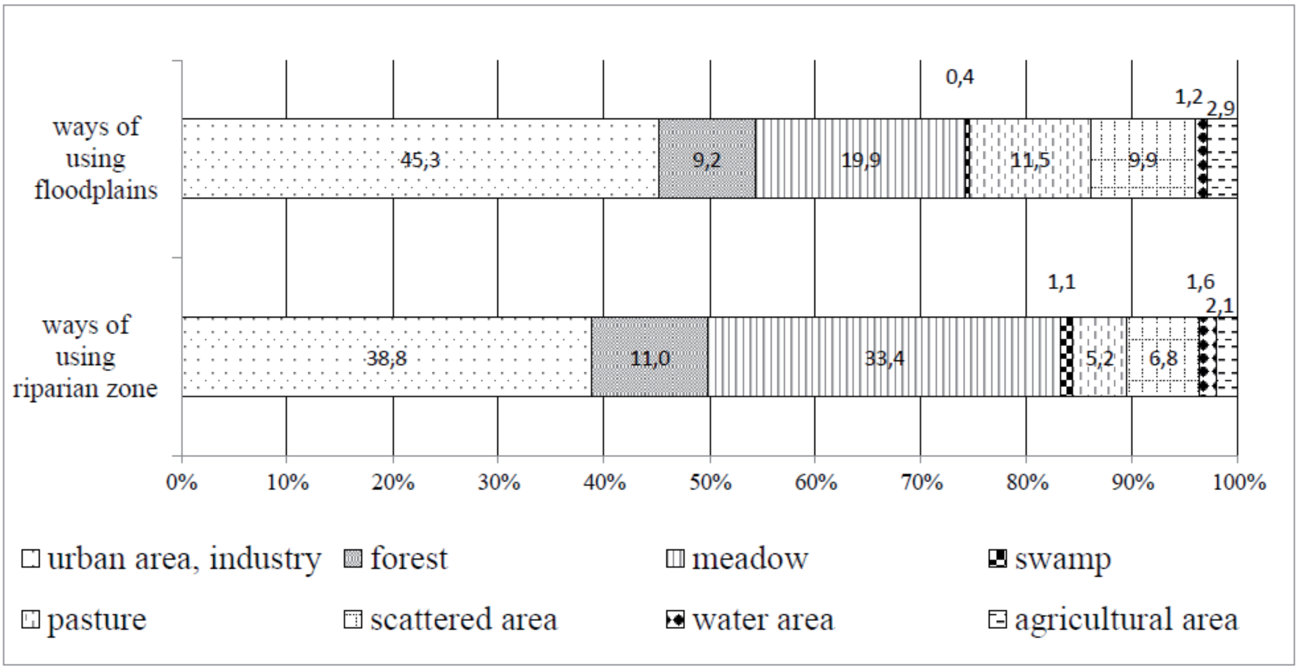

Fig. 6 Percentage of land cover using in the reporting period.

vegetation. Eight main types of use of the riparian zone and floodplains were recorded when mapping the area. All these types of use along both mapped categories correspond to its share. Most are urban and industrial areas. Of the total length of the mapped stream the water flows directly through 17 municipalities, which is over 40% of the length of the flow. More than 30% of the floodplain and over 35% of the riparian zone are used as meadows or pastures. These areas are suitable for the natural overflow of the river at time of increased flood flows, but they do not have such an interception rate as forests, of which there is only about 10% percent in both categories. The mapped area is also suitable for intensive agricultural production in terms of its climatic and geomorphologic characteristics, but the category of agricultural area is less than 3%. The multiple buildings category is also below 10%. These are areas of isolated buildings, especially on the edges of a municipality or outside. These buildings are a particular problem because they are often right near the riverbed, less than 7% in the riparian belt. Therefore they are directly threatened by flood situations.

4.6 Water passages throughout the floodplain

Water passages throughout the floodplain are indicators of mapping structures and objects that may hinder the passage of flood waves at high flow rates. More than half of the floodplain not pass any structures that would prevent the passage of water during an inundation. However, along the route the flow passes through two major potential barriers that are in different places at different distances. The first is the railway line Ústí nad Labem west of (station 5) – Bílina. The railway follows the flow of water through several passes. Some sections go directly along the bank. The track may prevent water overflows on one bank and multiply overflows on the opposite bank. The D8 motorway crosses the Bílina River several times. It is very high above the surface of the water but the bridge pillars extend to it and to its banks, which may act as barriers to the flow. Furthermore, to a lesser extent in some sections there are buildings in the floodplain, for example industrial areas.

4.7 The resulting point evaluation of the mapped sections

In total the 36 sections were analyzed; each section was based on predefined criteria, a specific point value was assigned for each sub-section examined. Only indicators that have a predictable value of the anthropogenic influence on the water flow were included (flow path, obstacles in the riverbed, variability depths, bottom and bank tidiness, green belt, use of riparian zone and flood plains affecting the hydrological regime). The principle of the scoring is that the more characteristic like anthropogenic nature, the fewer points in relation to the suitability or otherwise of these treatments. Natural regions have the largest number of points. In the mapping records the percentage of the occurring phenomena is allocated a point value converted to a ratio of observed phenomenon. For example, if the value of phenomenon A with 85% has 5 points, and the value of phenomenon B with 15% has 1 point, after conversion the resulting phenomenon value is 4.4 points.

To clarify the points according to the kilometres of the river flow, see Figure 7. The lowest score was 20.48 points for the section within the boundaries of the city of Ústí nad Labem, where the riverbed is largely artificially altered. Almost the entire length is straightened and

Tab. 3 The resulting number of points of individual map sections.

Section code	River km	Total points	Section code	River km	Total points	Section code	River km	Total points
BIL001	0.00	21.00	**BIL013**	10.22	36.50	**BIL026**	20.56	32.80
BIL002	0.45	20.48	**BIL014**	11.15	29.75	**BIL027**	21.46	31.30
BIL003	0.87	24.40	**BIL015**	12.50	28.50	**BIL028**	23.26	33.16
BIL004	2.27	29.75	**BIL016**	12.80	33.83	**BIL029**	24.66	28.30
BIL005	3.37	27.40	**BIL017**	13.63	29.16	**BIL030**	26.31	21.23
BIL006	4.02	21.40	**BIL018**	14.28	37.00	**BIL031**	26.91	26.83
BIL007	4.90	34.65	**BIL019**	14.73	24.99	**BIL032**	28.56	32.88
BIL008	5.60	32.85	**BIL020**	15.53	38.50	**BIL033**	29.72	27.60
BIL009	6.48	27.80	**BIL021**	16.36	36.50	**BIL034**	30.07	28.20
BIL010	7.10	30.67	**BIL022**	17.31	37.50	**BIL035**	31.37	22.50
BIL011	8.70	28.86	**BIL023**	18.01	27.50	**BIL036**	32.51	20.96
BIL012	9.70	30.00	**BIL024**	19.36	31.00			

Note: River kilometer unit corresponds to the start point of the section.

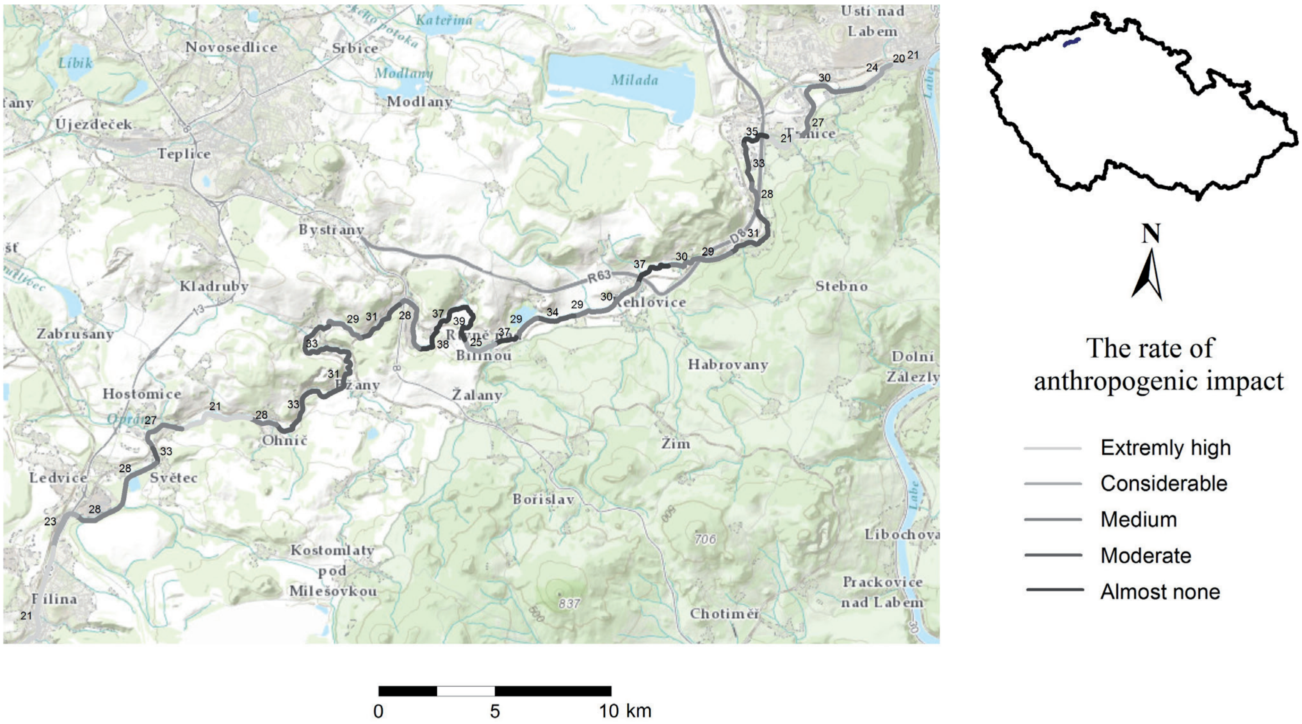

Fig. 7 Analyzed parts of the river with their rates of anthropogenic impacts.

the river has a culvert that prevents the natural flow of water. Larger flow rates cause water to overflow through it and communicate this after it passes. Furthermore, the inundation area is narrowed by adjacent routes. The highest score was 38.5 for the section between the villages of Rtyně nad Bílinou and Sezmice. The river passes through undeveloped country and meanders naturally. There are no signs of anthropogenic alterations of the bottom or bank. Both banks have developed a broad floodplain. The surroundings of the river are used as meadows or pastures. The average score was 29.3 (on Figure 7 shown by a bright line). A total of 19 mapped sections (52.8%) had values below a predetermined level and 17 segments (47.2%) were above the average point value. A large number of sections oscillate around the average number of points. These are segments in which adjustments have been carried out to a lesser extent; the river passes through smaller villages where no extensive alterations have been carried out. The watercourse is largely straightened or part of a natural meander. The bottom is only partly converted, either by stone or in smaller sections by pavement. The banks are regulated by stone fortifications, gravel or vegetation. There are small dams causing backwater, but not more than 1 metre high. Neither are there sections with complete alterations, such as concrete.

Tab. 4 List of critical parts.

Section code	Title	Description	Regulation proposal
BIL001	road bridge	under the bridge on the right side are lots of silt deposits accumulation	cleaning the silt deposits by water basin authority
BIL002	system of conduit	barrier in the riverbed	removing conduites
BIL003	unfinished building	unfinished building near the riverbed	completion and protection of the object
BIL005	stone wall in the riverbed	Artificially created stone wall in the riverbed, restricts the water flow	removing object
BIL005	cottage on the riparian zone	inconveniently placed objects near the riverbed	removing object
BIL007	riparian vegetation	riparian vegetation and silt extending into the riverbed	pruning riparian vegetation
BIL013	riparian vegetation	riparian vegetation and silt extending into the riverbed	Pruning riparian vegetation
BIL015	historical bridge	historical bridge in Brozánky village, where are deposits of silts	cleaning the silts by river trustee
BIL019	urban village of Rtyně Bílinou	inappropriately placed buildings directly on the edge of the watercourse	construction elements of flood protections around the buildings
BIL029	destroyed concrete adaptation shore	destroying the concrete bank fortifications and lateral water erosion	repair fortifications by river trustee
BIL032	old bridge	old concrete bridge over the river, which is in disrepair and threatening to collapse into the riverbed	repair or remove of the bridge

Parts that overlap the final score value of 35 can be described as very slightly modified; in a near-natural state. The flow in these sections naturally meanders or could even be described as natural, depth variability and the recess channel is moderate, i.e. the natural state. The sufficiently developed floodplain is not in the area of potentially endangered objects or obstructions to the flow in the channel (weirs, dams) or in the floodplain (road embankments). The flow of the surrounding forest or grassland, the bottom and the banks are not regulated or are used close to nature and the near-natural river state (vegetation fortification). These sections do not need any further adjustments to ensure the ecological stability. The opposite are sections with a score of under 25. This category includes partial flow through an urban area where there is a great emphasis on flood control and the riverbed and its surroundings are heavily anthropogenically altered. Specifically, the city at the beginning of the mapped route (Ústí nad Labem), and its end (Bílina). These sections are artificially straightened, the channel recess is over 4 metres because of its capacity. Also, in most cases it is paved or concreted. The surrounding area is intensively used for industrial purposes.

When comparing the various categories we can generally say that the proportion of near-natural and modified reach is equivalent. Many of the parts around the average value change but the number of sections near-natural is greater than the number of those strongly anthropogenic treated. Therefore, unlike the original assumptions the mapped stretch of the Bílina River was rated as slightly modified. The exceptions are, as already mentioned, large urban cities. Furthermore, a great change in the natural and modified sections can be observed. This is due to the water flow through a plurality of small communities. This is a potential major problem during flooding. In other than urban areas the water has a great potential to spill over the riverbed. However, in urban areas, although water is transferred into a deep riverbed when it overflows it flows directly into the built-up area. This issue was discussed in the introduction, where it was stated that adjusted riverbed provide stability and protection against floods only to the point where it exceeds the limit flow.

5. Discussion (identify problematic parts)

The aim was to identify problematic parts or sections and generally highlight potentially endangered objects. The risk analysis is essential to assess the critical sections and locations. The risk is seen as probably experiencing undesirable phenomenon that has negative impacts (e.g. on the lives and health of people, their property and the environment). The essential steps of identifying hazard scenarios (presence of undesirable phenomenon), estimating the probability of the occurrence of the phenomenon and quantifying the impacts and risks include identifying and evaluating the flood risk. The risk analysis and defining potentially vulnerable sites can be divided into qualitative, quantitative and semi-quantitative (Drbal et al. 2005). The choice of the method of analyzing the critical points depends primarily on how the results will be used, as well as the availability, correctness and accuracy of the input data and finally the available resources of their own investigation. The choice then determines the level of detail of the endangered area and determines other procedures and specific methods. For this study it was critical that the points and sections identified a synthesis of several aspects. A qualitative analysis was carried out from the view point of the researcher. Critical points were identified according to several criteria of potential threats:

- The health and lives of people
- Property population
- Environment
- Cultural heritage
- Economic activities
- The effects and functionality of existing flood control measures
- The course of the watercourse and its natural properties

The principle of determining problematic parts because the object is inappropriately positioned near the edge of the flow channel and thus at the risk of increased flow rates was used. Increased attention is paid to bridge structures, both in terms of their technical condition and the capacity of their flow profile. These are bridges with a profile that is estimated to be insufficient for high water flows and the culvert could be blocked causing water to overflow the riverbed. Then silt is deposited as this it is a good place to create a temporary dike with the clogging. It also identifies a breach of a bank and the days of treating a watercourse. Despite the overall weak rate of anthropogenic effect on the mapped sections of the Bílina River locations and regions were identified during the field survey that could cause complications during any increased flows of water and also objects that could be directly affected by floods and damage.

The list of all critical parts is on Table 4. There are describe the problematic parts and situations on riverbed or its surroundings and suggest interventions which could lead to eliminate problems.

In following article are some examples of selected problematic parts. In a larger study would be proposed interventions to reduce the risk in these areas. In general, can be said, that among the measures should include periodic service of the riverbeds and riparian belt. These are mainly the removal of silt, fallen trees or bushes. Attention should be paied to periodic services and repairs river bank fortifications and bridges. In case that it's construction is already in a dangerous condition and does not serve original purpose, their demolition is suitable (Figure 11). A separate chapter is also development in the riverbeds, floodplains and riparian

Fig. 8 Riparian vegetation and silt extending into the riverbed.
Reach BIL007, vegetation extending into the riverbed that could collect silt. This narrowing of the riverbed silt, along with a conduit across the river could cause clogging of the riverbed and water overflowing outside.

Fig. 9 The urban village of Rtyně nad Bílinou.
Reach BIL019, inappropriately placed buildings directly on the edge of the watercourse. In combination with reduced throughput caused by narrowing the channel profile bridge, high water flows could threaten buildings along the river channel.

Fig. 10 Destroyed concrete adaptation shore.
Reach BIL029, because of the riparian vegetation and water destroying the concrete bank fortifications and lateral water erosion the situation before the bridge over the river could eventually disrupt the bridge structure and scour the adjacent road.

Fig. 11 Old bridge.
Reach BIL032 stretch of an old concrete bridge over the river, which is in disrepair and threatening to collapse into the riverbed. This could clog the riverbed and make the water overflow.

belt. Generally, the construction in floodplains are always risky. They are not only threatened by floods, but also can influence the direction of the flood wave into the territory. The main objective of government should be in places for the natural overflow of water at all not built buildings.

Examples

6. Conclusion

The study is focussed on evaluating the anthropogenic interference with the nature of watercourses and their manifestations in the context floods. It focused on mapping alterations of riverbed in connection with floods. The analysis was conducted on anthropogenic alterations of riverbed and evaluated their positive or negative effect on the course of a flood. This methodology was used on the 36.51 km long section of the Bílina River through different types of landscapes. The sample is long enough to be representative and nearly all these mappable characteristics could be observed on it. Some critical sections were also identified that, during increased flows of water, could cause problems during a flood wave. After analyzing the impact of anthropogenic river alteration and evaluating the potential effects on the development of floods the surveyed stretch would be labelled as moderately influenced by human activity. Based on the results of the previous survey and analysis of the resources it can be said that the examined part of the watercourse is not subject to a greater degree of the consequences of inadequate or poorly implemented flood protection or inappropriate alterations.

It must however be observed that if the field survey of only part of the water flow had included its entire length, especially sections passing through the area of the North lignite basin, the final results would be different.

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RESUMÉ

Antropogenní úpravy vodních toků a jejich vliv na průběh povodní (případová studie řeky Bíliny)

Příspěvek se zabývá hodnocením jednotlivých druhů antropogenních zásahů do přirozenosti říčních koryt a jejich okolí, antropogenními změnami v krajině a jejich dopady na hydrologické poměry daného povodí a případnými dopady na vznik a průběh povodní. V práci je předložena vlastní metodika terénního mapování, vycházející z již existujících prací. Metodika je navržená k mapování klidového stavu řek, poukazuje na případná povodňová rizika a pomáhá vytipovat potenciální riziková místa, ve kterých by při případné povodňové události mohlo docházet ke škodám na majetku. Navržená metodika je testovaná na dílčím úseku vodního toku Bíliny. Tento vodní tok se nachází v silně industriální oblasti severních Čech, a proto zde byl předpoklad silného antropogenního ovlivnění koryta vodního toku. Při mapování dílčího úseku mezi městy Ústí nad Labem a Bílina se však tento předpoklad nepotvrdil, neboť vodní tok jevil známky spíše menšího stupně antropogenní upravenosti.

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CLASSIFICATION OF VEGETATION ABOVE THE TREE LINE IN THE KRKONOŠE MTS. NATIONAL PARK USING REMOTE SENSING MULTISPECTRAL DATA

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ABSTRACT

This paper compares suitability of multispectral data with different spatial and spectral resolutions for classifications of vegetation above the tree line in the Krkonoše Mts. National Park. Two legends were proposed: the detailed one with twelve classes, and simplified legend with eight classes. Aerial orthorectified images (orthoimages) with very high spatial resolution (12.5 cm) and four spectral bands have been examined using the object based classification. Satellite data WorldView-2 (WV-2) with high spatial resolution (2 metres) and eight spectral bands have been examined using object based classification and per-pixel classification. Per-pixel classification has been applied also to the freely available Landsat 8 data (spatial resolution 30 metres, seven spectral bands). Of the algorithms for per-pixel classification, the following classifiers were compared: maximum likelihood classification (MLC), support vector machine (SVM), and neural net (NN). The object based classification utilized the example-based approach and SVM algorithm (all available in ENVI 5.2). Both legends (simplified and detailed ones) show best results in the case of orthoimages (overall accuracy 83.56% and 71.96% respectively, Kappa coefficient 0.8 and 0.65 respectively). The WV-2 classification brought best results using the object based approach and simplified legend (68.4%); in the case of per-pixel classification it was the SVM method (RBF) and detailed legend (60.82%). Landsat data were best classified using the MLC (78.31%). Our research confirmed that Landsat data are sufficient to get a general overview of basic land cover classes above the tree line in the Krkonoše Mts. National Park. Based on the comparison of the data with different spectral and spatial resolution we can however conclude that very high spatial resolution is the decisive feature that is essential to reach high overall classification accuracy in the detailed level.

Keywords: vegetation above the tree line, Krkonoše Mountains, object based classification, per-pixel classification, multispectral data

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1. Introduction

The Krkonoše Mountains is a mountain range with a fragmented alpine zone that occupies a narrow span of elevations and has developed into two separated areas. The highest parts of the Krkonoše Mts. National Park (KRNAP) rise above the tree line and are covered by relict tundra. These areas are included in the international tundra monitoring program (INTERACT: International Network for Terrestrial Research and Monitoring in the Arctic) (Soukupová et al. 1995; Jeník and Štursa 2003).

For vegetation mapping and related analyses in large, isolated areas that often receive legal protection, such as tundra, remote sensing methods are commonly used. Data with various spatial and spectral resolutions are analysed using different methods of per-pixel and object based classification.

Regarding the vegetation classification above the tree line, Král (2009) classified the orthoimages with infrared band with spatial resolution 0.9 metres using the maximum likelihood algorithm in Jeseníky Mountains. Král (2009) especially focused on transitional zones between subalpine forests and alpine tundra. In this way, he defined seven land cover classes: anthropogenic areas, pastures and barren land, *Pinus mugo* scrub, deciduous trees, spruce cultures, dry spruce stands, and rocks. The overall accuracy equalled 78%.

Orthoimages were also examined by Müllerová (2005) who studied the tundra vegetation in the Krkonoše Mts. National Park. Having used multispectral aerial data and the maximum likelihood method, she defined seven classes: *Pinus mugo* scrub, *Nardus stricta* stands, subalpine tall grasslands and tall-herb vegetation, vegetation along roads, roads, water areas, and wetlands. The overall accuracy equalled 79%. The use of unsupervised classification (ISODATA method) brought overall accuracy of 63% and six classes were identified.

Zagajewski et al. (2005) conducted mapping in the eastern part of the Tatra National Park, Poland. They focused on the mountain vegetation of subalpine, alpine, and sub-nival zones utilizing hyperspectral data and maximum likelihood and neural net methods. Hyperspectral aerial images were acquired by DAIS 7915 and by ROSIS sensors. Based on unsupervised classification and visual interpretation of the images, seven classes for supervised classification were defined: *Pinus mugo* scrub, forests, meadows, rocks, lakes, shadows, and roads. Overall accuracy reached 71–85%. Hyperspectral data were used also by Marcinkowska et al. (2014). They classified vegetation communities in the Krkonoše Mts. National Park using APEX data and Support Vector Machines classifier.

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Object based classification was used by Laliberte et al. (2007) in order to distinguish between green and aging vegetation in New Mexico. The study area was located about 1,200 metres a. s. l. They combined the methods of decision tree and nearest neighbour. The classification accuracy equalled 92%. Object based classifications of orthoimages was also used by Lantz et al. (2010) in order to examine changes in vegetation characteristics (cover and patch size) across a latitudinal gradient in the Mackenzie Delta Uplands. Four classes were identified: shrub tundra, dwarf shrub tundra, water, and bare ground, with overall accuracy 78.1% (Kappa coefficient 0.66).

All of the above-mentioned studies used data with very high spatial resolution. Data collected by Landsat sensors (one pixel equals to 30 × 30 metres) are commonly used to produce land cover classifications in large areas (see Dixon, Candade 2008) or to examine forest cover (Wolter et al. 1995, etc.). Landsat data, however, are only rarely used for examination of grassland vegetation, except in the case of vast regions in the northern tundra (Johansen et al. 2012; Pattison et al. 2015).

Several authors compared a number of pixel classification algorithms (Zagajewski 2005) or per-pixel and object based classification – see Yu et al. (2006), Cleve et al. (2008), or Myint et al. (2011). So far, no study has been carried out that would compare the potential of different multispectral data and different types of classification algorithms, including comparison of object based and per-pixel approach for classification of alpine vegetation. Thus, our study aims at evaluation and comparison of selected multispectral data with various spatial and spectral resolutions for land cover classification above the tree line (focus is put on different vegetation classes), using different classifiers including object based image analysis (OBIA) and per-pixel approach. Orthoimages can serve as an example of very high resolution data in this study. Data collected by WorldView-2 satellite show high spatial and spectral resolutions; the freely available data collected by Landsat 8 (moderate resolution) are also examined.

As different vegetation types cover only small patches of land, it is expected that spatial resolution of the data may be crucial for the classification. On the other hand, different vegetation types are clearly confined and usually do not overlap. Thus, we presume that the object based approach applied to high resolution data should bring more accurate results than the per-pixel approach.

2. Study Area

Arctic-alpine tundra occurs in the highest parts of the Krkonoše Mountains above the tree line (from 1,300 m a. s. l. up). It covers a limited area of 47 km² (32 km² on the Czech territory, 15 km² on the Polish territory), i. e. just 7.4% of the total Krkonoše area. The Scandinavian Ice Sheet repeatedly expanded as far as to the northern foothills of the Krkonoše Mountains and during the Holocene, tundra was a permanent phenomenon here (Treml et al. 2008; Margold et al. 2011). As a result of this palaeogeographical history, the Krkonoše Mountains represent a "biodiversity crossroads" where Nordic and alpine flora and fauna coexist (Jeník and Štursa 2003).

The area covered by natural arctic-alpine tundra was expanding due to deforestation and grazing from Early Middle Ages (9th–11th century, Speranza et al. 2000; Novák et al. 2010) until the beginning of the 19th century when mountain agriculture (grazing and grass mowing) peaked (Lokvenc 1995). Direct human impacts then gradually diminished until the 1940s. Almost no direct human intervention in the tundra zone has occurred since then as these areas became strictly protected as nature reserves. The alpine vegetation is being occasionally disturbed mainly by periodical avalanches and debris flows. Closed alpine grasslands, subalpine tall grasslands, *Pinus mugo* scrub, alpine and subalpine scrub currently form the prevailing vegetation types; in the highest altitudes also mosses, lichens, and alpine heathlands are common (Chytrý et al. 2001).

Two spatially separated parts make up the study area: Western Tundra and Eastern Tundra (Figure 1). The western part is situated near Labská bouda and covers about 1,284 hectares. The Eastern part is located around Luční bouda covering 2,284 hectares.

Both parts of tundra on the Czech territory were examined in full using the Landsat data. Classifications of the other data sources have been executed only in selected parts of the study area (565 hectares in the western part, 839 hectares in the eastern part) – Figure 1. Classifications using the detailed legend were applied only in the western area.

3. Data and Methods

3.1 Data

Three sensors of different spectral and spatial resolution represent multispectral data in this study. First, there are orthoimages acquired by aerial sensor on June 18, 2012. Second and third are two satellite sensors: WordView-2 and freely available Landsat 8. The WordView-2 images were acquired on July 22, 2014 (western part) and on August 10, 2014 (eastern part). The Landsat 8 cloud-free image acquired on July 27, 2013 (ID: LC81910252013208LGN00) was chosen from the Landsat archive.

Table 1 shows basic information on the data. No atmospheric corrections were made as classifications were carried out separately for all images; consequently, such adjustments were not necessary (Song et al 2001). Spatial accuracy was secured by geometric corrections and orthorectification (orthoimages, WV-2) using digital surface model created from aerial laser data (cloud of points, 5 points/m²) and L1T product in the case of Landsat

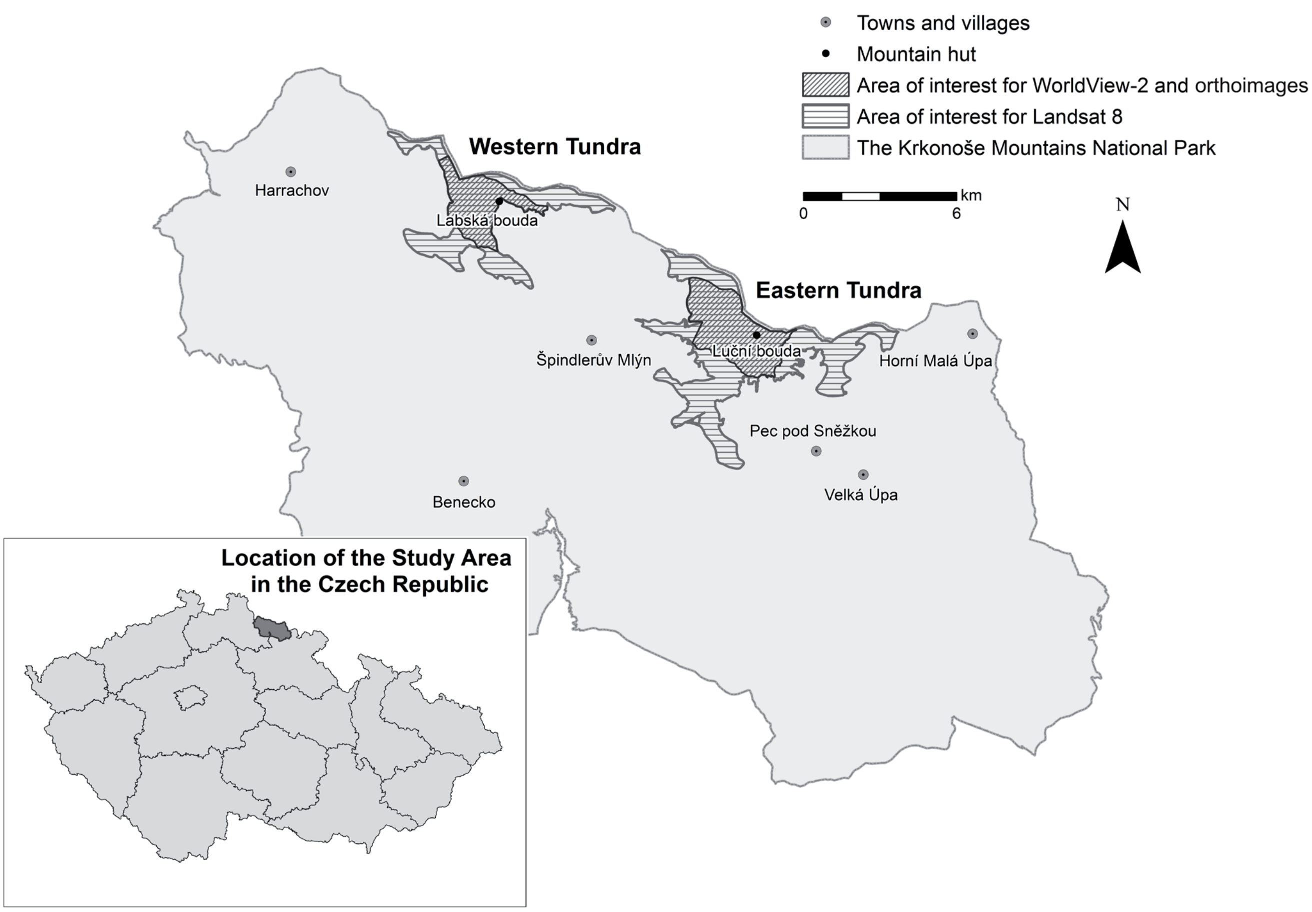

Fig. 1 Study area. Source: Authors

Tab. 1 Data parameters.

Data	Spatial resolution (metres)	Number of bands used for classifications	Radiometric resolution	Date
Orthoimages	0.125	4 (blue, green, red, NIR)	8 bit	June 18th, 2012
WV-2	2	8 (coastal, blue, green, yellow, red, red edge, NIR, NIR2)	11 bit	July 22th, 2014; August 10th, 2014
Landsat 8	30	7 (coastal, blue, green, red, NIR, SWIR1, SWIR2)	12 bit	July 27th, 2013

data (the latter utilizes corrections of digital surface model and surface points GLS2000).

Fifty nine polygons corresponding to vegetation classes as defined in the legend were identified in the field. Data were collected in the period June 23 – June 25, 2014. Polygons were located by GPS (Trimble Geoexplorer 3000 Geo XT, accuracy 10 centimetres) and classified on the botanical basis according to the legend (see Chapter 3.2). Polygons corresponding to classes *Pinus mugo* scrub, *Picea abies* stands, water and block fields, and anthropogenic areas were added later using manual vectorization based on visual interpretation of orthoimages.

3.2 Classification Legend

Definition of the legend constitutes the crucial part of the research. Classifications were made using two types of legends: the detailed legend (12 classes, respectively 13 for OBIA – Figure 3) for orthoimages and WV-2 data, and simplified one (8 classes, respectively 9 classed for OBIA – Figure 3) for all three types of data.

The detailed legend was created in cooperation with national park botanists and includes the most important classes of grassland vegetation as well as other vegetation classes, and also classes without any vegetation cover (Figure 2).

The detailed legend was used for orthoimages and WV-2 in the Western Tundra only. As many vegetation classes cover small patches of land less than 900 m^2 (equal to 1 pixel of Landsat 8), it became necessary to create a simplified legend suitable also for Landsat data classification. This simplified legend includes eight classes and was used for classification of all data types for the sake of comparison.

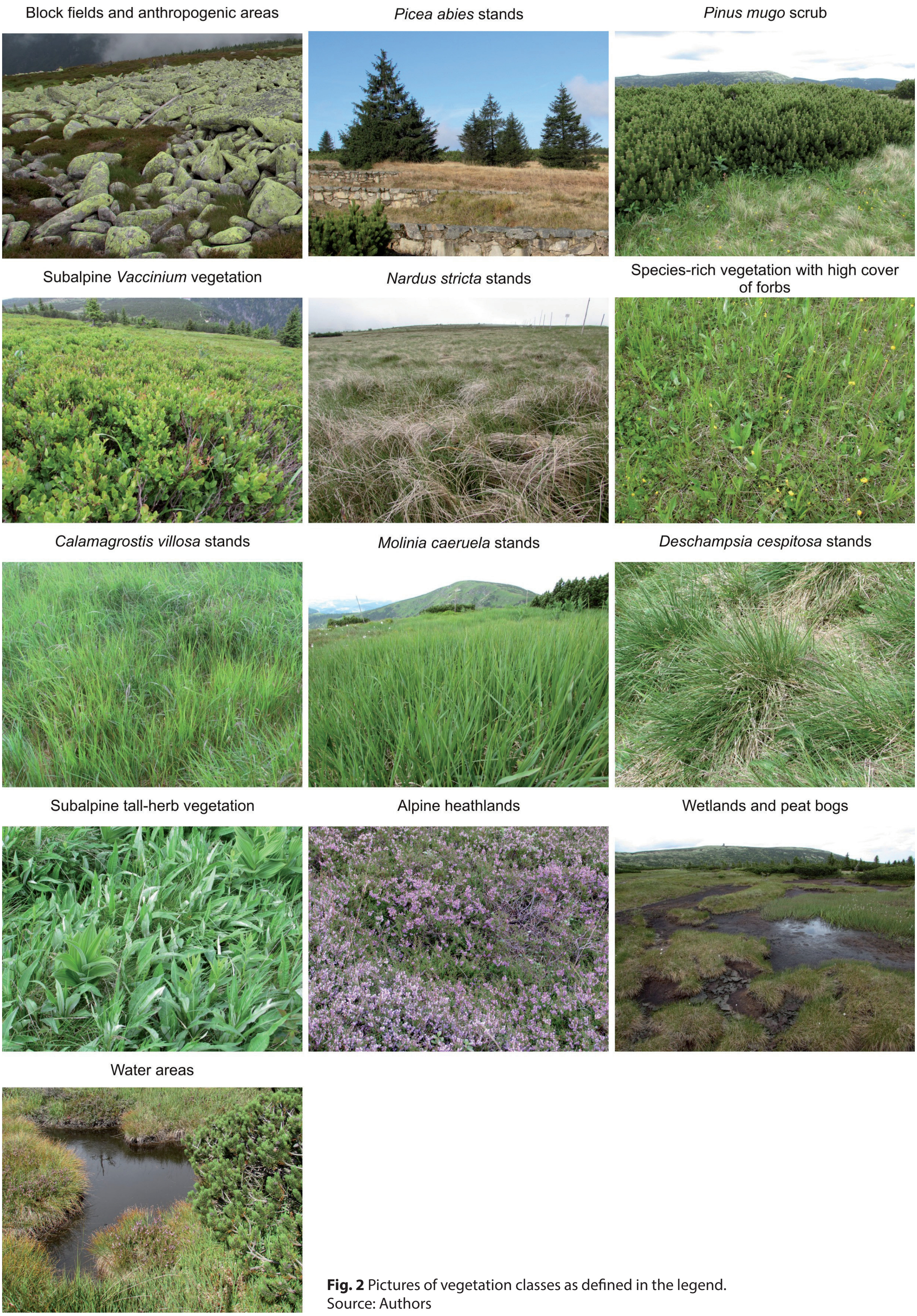

Fig. 2 Pictures of vegetation classes as defined in the legend.
Source: Authors

Detailed legend
1. Block fields and anthropogenic areas
2. *Picea abies* stands
3. *Pinus mugo* scrub
4. Subalpine *Vaccinium* vegetation
5. Closed alpine grasslands
5a. *Nardus stricta* stands
5b. Species-rich vegetation with high cover of forbs
6. Subalpine tall grasslands
6a. *Calamagrostis villosa* stands
6b. *Molinia caeruela* stands
6c. *Deschampsia cespitosa* stands
7. Subalpine tall-herb vegetation
8. Alpine heathlands
9. Wetlands and peat bogs
10. Water areas (only for OBIA)

Simplified legend
1. Block fields and anthropogenic areas
2. *Picea abies* stands
3a. *Pinus mugo* scrub dense (more than 80% of total cover)
3b. *Pinus mugo* scrub sparse (30–80% of total cover)
4. Closed alpine grasslands dominated by *Nardus stricta*
5. Grasses (except *Nardus stricta*) and subalpine *Vaccinium* vegetation
6. Alpine heathlands
7. Wetlands and peat bogs
8. Water areas (only for OBIA)

3.3 Training and Validation Data

The dataset collected in the field and completed with polygons added on the basis of orthoimages visual interpretation (see Chapter 3.1) was divided into training and validation parts.

Training dataset for per-pixel and object based classification of WV-2 and orthoimages using detailed classification legend contains 33 training polygons divided into 13 classes. The total area of training dataset is about 6,700 m^2.

Thirty seven polygons (area of 11,800 m^2) were used for validation. The training dataset for simplified legend was created by visual interpretation of orthoimages (WV-2 data, orthoimages). The total area of training data covered 17,396 m^2 (western part) and 31,800 m^2 (eastern part), respectively. For validation, combined validation and training datasets for the detailed legend (see above) re-classified into the simplified legend were utilized.

Training dataset for the simplified legend, based on visual interpretation of orthoimages, was also created in the case of Landsat 8 data. The rather big size of Landsat pixels, however, necessitated the use of larger areas. Altogether 1,133 pixels were trained (total area 1,019,700 m^2). The validation was again based on the dataset collected in the field (see Chapter 3.1). This dataset, however, had to be radically altered using visual interpretation of orthoimages and Landsat 8 images. The polygons identified in the field were always smaller than one Landsat 8 pixel. Thus, in cases when also the surrounding area was identified as the same class of the simplified legend, the respective pixels were taken into consideration in the accuracy assessment. On the contrary, pixels that clearly included a different land cover were deleted. Following the above mentioned adjustments, the Landsat validation dataset included 332 pixels covering the area of 298,000 m^2.

3.4 Mask

Clouds, shadows, and snow had to be masked from the imagery. The mask for WV-2 images was created by unsupervised classification ISODATA. Altogether 40 classes were identified and further aggregated into four groups: shadows and water areas in Western Tundra, plus clouds and snow in Eastern Tundra. The mask consisting of mentioned four classes had been applied to the imagery before the classification process started.

The mask applied to orthoimages (snow, shadows of vegetation and terrain) was created by object based classification using ENVI software and the rule-based approach. For the rules and attributes see Table 2. All four spectral bands and two parameters (Scale Level 40, Merge Level 80) were employed to carry out the segmentation.

For Landsat data, the mask of clouds and their shadows (located at NW part of the study area) was created using ISODATA classification.

Tab. 2 Rules and attributes used for orthoimages mask creation

Class	Attribute	Rule
shadows	Spectral Mean	1 < NIR < 65
snow	Spectral Mean	NIR > 255

3.5 Classification

The classification methods correspond to data types. Big differences among spatial resolutions of different data types justify the use of per-pixel and object based classification. Blaschke (2010) argues that the per-pixel approach brings better results when data with low spatial resolution are used; on the contrary, if data with high spatial resolution were available, object based classification is more appropriate. In our research, only object based classification is used for orthoimages, and only per-pixel classification for Landsat data. The WorldView-2 data were analysed using both object based and per-pixel approach enabling the comparison of results brought by these two methods. For schematic workflow see Figure 3.

3.6 Classification per-pixel

Three different per-pixel supervised classification algorithms were employed in this study: maximum likelihood

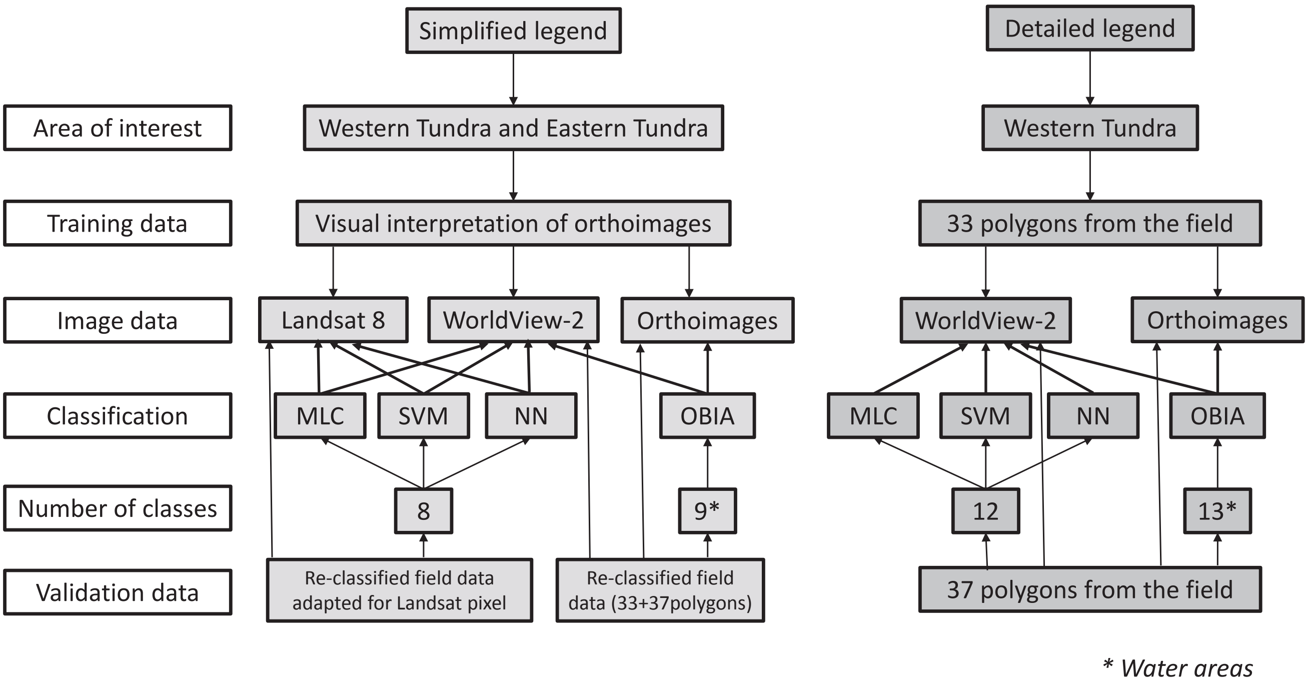

Fig. 3 Workflow.

classification (MLC), support vector machine (SVM), and neural net algorithms (NN).

Maximum likelihood classification

There are two conditions for successful application of this widely used algorithm. First, the image data should show normal distribution (Fernandez-Prieto 2006). Second, the training samples' statistical parameters (e.g., mean vector and covariance matrix) should truly represent the corresponding land cover class (Duarte et al. 2005). When ENVI software is used for maximum likelihood algorithm, parameters cannot be changed in any way with the exception of probability threshold parameter. The latter, however, was not used.

Machine learning algorithms

The machine learning classification algorithms, such as support vector machines (SVM) or artificial neural networks (or neural networks; NN), are also pixel-based classifiers (Petropoulos et al. 2012; Camps-Valls et al. 2004). Both methods belong among supervised non-parametric methods, which means that no particular data distribution is required (e.g. normal distribution). This makes a difference compared to other conventional classifiers, such as maximum likelihood classifier (Jones and Vaughan 2010). This fact is a big advantage of NN and SVM as the majority of remotely sensed data show an unknown statistical distribution.

Support vector machines algorithm

The support vector machines algorithm is based on the statistical learning theory and aims to find the best hyperplane in a multidimensional feature space that optimally separates classes. The term "best hyperplane" is used to refer to a decision boundary obtained in a training step and minimizing misclassifications. Training samples used for construction of hyperplane are called support vectors. These lie on the margin of classes to be classified and are extracted automatically by the algorithm (Jones and Vaughan 2010; Petropoulos et al. 2012; Mountrakis et al. 2011; Camps-Valls et al. 2004). Three Kernel types were tested using ENVI software in the case of SVM classification: radial basic functions (RBF), linear, and polynomial. In the case of RBF, Gamma was set to 0.125 for WV-2 and 0.143 for Landsat 8. Kernel Polynomial 2 was chosen in the case of polynomial function.

Neural networks algorithm

The artificial neural networks algorithm is designed to simulate human learning process by establishing linkages between input and output data via one or more hidden layers. The basic unit of each layer is called neuron (node) (Benediktsson et al. 1990). The classic model of a feed-forward multilayer neural network, known as multilayer perception (MLP) has fully-connected neurons between all layers (input, output, and hidden), which means that each neuron of a given layer feeds all the neurons in the next layer (Camps-Valls et al. 2004). This model is used in our processing tool, ENVI 5.2 software.

The neural network algorithm, applied to WV-2 data, was used in two modes. First, the default setting of ENVI software was applied. Second, the setting shown in Table 3 was used. Default setting was also applied to Landsat 8 data as the hidden layers and changes of some other parameters did not bring better results.

Table 3 Parameters of neural network algorithm

Training Threshold Contribution	0.9
Training Rate	0.9
Training Momentum	0.1
Training RMS Exit Criteria	0.05
Iteration	5000

3.7 Object based image classification

The object based image analysis (OBIA) does not examine pixels, but works with homogeneous clusters of pixels called segments. Segments are areas generated by one or more criteria of homogeneity. Thus, compared to single pixels, segments include additional spectral information (e.g. mean values per band, minimum and maximum values, mean ratios, variance etc.) (Blashke 2010). The example-based approach in ENVI software was employed for object based classification using the support vector machine algorithm.

Segmentation

The ENVI software includes only two segmentation algorithms: edge and intensity. The edge algorithm, where images are divided on the bases of Sobel's method of edge detection, was chosen in this study. Segmentation (orthoimages and WV-2) was carried out using all four/eight spectral bands. The parameters applied are shown in Table 4.

The ENVI software processes the segmentation each time it is started; consequently, the software does not allow to use any previously segmented image for further classifications.

Tab. 4 Segmentation parameters

Parameter	Orthoimages	WV-2
scale level	45	50
merge level	80	85
texture kernel size (pixels)	5 × 5	3 × 3

Example based classification

The example based classification sorts segments into pre-defined classes using training areas (segments), selected attributes, and classification algorithm. The following spectral and texture attributes were chosen: spectral mean, spectral max, spectral min, spectral standard deviation, texture mean, and texture variance. The above mentioned attributes were calculated for all spectral bands. The SVM classification algorithm with Kernel type radial basic function was used.

3.8 Accuracy Assessment

The ENVI software was used for accuracy assessment in all cases using validation polygons as defined for different data types (Chapter 3.3 and Figure 3). First, Confusion Matrix was created on the basis of ground true ROIs. The total accuracy was assessed as was the producer's and user's accuracy for different classes. Kappa coefficient for each classification was calculated, too.

4. Results

Table 5 shows the results of classifications (object based and per-pixel) for the detailed legend (applied in the western part of the tundra for orthoimages and WV-2 data). Table 6 shows the results for the simplified legend (applied in both parts of the tundra for all types of data). Figures 4–7 show the best classification map outputs for different types of data.

Tab. 5 Results of different classification methods (detailed legend) in Western Tundra.

Method	Data	Accuracy (%)	Kappa coeficient
OBIA-SVM (RBF)	orthoimages	**71.96**	0.65
	WV-2	**66.50**	0.60
SVM (RBF)	WV-2	60.82	0.54
SVM (polynomial)	WV-2	60.45	0.54
SVM (linear)	WV-2	60.30	0.54
NN	WV-2	60.13	0.54
MLC	WV-2	58.07	0.53
NN (default)	WV-2	54.59	0.49

4.1 Classification results: orthoimages

Orthoimages were classified by the object based approach only. This was applied to the detailed legend (western part) as well as to the simplified legend (western and eastern parts). The best classification results were obtained in the Eastern Tundra for simplified legend; the overall accuracy reached 83.56% (Kappa coefficient = 0.8). When different classes of the legend are compared, the classes "block field and anthropogenic areas", "water areas", and "wetlands and peatbogs" show the best results. The user's and producer's accuracy exceeded 90% in all cases.

On the contrary, the class "closed alpine grasslands dominated by *Nardus stricta*" shows the worst results of all. Though the producer's accuracy equalled 99.7%, the user's accuracy reached only 27%. The most common overlaps were with "*Pinus mugo* scrub sparse" and also with "wetlands and peatbogs".

In the case of detailed legend (Western Tundra), the overall accuracy equals 71.96% and Kappa coefficient 0.65. The best results were again achieved for the classes "water areas", "block fields and anthropogenic areas", and also for "*Pinus mugo* scrub". Producer's and user's accuracy varied in the range 87–100%. The classes "wetlands and peat bogs" and "subalpine *Vaccinium* vegetation" also show very good results with producer's and user's accuracy

Tab. 6 Results of different classification methods (simplified legend) in both parts of Tundra.

Method	Data	Area	Accuracy (%)	Kappa coefficient
OBIA-SVM (RBF)	orthoimages	East	**83.56**	0.8
	orthoimages	West	73.1	0.67
	WV-2	East	**66.37**	0.6
	WV-2	West	**68.4**	0.62
MLC	WV-2	East	57.04	0.48
	WV-2	West	59.96	0.51
	Landsat	West/East	**78.31**	0.75
SVM (polynomial)	WV-2	East	42.49	0.39
	WV-2	West	56.11	0.46
	Landsat	West/East	68.37	0.63
SVM (RBF)	WV-2	East	42.82	0.35
	WV-2	West	56	0.46
	Landsat	West/East	68.67	0.64
SVM (linear)	WV-2	East	41.19	0.32
	WV-2	West	55.28	0.45
	Landsat	West/East	68.37	0.64
NN (default)	WV-2	East	41.71	0.33
NN (default)	WV-2	West	57.42	0.47
NN	WV-2	East	36.64	0.27
NN	WV-2	West	58.36	0.48
NN (log)	Landsat	West/East	63.55	0.58

ranging between 70% and 80%. On the contrary, the classes "alpine heathlands", "*Calamagrostis villosa* stands", and "*Deschampsia cespitosa* stands" show poor accuracy (less than 10%). In the case of alpine heathlands, the selected sample did not include enough training areas.

4.2 Classification results: WV-2 data

Per-pixel and object based approaches were used in the case of WV-2 data. Both classifications were applied to detailed legend (Western Tundra) as well as to simplified legend (Western and Eastern Tundra).

Best results were obtained in the case of object based classification applied to simplified legend in the western part (overall accuracy = 68.4%, Kappa coefficient = 0.62). Classes "*Picea abies* stands" and "block fields and anthropogenic areas" were classified with the highest accuracy. Producer's and user's accuracy varied in the range 90–100%. Very good results were also obtained in the case of "grasses (except *Nardus stricta*) and subalpine *Vaccinium* vegetation" with producer's and user's accuracy equalling ca. 80%. "*Pinus mugo* scrub dense" was often confused with "*Pinus mugo* scrub sparse". The class "closed alpine grasslands dominated by *Nardus stricta*" shows the worst results (producer's accuracy = 73.73%, user's accuracy = 35.51%).

The overall accuracy of object based classification in the western part (detailed legend) was almost identical to that in the eastern part (simplified legend) – around 66%, Kappa coefficient = 0.6). Producer's and user's accuracy reached almost 100% in the case of "block fields and anthropogenic areas" class. Also the classes "*Pinus mugo* scrub" and "*Picea abies* stands" showed very good results (producer's and user's accuracy 80–99%). As in the case of orthoimages, the classes "alpine heathlands", "*Calamagrostis villosa* stands", and "*Deschampsia cespitosa* stands" were classified with poor accuracy (producer's and user's accuracy below 5%).

Per-pixel classifications of WV-2 brought worse results than the object based one. Overall accuracy ranged between 50 and 60%. As regards the detailed legend (Western Tundra), the SVM (RBF) classification brought the best results (60.82%, Cappa coefficient = 0.54). The MLC method worked best for the simplified legend (59.96%, Cappa coefficient = 0.51).

Classes "*Pinus mugo* scrub" (producer's accuracy = 85.35%, user's accuracy = 76.49%) and "block fields and anthropogenic areas" show best results within the detailed legend classified by per-pixel approach (SVM RBF method). Also "subalpine *Vaccinium* vegetation" was classified well (producer's accuracy = 70.26%, user's accuracy = 70.14%)

The results of earlier field research suggested that classes "*Calamagrostis villosa* stands" and "*Molinia caeruela* stands" would be confused with each other most often. This assumption was partly confirmed by per-pixel approach; however, also classes "*Nardus stricta* stands" and "*Deschampsia cespitosa* stands" often overlapped. Surprisingly, it was "*Deschampsia cespitosa* stands" that showed the best results of all grassland vegetation – producer's accuracy equalled 70.26%, user's accuracy 40.21% (SVM RBF method).

Regarding the assessment of simplified legend in Western and Eastern Tundra, "*Pinus mugo* scrub" (dense and sparse) again showed the bests results. The producer's accuracy exceeded 90% in both cases; user's accuracy ranged around 60%. However, "*Pinus mugo* scrub dense" was often confused with "*Pinus mugo* scrub sparse". For future WV-2 classification, it may be appropriate to merge these two classes.

In the Western Tundra, "block fields and anthropogenic areas" and "closed alpine grasslands dominated by *Nardus stricta*" showed very good results. Classes "Alpine heathlands" and "block fields and anthropogenic areas" performed best in the East.

4.3 Classification results: per-pixel approach applied to Landsat data

Landsat data were classified only by per-pixel algorithms that were applied to simplified legend, simultaneously in both parts of the tundra. MLC algorithm brought the best results (overall accuracy 78.31%); other algorithms brought worse results by more than 10%.

The classes "*Pinus mugo* srub dense", "Alpine heathlands", "*Picea abies* stands", and "block fields and anthropogenic areas" were classified without major problems – producer's and user' accuracy exceeded 80% and often were close to 100%. In the case of "*Pinus mugo* scrub sparse", producer's accuracy equals 100%, but user's accuracy was rather low (45.9%). It means that "*Pinus mugo* scrub sparse" was overclassified, largely to the detriment of "grasses (except *Nardus stricta*) and subalpine *Vaccinium* vegetation". On the contrary, the class "closed alpine grasslands dominated by *Nardus stricta*" showed a sort of a reverse effect: the producer's accuracy was rather low (44.44%) as the latter was often confused with "grasses (except *Nardus stricta*) and subalpine *Vaccinium* vegetation".

It can be concluded that most problems were posed by grassland vegetation and by classes where grassland vegetation occurs extensively. Other land cover types were classified well also by Landsat data.

4.4 Classification results: map outputs

Classification map outputs can be found in Colour Appendix. Figure 4 shows the best classification results for detailed legend; Figures 5 and 6 show that for simplified legend and object based classification of orthoimages and WordView-2 data in Western and Eastern Tundra. The best results for Landsat 8 data are shown in Figure 7.

When classification outputs are compared, varying spatial resolution of different data types is instantly recognizable. Based on different spatial resolution final mosaics of classified categories differs (areal extent, spatial distribution, shape). While Landsat 8 data are useful rather for general overview, orthoimages provide accurate maps of land cover within the study area for all classes of the detailed legend.

5. Discussion and Conclusions

The major aim of this study was to assess and compare the potential of selected multispectral data with various spatial and spectral resolutions for land cover classification above the tree line. Different types of classifiers were used including per-pixel and object based approach.

Though vegetation types are usually well defined and do not overlap too much in the tundra of Krkonoše, a vast array of species exists there. These species often alternate with each other within a limited area. Consequently, spatial resolution plays a more important role than spectral resolution in the case of object based classification. It was the object based classification of orthoimages (spatial resolution 12.5 cm, four spectral bands) that brought the best results for both legends – overall accuracy equalled 72–84%. Thus, it has been confirmed that application of object based classification is more appropriate than per-pixel approach when data with very high spatial resolution are examined. Orthoimages and object based classification can be recommended to National Park authorities as appropriate tools for landscape monitoring in this area of high nature value. Another advantage is that orthoimages are updated every second year by the state and consequently available for free to the National Park management. On the contrary, object based classification requires a specialized software, the classification itself is rather difficult, and processing time quite long.

The object based classification of WorldView-2 data was less accurate than in the case of orthoimages (68.4% at best) though WV-2 data provide better spectral resolution. The per-pixel approach applied to WV-2 data (detailed legend) was even less accurate; the highest accuracy (60.82%) brought the SVM (RBF) algorithm.

Classification of Landsat data applied to simplified legend (MLC method) brought surprisingly good results – overall accuracy equalled 78%. Construction of the legends may be the reason why per-pixel classifications applied to simplified legend were more accurate in the case of Landsat data rather than for WV-2 data. A special simplified legend optimized for Landsat data was created. The use of training or validation polygons for detailed legend proved to be impossible as in most cases these polygons were smaller than the pixel size (30 × 30 metres); thus, clear pixels for detailed legend could not be defined.

Such a simplified, specially adjusted legend, however, was not fully appropriate for WorldView-2 data. Classes "*Pinus mugo* scrub dense" and "*Pinus mugo* scrub sparse" posed biggest problems in the case of simplified legend and were often confused with each other. Though such a precise definition of *Pinus mugo* (dense vs. sparse) is essential for Landsat data, it is apparently not appropriate for high resolution data as WV-2. Moreover, some training and validation polygons were covered by clouds during research time; consequently, part of WV-2 data could not be used.

This study also compared the suitability of per-pixel and object based classification for different data types. Per-pixel classification proved to be fully appropriate in the case of Landsat data. On the contrary, per-pixel classification of high resolution orthoimages brought unsatisfactory results. Object based classification of Landsat data (spatial resolution 30 metres) does not make much sense either on such a small territory where vegetation classes alternate often. Both types of classification were applied to WorldView-2 data; object based classification brought better results by some 10% than the per-pixel one.

Different algorithms for per-pixel classification were compared, too. The examination of WV-2 data showed that the MLC classifier worked best for simplified legend. In the case of detailed legend, however, the more sophisticated algorithm, SVM (RBF), brought better results.

Earlier field research suggested that classifications would be more accurate in the Eastern Tundra as different vegetation types as specified in the legends seemed to be clearly defined there. As an example, "*Molinia caeruela* stands" and "*Calamagrostis villosa* stands" covered compact areas surrounded by "*Nardus stricta* stands". This presumption was confirmed by orthoimages classification (overall accuracy 83.56%). Classification of WV-2 data, however, brought different results – in part probably due to clouds and shadows on the image.

Classification results may be influenced by varying weather conditions, and also by the season. Vegetation classes tend to be rather compact during spring and autumn, while in summer (July, August) the grassland vegetation advances and different types blend. The blossom may also influence spectral bands in some cases. The above mentioned differences may have played a certain role when orthoimages and WV-2 data were compared. Unfortunately, it is practically impossible to acquire all required multispectral data of different spectral and spatial resolution within one year and one season. That is why it was necessary to examine data acquired in different years. Research results may be partly influenced by this fact.

Regarding classification accuracy of different classes, all types of data brought good results for non-vegetation classes (block fields and anthropogenic areas, water areas). Also the category subalpine *Vaccinium* vegetation shows high accuracy for detailed legend (orthoimages and WV-2 data). As expected, subalpine tall grasslands subcategories with similar spectral signatures (*Calamagrostis villosa* stands and *Deschampsia cespitosa* stands, *Molinia caeruela* stands) show less satisfactory results. The worse-than-expected results in the case of alpine heathlands were probably influenced by the low presence of training polygons. On the contrary, Landsat 8 data covered the whole tundra and therefore also more training polygons – consequently, alpine heathlands were classified with high accuracy (MLC: user's accuracy 95.65%, producer's accuracy 81.48%).

Pinus mugo scrub usually shows good classification results, too. In the case of simplified legend, *Pinus mugo* scrub was further subdivided into dense and spare subcategories; such a subdivision, however, proved to be inappropriate for WV-2 data and orthoimages. As Landsat data consist of rather big pixels, it is difficult to find really uniform categories. *Pinus mugo* scrub sparse is often mixed with grassland vegetation within one pixel. *Pinus mugo* scrub dense does not have this problem and brings better results when classified as a separate class. When it comes to very high resolution data, however, *Pinus mugo* scrub practically does not mix with other categories. Some categories of simplified legend may be too broadly defined for high resolution data. This was proved to a certain extent in the case of closed alpine grasslands dominated by *Nardus stricta* and grasses (except *Nardus stricta*) and subalpine *Vaccinium* vegetation classes.

The results comparing detailed and simplified legends show that in the case of multispectral data with different spatial resolution it is difficult – if not impossible – to find such a compromise that would be appropriate for data of different resolution. One single legend cannot serve a basis for comparison of different data; the level of detail should always be related to data resolution.

It can be concluded that in the case of simplified legend – the overall accuracy of Landsat data (MLC algorithm, 78.31%) and object based classification of orthoimages (83.56%) – our results are similar to those mentioned in earlier scientific sources. As an example, Müllerová (2004) classified multispectral data in Krkonoše in 1986, 1989, and 1997; supervised classification identified nine classes of local vegetation with accuracy 81.1%. Král (2009) classified alpine vegetation on the Czech territory, too. In the latter case, the accuracy of orthoimages equalled 78% (MLC method). However, the rather high spectral variation of different land cover classes and low spectral resolution of orthoimages resulted in mixed character of many classes. Wundram a Loffler (2008) classified alpine vegetation in Norway and achieved similar results. The maximum likelihood method applied to orthoimages (RGB bands) resulted in overall accuracy equalling 51%.

Algorithm MLC used for Landsat data classification brought the accuracy of 78.31% in our research. Knorn et al. (2009) utilized Landsat data for land cover classification in the Carpathians; SVM method brought accuracy up to 98.9% for nine classes. Landsat data were also used by Johansen et al. (2012) for tundra mapping on Svalbard. The final product was a map (scale 1: 500,000) containing eighteen classes. The processing chain contained six stages including unsupervised classification and merging the classes based on ancillary data. Verification of the final product is problematic in such remote areas; the overlap between Landsat data classification and traditional vegetation mapping in Gipsdalen Valley reached 55.36% (eight aggregated classes were tested).

Our research confirms that Landsat data are sufficient to get a general overview of basic land cover classes above the tree line in the Krkonoše Mts. National Park. Alternatively, the recently launched Sentinel-2 satellite could be used – images have comparable spatial resolution and better spectral resolution. Detailed classification, however, requires orthoimages with very high spatial resolution, plus sophisticated algorithms of object based classification should be used. WorldView-2 data brought the least satisfactory results in our research. However, this may have been influenced by clouds, and also by problems with exact definition of the legend as discussed above. Based on the comparison of the data with different spectral and spatial resolution we can conclude that very high spatial resolution is the decisive feature that is essential to reach high overall classification accuracy in the detailed level. Zagajewski (2005) and other scientists suggest that utilization of hyperspectral data of very high spatial resolution (alternatively combined with LiDAR data – see Dalponte 2012) could bring further improvements of classification accuracy.

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RESUMÉ

Klasifikace vegetace nad horní hranicí lesa v Krkonošském národním parku s využitím multispektrálních dat

Článek hodnotí možnosti multispektrálních dat s rozdílným prostorovým a spektrálním rozlišením pro klasifikaci vegetace nad horní hranicí lesa v Krkonošském národním parku. Letecká ortofota s velmi vysokým prostorovým rozlišením 12,5 cm a čtyřmi spektrálními pásmy byla klasifikována objektovou klasifikací. Družicová data WorldView-2 (WV-2) s vysokým prostorovým rozlišením 2 m a osmi spektrálními pásmy byla klasifikována jak objektově, tak pixelově. Pixelová klasifikace byla provedena i na volně dostupných datech Landsat 8 s prostorovým rozlišením 30 m a sedmi spektrálními pásmy. Z algoritmů pro pixelovou klasifikaci byly porovnávány klasifikátory maximum likelihood classification (MLC), support vector machine (SVM) a neural net (NN). Pro objektovou klasifikaci byl využíván přístup example-based a algoritmus SVM (vše dostupné v ENVI 5.2). Schéma pracovního postupu je na obrázku 3.

Analýza byla provedena v krkonošské tundře. Modelová oblast je situována ve dvou prostorově oddělených částech – východní a západní části tundry (obrázek 1). Pomocí dat Landsat byla hodnocena celá oblast východní (rozloha 1284 ha) i západní (rozloha 2284 ha) tundry v české části KRNAP. Pomocí ostatních datových zdrojů vzhledem k výpočetní náročnosti klasifikací pouze vybrané části území (565 ha na západě v and 839 ha na východě) reprezentativní pro danou oblast.

Klíčovou částí práce byla definice legendy, která byla vytvořena ve spolupráci s botanikem Krkonošského národního parku. Základní podrobná legenda obsahuje celkem 12 tříd (viz níže a viz obrázek 2). Byla využita pro ortofota a WV-2, a to pouze v západní tundře. Vzhledem k tomu, že se dané třídy vyskytují velmi často na menších plochách, než je pixel Landsatu 8 (tj. 900 m^2), bylo nutné vytvořit i zjednodušenou legendu vhodnou pro klasifikaci dat Landsat. Zjednodušená legenda obsahuje 8 tříd a byla použita pro klasifikaci všech zmíněných typů dat za účelem jejich porovnání.

Podrobná legenda
1. kamenná moře a antropogenní plochy
2. smrkové porosty
3. kosodřevina
4. subalpínská brusnicová vegetace
5. alpínské trávníky zapojené
5a. smilka tuhá
5b. druhově bohaté porosty s vysokým zastoupením dvouděložných
6. subalpínské vysokostébelné trávníky
6a. třtina chloupkatá
6b. bezkolenec modrý
6c. metlice trsnatá
7. subalpínské vysokobylinné trávníky
8. alpínská vřesoviště
9. mokřady a rašeliniště
10. vodní plochy (klasifikovány pouze z ortofot)

Zjednodušená legenda
1. kamenná moře a antropogenní plochy
2. smrkové porosty
3a. kosodřevina hustá (> 80% porostu)
3b. kosodřevina řídká (30% - 80% porostu)
4. alpínské trávníky zapojené s vysokým zastoupením smilky tuhé
5. trávy (vyjma smilky tuhé) a subalpínská brusnicová vegetace
6. alpínská vřesoviště
7. mokřady a rašeliniště
8. vodní plochy (klasifikovány pouze z ortofot)

Nejlepší výsledky byly v případě podrobné i zjednodušené legendy dosaženy pro ortofota (celková přesnost klasifikace 83,56, resp. 71,96 %, Kappa koeficient 0,8, resp. 0,65). Klasifikace WV-2 dosáhla nejlepšího výsledku v případě objektového přístupu a zjednodušené legendy (68,4 %), z pixelových klasifikací v případě metody SVM (RBF) a podrobné legendy (60,82 %). Data Landsat byla nejpřesněji klasifikována s využitím MLC (78,31 %). Nejlepší klasifikační výstupy pro jednotlivé typy dat jsou na obrázcích 4–7.

Potvrdil se náš předpoklad, že v případě vegetace v tundře dosáhneme pro data s velmi vysokým prostorovým rozlišením objektovou klasifikací lepších výsledků než klasifikací pixelovou. Ortofota a objektovou klasifikaci lze na základě našich výsledků doporučit managementu národního parku pro monitoring této cenné části Krkonoš. Výhodou je i to, že ortofota jsou pravidelně každé dva roky pořizována ze státních zdrojů a národní parky je mají volně k dispozici. Nevýhodou je naopak nutnost vlastnit SW pro objektovou klasifikaci, poměrně náročný postup klasifikace a delší výpočetní čas.

Pokud se týká přesnosti klasifikace jednotlivých tříd, tak lze říci, že v žádném z typů dat nebyl problém s klasifikací nevegetačních tříd (kamenná moře a antropogenní plochy, vodní plochy). Dobře byla také většinou vyklasifikována kategorie kosodřevina. Pro detailní legendu dosahovala dobré přesnosti také kategorie subalpínská brusnicová vegetace (v případě ortofot i WV-2). Horší klasifikační výsledky jsme podle očekávání zaznamenali v případě podkategorií třídy subalpínské vysokostébelné trávníky, jejichž spektrální signál je podobný (třtina chloupkatá, bezkolenec modrý, metlice trsnatá).

Na základě výsledků klasifikace jednotlivých kategorií s využitím podrobné a zjednodušené legendy lze učinit závěr, že v případě klasifikace multispektrálních dat s řádově různým prostorovým rozlišením je problém najít takovou kompromisní legendu, která by vyhovovala všem prostorovým rozlišením. Srovnání potenciálu těchto dat na základě jedné legendy tedy není zcela možné a při sestavování legendy vždy musíme její podrobnost vztáhnout k rozlišení dat.

Z porovnání dat s rozdílným spektrálním a prostorovým rozlišením vyplynulo, že velmi vysoké prostorové rozlišení dat je zásadním parametrem pro dosažení vysoké celkové přesnosti klasifikace v detailní úrovni.

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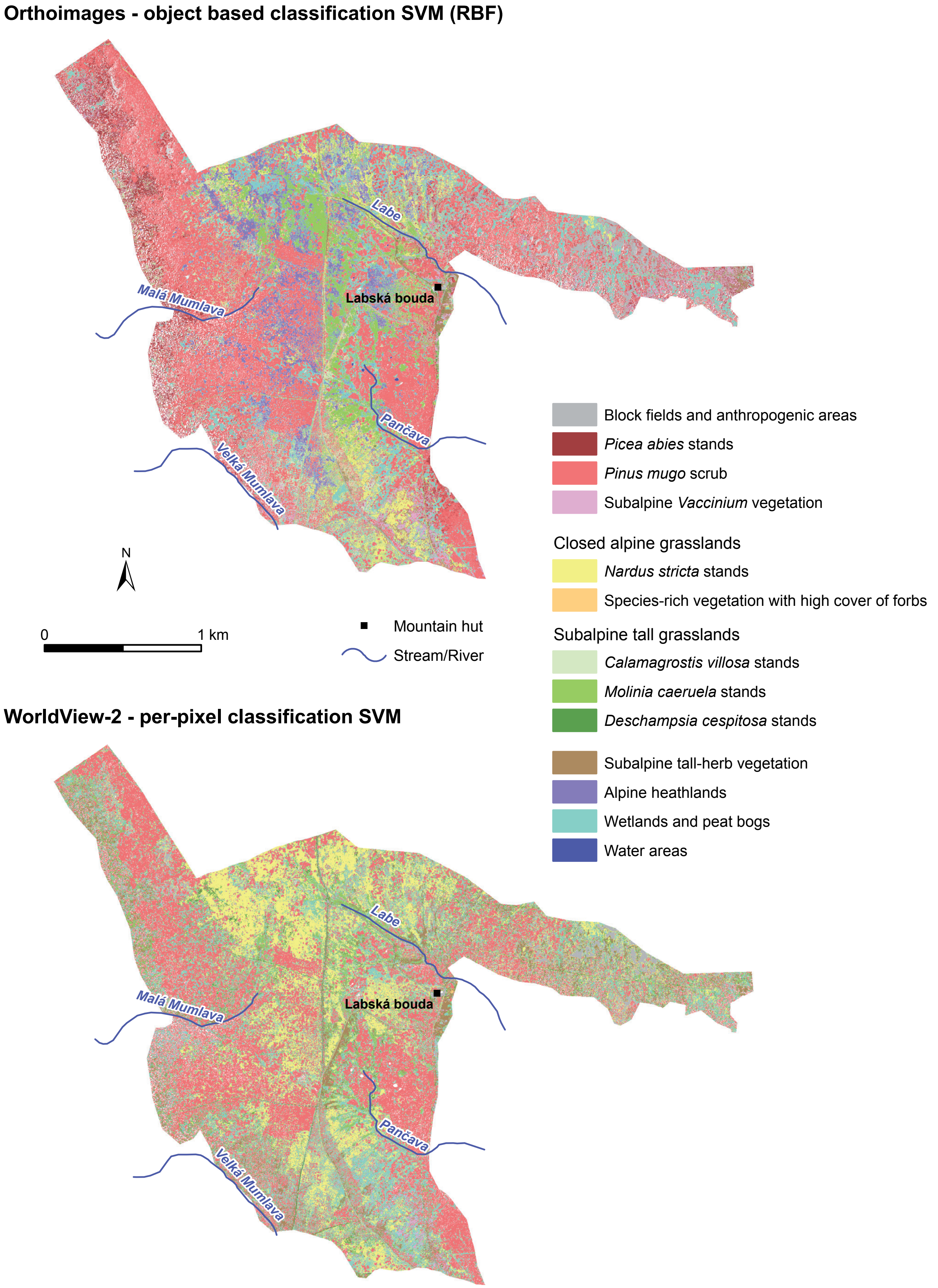

Fig. 4 Classification results for **detailed legend** in **Western** Tundra. Upper figure: **orthoimages – object based** classification SVM (RBF); lower figure: **WordView-2** – **per-pixel** classification SVM (RBF). Source: Authors

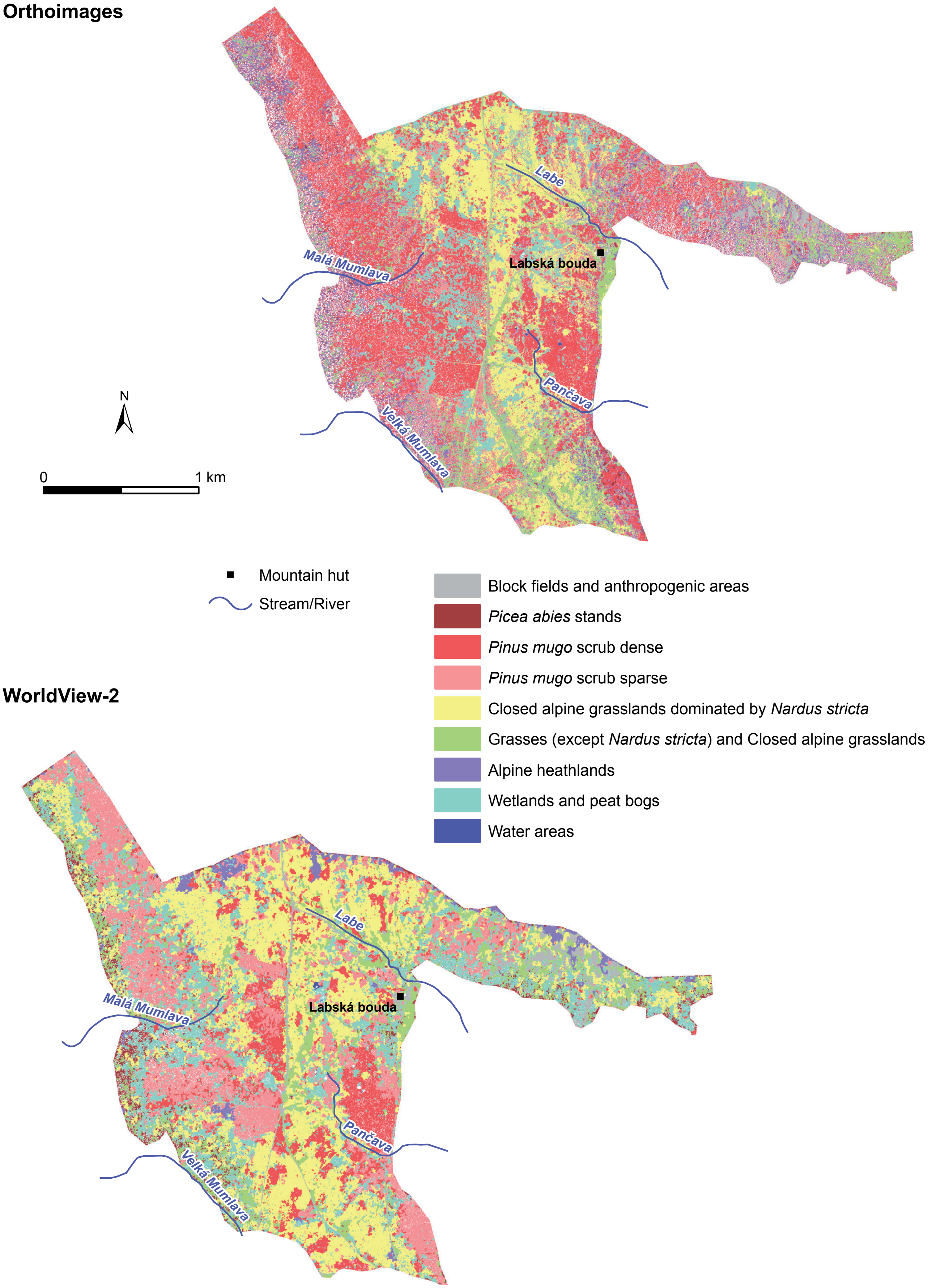

Fig. 5 Results of object based classification SVM (RBF) for **simplified legend** in **Western** Tundra. Upper figure **orthoimages**, lower figure **WordView-2**. Source: Authors

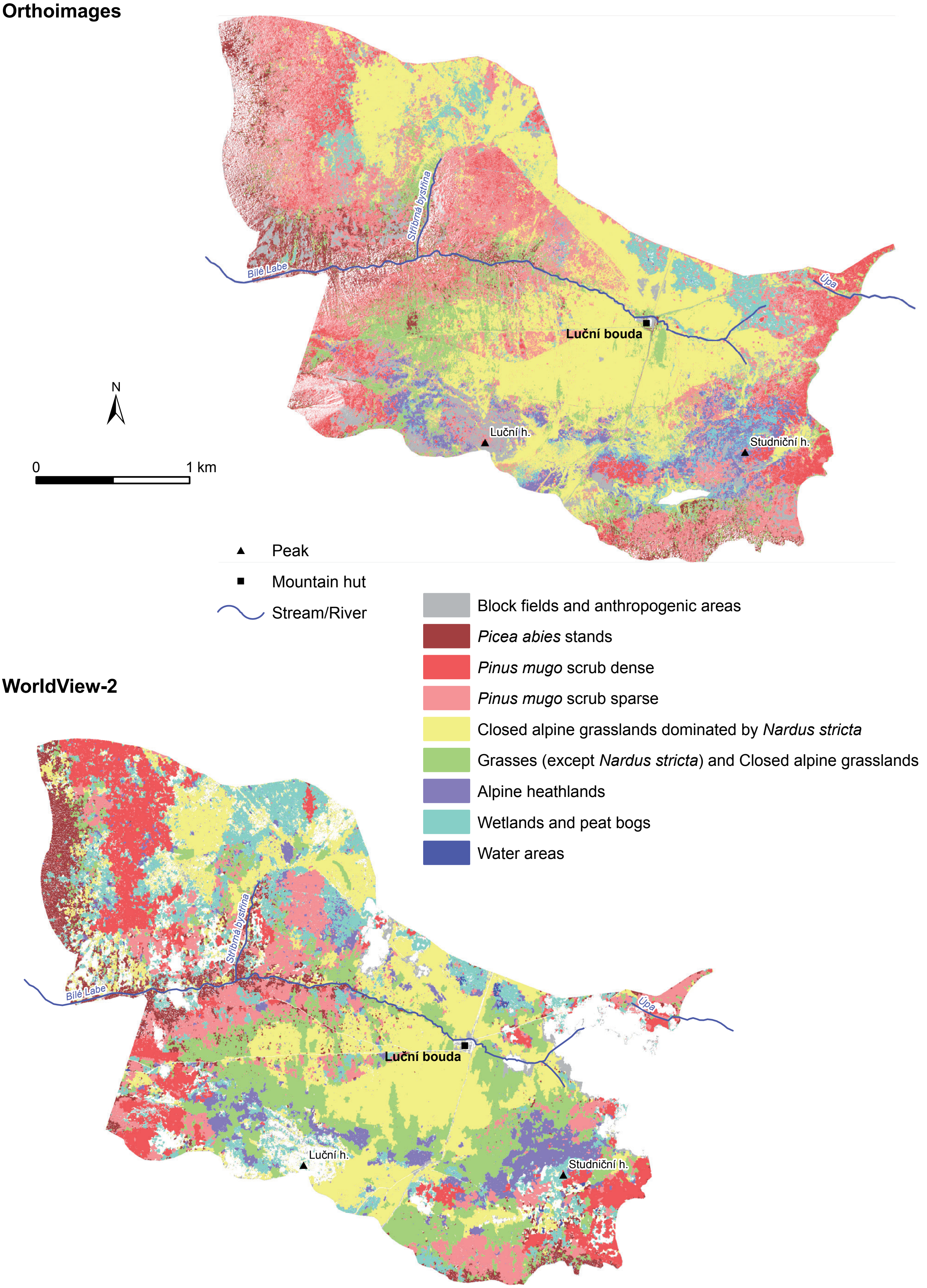

Fig. 6 Results of object based classification SVM (RBF) for **simplified legend** in **Eastern** Tundra. Upper figure **orthoimages**, lower figure **WorldView-2**. Source: Authors

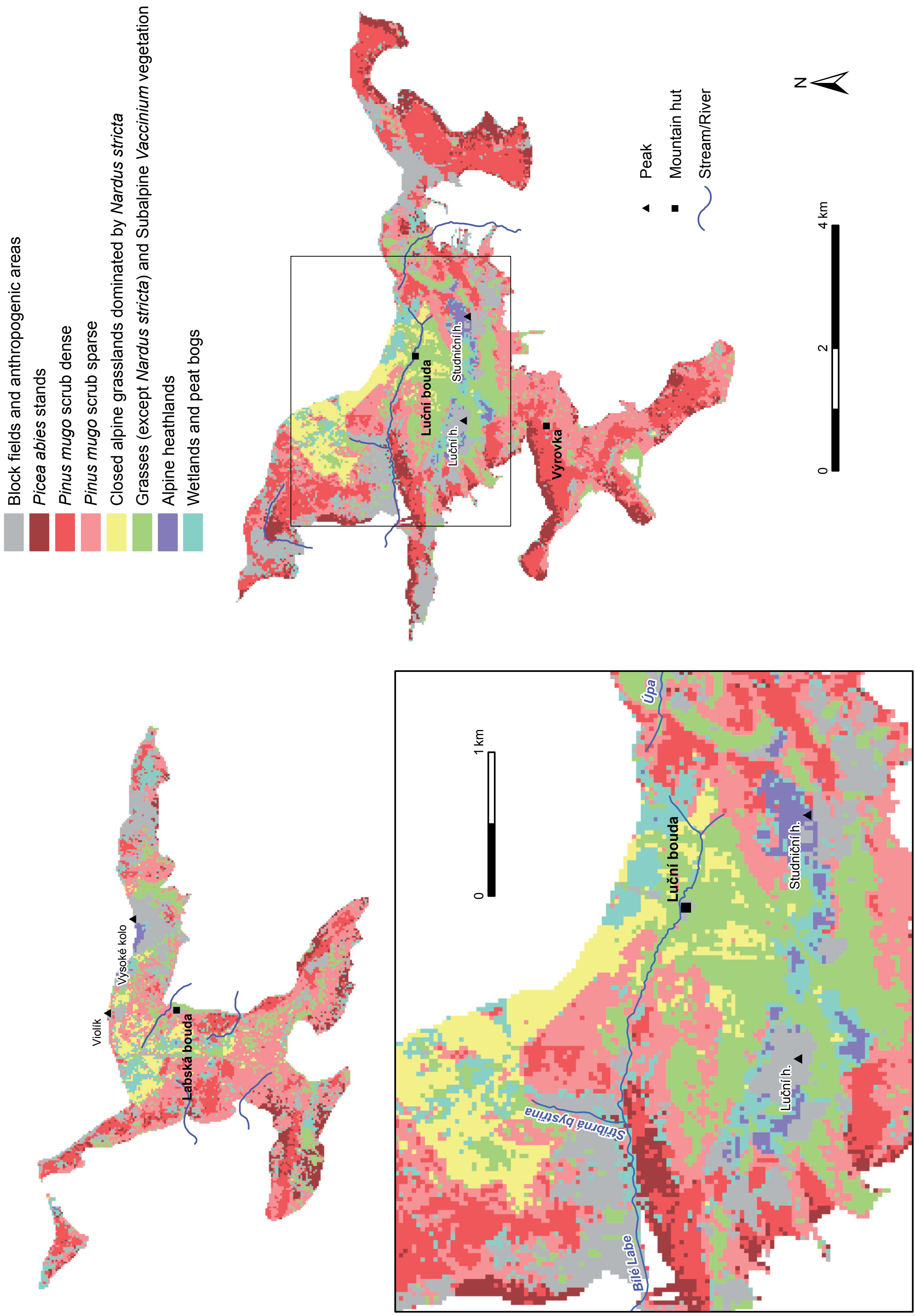

Fig. 7 Classification results for **Landsat 8** – maximum likelihood classifier. Source: Authors