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REPORTS

THEORETICAL VIEW OF THE SHANNON INDEX IN THE EVALUATION OF LANDSCAPE DIVERSITY

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ABSTRACT

Shannon's diversity index is frequently used in the determination of landscape diversity. Its indisputable advantage is a possibility to obtain numeric values that can subsequently be easily compared. However, accurate evaluation of landscape diversity from obtained results is rather complicated. The aim of the article is (i) to take a closer look at the theoretical origin of the formula that stems from the principles of the calculation of information entropy and (ii) to draw attention to several issues connected to the Shannon index application in landscape diversity assessment.

Numeric value of the Shannon's index depends on applied logarithm base that is not precisely specified by the formula. Presenting the resulting Shannon index value without stating the logarithm base is not very suitable. Nevertheless, a bigger problem is the dependence of the resulting Shannon's diversity index value on two parameters, namely the number of studied categories and evenness of spatial distribution of individual categories. The resulting value may be identical for different types of the division of the study area. Therefore, the number of categories and the evenness of spatial distribution need to be taken into consideration in the very assessment of the Shannon index result. The number of categories could also be presented along with the resulting Shannon's index value. A major drawback of the Shannon index is its inability to express spatial distribution of patches within the area; it only presents the total extent of each category. Out of existing modifications of the index that try to take spatial distribution into consideration, the most convenient is the coefficient of the distance between the extent of identical and different categories.

Based on arguments deriving from theoretical basis of the Shannon index formula and its practical application, a new view of landscape diversity maximum is presented. The application of the Shannon index disregards the fact that the original relation required for entropy calculation presupposes independence of the existing state (e.g. land cover categories in case of landscape assessment). With regard to the fact that commonly defined categories of patches are independent; the index calculation should make use of the relation considering conditional probabilities of the occurrence of a certain category.

Key words: Shannon index, entropy, landscape diversity, maximum diversity

1. Introduction

Landscape assessment represents a complex activity. Landscape can be described from the point of quality and quantity. Quality description of landscape mosaic focuses particularly on its content. On the base of qualitative characteristics all structures of landscape mosaic are ranged into individual categories, e.g. land cover categories. Quantitative approach deals with quantitative assessment, i.e. possibilities to measure and calculate various values of the landscape structure. Quantitative landscape characteristics are determined by means of landscape metrics describing landscape structure and evolution. A benefit of quantitative values consists in obtaining exact numeric data on the landscape structure that can be compared, e.g. various years within one locality or various localities in individual years (Popelková 2009). The number of landscape metrics is high. For example, McGarigal and Marks (1995) present 100 landscape metrics, many of which are mutually dependent (Cushman et al. 2008). Existing metrics are often modified and completely new metrics occur as well. One of them is a newly created coefficient of mining-based landscape transformation (Mulková, Popelková 2008), which is defined as the ratio of the area that originated due to mining to the area representing original cultural landscape. The coefficient represents the transformation process of original cultural landscape into mining landscape (Mulková 2007).

The use of landscape metrics for the assessment of landscape structure and evolution is, however, connected with many problems. The metrics cannot always be applied to all data. Special attention thus needs to be paid to the interpretation of quantitative data.

Landscape can be characterised by diversity expressing the extent of heterogeneity and variety of landscape structure. In ecology, landscape diversity indices are, for example, the Simpson's diversity index, which is particularly sensitive to species richness, and the Shannon index, which is sensitive to rare species (Farina 2006). Shannon's and Simpson's diversity indices can also be applied to landscape (UMass Landscape Ecology Lab 2012).

If landscape diversity needs to be assessed, it is Shannon's diversity index that is used most frequently, as stated by McGarigal and Marks (1995). The aim of the article is to draw attention to difficulties related to the application of this landscape assessment index.

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2. Theoretic background

2.1 Origin

The author of Shannon's diversity index equation is Claude Elwood Shannon (1916–2001), an American electronic engineer and mathematician, known as the father of information theory. The equation, which was published in *A Mathematical Theory of Communication* in 1948 (Shannon 1948), was derived within information theory and the quantity that it expresses was named *entropy*. Shannon adopted this denomination from Boltzmann's thermodynamic entropy. Although there is formal congruence of the relations within information and thermodynamic entropy, it took many years until their mutual relation was proved. At present, the relation is applied in many scientific fields; among others, in geography and biology for diversity determination.

2.2 Information and entropy

In order to understand the importance of the relation that is used in connection with landscape diversity, its origin within the information theory needs to be shown.

Basic concepts:

– **alphabet** is a set of symbols – the number of symbols s, e.g. for the alphabet {a, b, c, d, e} is $s = 5$.

– **message** is a sequence of symbols, e.g. 'babaccdbeae', of the length n. In the given example $n = 11$.

The number of possible messages N of the length n over the alphabet of symbols s is calculated as a variation with repetition:

$N = s^n$.

In the above case $N = 5^{11} = 48{,}828{,}125$ possible messages.

We look for a function that can express information extent (I) contained in a single message. This function must comply with two requirements:

1. the amount of information in a message depends on the number of possibilities (alternatives) N – the higher N *is*, the more information the message contains

$I = f(N) = f(s^n)$,

2. if one message originates as a compilation of two messages ($n = n_1 + n_2$), the amount of information in the resulting message equals the sum of information contained in individual messages:

$I = f(s^{n_1+n_2})$ … the message originates as a compilation of two messages,

$I = I_1 + I_2 = f(s^{n_1}) + f(s^{n_2})$ … the resulting information is the sum of all information,

$f(s^{n_1+n_2}) = f(s^{n_1}) + f(s^{n_2})$ … we look for a function that complies with this equality relation.

The mathematical solution (Shannon 1948) is the equation:

$$I = k \cdot \log(s^n) = k \cdot n \cdot \log s, \tag{1}$$

where k is any constant – the issues of the constant are dealt with in the section 'Logarithm base'. The equation expresses the information extent within one message. If we want to express the average information extent for one symbol of the message, then we get

$$H = \frac{1}{n} = k \log s. \tag{2}$$

This relation is valid in the case of equal probability (frequency) of the occurrence of individual symbols in one message. If the symbols appear with dissimilar probability $p_i \in (p_1, p_2 \dots p_s)$, where $0 \le p_i \le 1$, then after making modifications and using Stirling's formula (Shannon 1948) we get the relation expressing the amount of information for one symbol of a message

$$H = \frac{1}{n} = -k\sum_{i=1}^{s} p_i \log p_i\,. \tag{3}$$

As stated above, the quantity H was denominated entropy (information entropy). The relation (3) presents the features of entropy:

1. entropy only depends on probabilities (not on values of symbols in a message),

2. entropy is invariant to the sequence of symbols,

3. for a concrete s, maximum entropy occurs for $p_1 = p_2 = \dots = p_s = 1/s$, i.e. for steady representation of symbols,

4. minimum entropy occurs for $s = 1$, then $p_1 = p = 1$ and $p \log p = 1 \cdot \log 1 = 1 \cdot 0 = 0 \rightarrow H = 0$.

2.3 Application for landscape diversity

The original equation contained probabilities of phenomena (symbols) that in landscape assessment were substituted with proportional representation of areas of individual categories. Proportional representation of individuals within individual categories is used in order to determine the diversity of species in biology. Shannon's diversity index (*ShI*) used in landscape assessment is defined as follows:

$$ShI = -\sum_{i=1}^{m} P_i \log P_i\,, \tag{4}$$

where m is the number of the studied categories (e.g. land cover categories), P_i is proportional representation of i-th category in the total area:

$$P_i = \frac{B_i}{\sum_{i=1}^{m} B_i}\,,\ B_i \text{ is surface area of } i\text{-th category.}$$

ShI expresses uncertainty with which we are able to predict which category a randomly selected point within the studied area will belong to.

The calculation of *ShI* derives from the fact that a higher value of *ShI* points to higher landscape diversity. Although absolute *ShI* amount can be interpreted with difficulties, *ShI* is frequently used as a relative index in the comparison of various areas or the same locality in several years (McGarigal and Marks 1995).

The calculation of diversity by means of *ShI* is not the only use case the logarithmic function in geography. The other applications are presented for example in Thomas and Huggett (1980).

3. Practical problems related to the Shannon index application

Equation (1) and subsequently equation (3) were derived from basic requirements of the function I or H. The equations do not define the values I and H absolutely clearly because they contain a constant k and a logarithmic function. As for the logarithmic function, a parameter is logarithm base a which the equations do not determine. With regard to the fact that the logarithmic function generally complies with the requirements of the equations, it is possible to select a random value complying with the condition $a \in \mathrm{R}, 0 < a \neq 1$ as the logarithm base. The logarithm base is also related to the constant k. In the calculation, the constant is a criterion that decides about the units in which the result will be expressed. The constant can be selected based on the requirements of a concrete equation value for given values n and s. For example, if the average information extent for one symbol of binary alphabet ($s = 2$) is required to equal one, we can start from equation (2):

$H = I/n = k \cdot \log_a s$,
$H = k \cdot \log_a 2 = 1$,
$\mathrm{k} = 1/\log_a 2$.

Using the relation (Rektorys 1963)

$$\log_b x = \frac{\log_a x}{\log_a b} \qquad (5)$$

we get: $H = \dfrac{1}{\log_a 2} \log_a s = \log_2 s$.

The selection of the constant thus determined the logarithm base.

It is the binary logarithm (logarithm to the base 2) that is exclusively used in the information science because each symbol in a message brings one unit of information and the information of the whole message is given by the number of symbols. As it is generally known, a unit of information expressed by means of binary logarithm is the bit. Other commonly used logarithm bases are $e = 2.7182\ldots$ (Euler number) – the so-called natural logarithm and 10 – decadic logarithm.

The question of logarithm base in *ShI* remains often unresolved. Consequently, it is merely the *ShI* value that is presented regardless the concrete logarithm base. This fact is accompanied by disunity in logarithm denotation. Different countries and different fields of science use different logarithm denotations: log, lg, ln, lb, and ld. If the logarithm base used in the calculation is unknown, no comparison of calculated values with the values of other authors is possible. This problem could be solved by conventional modification of the equation in which the logarithm base is presented as an index, as in the case $ShI_2 = 1.12$, which means that the index was calculated by means of a binary logarithm.

3.1 Numeric perspective

For $P_i = 0$, the logarithm reaches the value minus infinity and the expression $P_i \cdot \log P_i$ is indefinite $(0 \cdot -\infty)$. On the basis of the limit it is determined that $0 \cdot \log 0 = 0$. There is a drawback in the practical calculation that $\log 0 = -\infty$ can cause calculation collapse. Therefore, there are two methods:

a) make sure zero stays away from the calculation – this is feasible using manual calculation in which zero values are left out,

b) include a condition into the calculation which says that for $P_i = 0$ the calculation disregards the equation and directly substitutes the expression $P_i \cdot \log P_i$ $(0 \cdot \log 0 = 0)$ with zero. This way it is necessary to treat all bulk calculations in e.g. spreadsheet or GIS software.

ShI can acquire values coming from real numbers from 0 to $+\infty$, while 0 is the result for $P_i = 1$. The value of P_i decreases with increasing number of categories, namely for $P_i \to 0$ there is, in theory, $\log P_i \to +\infty$. Practically, however, *ShI* never reaches high values – e.g. for a million of evenly represented categories and in case of the binary logarithm $ShI_2 = 20$. As for practical calculations, we are always limited by the number of categories which is always finite. Even theoretically, with an infinite number of categories, we are limited by the accuracy of processed data. If we suppose the accuracy of 1 m^2, in case of e.g. the United Kingdom (243,610 km^2) we are able to distinguish $2.44 \cdot 10^{11}$ of individual patches for which $ShI_2 = 37.8$. Thus, it is impossible to even remotely approximate infinitely high values in practical calculations.

In calculations and subsequent assessment of landscape diversity, it is essential that maximum diversity value is precisely given for a concrete number of patch categories. Maximum diversity value occurs with even representation of categories.

4. Theoretical problems of the application of the Shannon index

4.1 Dependence on two parameters

Equation (4) shows that *ShI* value depends on two parameters. The first parameter is the number of studied categories m; the ShI value increases with an increasing number of categories. The other parameter is the evenness of the spatial representation of individual categories; maximum ShI value is reached with fully even spatial representation of categories. The dependence of the only value of the result on two parameters is a drawback of the equation for ShI calculation. Equal diversity value is thus observed in the territory whose 90% is dominated by one category and the rest 10% is evenly divided into 10 parts (total number of categories in the area is thus 11) as well as in the territory that contains two categories in a ratio of 24.4 : 75.6. In both cases ShI_2 makes 0.8. The situation is graphically represented in Figure 1. The figure shows that ShI prefers large areas to small areas.

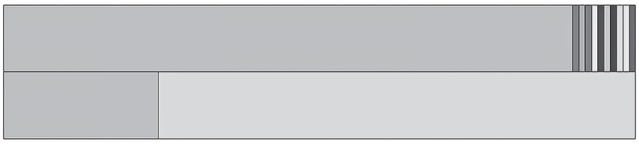

Fig. 1 Example of two areas with a different number of categories but equal *ShI* value

The dependence of ShI on two variables is given in Figure 2. The figure shows an isoline graph of ShI values. The calculation was carried out as follows:

1. the so-called basic part was singled out of the whole studied area (100%). The size of this basic part ranged from 1% (1/100 of the area) up to 50% (1/2 of the area) – the size of the basic part is presented on the horizontal axis in percentage,

2. the rest of the area (100% minus the basic part) was gradually divided into one, two, three up to fifty equal segments – the number of the segments is presented on the vertical axis,

3. providing each segment represents a different category, for the area divided in this way, ShI was calculated in the network of coordinates 1 × 1 and isolines were drawn.

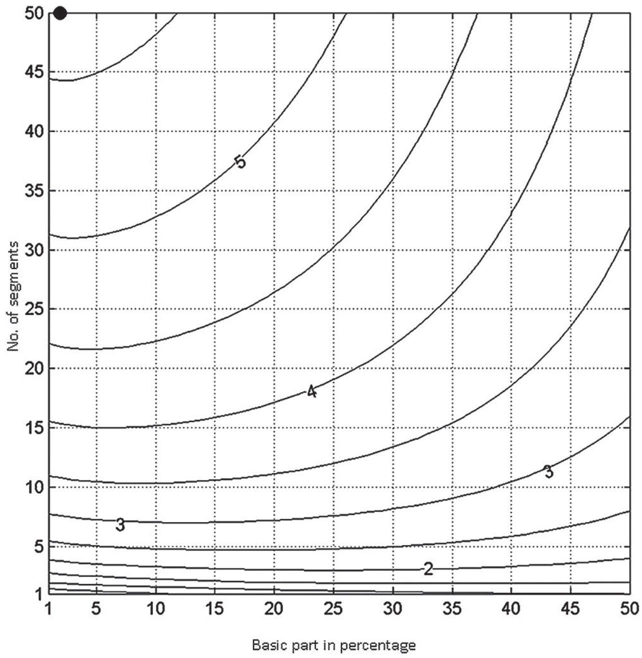

Fig. 2 *ShI* isoline graph for different types of area division – explanation in the text

As the graph shows, the highest ShI values are reached in the upper left corner (the upper limit is marked with a black point). A clear perspective view of the graph is given in Figure 3. The exact position of the upper limit occupies the coordinates $x = 1.96078 \doteq 1.96$; y = 50. In this case, the size of the basic part is 1.96% and the rest (98.04%) is divided into 50 segments. The size of one segment is 98.04/50 = 1.96. The whole area is therefore divided into 51 equal segments and ShI_2 = 5.672. The lower limit lies on the coordinates [1; 1], which correspond to the basic part equal to 1%, and the rest is divided into one segment – which means it is not further divided. The territory consists of two parts whose areas are in a ratio of 1 : 99 ShI_2 = 0.081. Then, ShI_2 = 1 for the coordinates [50; 1].

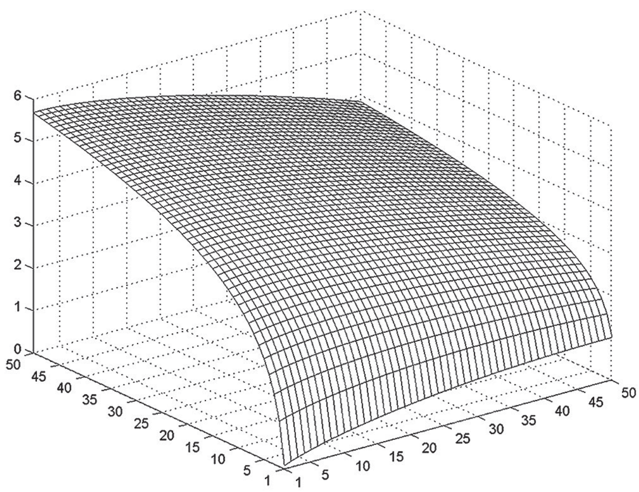

Fig. 3 Perspective view of the graph from Figure 2

Figure 2 demonstrates that *ShI* isolines are curves and the same index value thus holds true for more (in theory, infinitely many) variants of the area division. For this reason, the *ShI* interpretation is difficult.

Taking a formal view of diversity, the above described drawback of *ShI* can turn into a seeming asset. If we make little effort to understand diversity and simplify its definition to e.g. the Shannon index, then making an easy calculation we obtain a single number with which we can further work relatively blithely.

Similarly to the logarithm base, also in the case of the number of categories, it would be suitable to present the information together with *ShI* value. As for the example in Figure 1, it is convenient to distinguish $ShI_2 = 0.8\{11\}$ and $ShI_2 = 0.8\{2\}$, i.e. *ShI* calculated from eleven categories and two categories respectively. Gallego et al. (2000) use the denomination 'SH9, SH23' for the index calculated for 9 and 23 categories respectively. As in the case of logarithm base, concrete graphic form of the presentation of the number of categories is a question of convention. There is a multitude of possibilities (e.g. $ShI7_2 = 0.91$; $ShI(2) = 0.91[7]$; $ShI = 0.91[7/2]$; ${}^7ShI_2 = 0.91\ldots$) and the main problem is not how to visualise but to start visualising.

4.2 Diversity solving in the plane

Similarly to many other landscape metrics, a fundamental problem of *ShI* is that it is not explicitly spatial. Within the studied area, no attention is paid to spatial distribution of individual patch types with different land cover. This problem is demonstrated on two different territories in Figure 4. Both visualised territories contain three categories with spatial representation in a ratio of 36 : 34 : 30. Both the areas thus present identical $ShI_2 = 1.58\{3\}$. With the naked eye we can see in the figure that diversity within the first territory (Situation I) is higher than diversity within the other territory (Situation II), which, however, *ShI* results do not disclose. That is a fundamental problem of *ShI* related to its application. Landscape diversity should reflect not only the number of patches and their total extent but also the spatial distribution of individual landscape elements. *ShI*, however, is unable to express this information.

Although a majority of *ShI* users fail to occupy themselves with the issues of spatial distribution, some authors are evidently trying to deal with this disadvantage. One of the first authors to deal with the problem was Batty (1974) who used entropy for regionalization. Applying entropy in human geography, he completed the calculation with a parameter of the zone extent. Subsequently using the iterative technique, he clustered zones in order to achieve maximum entropy. One of his thoughts presented in the conclusion of his work can be mentioned in connection with the *ShI* application: 'It is unbelievable how many [geographic analyses] ignore the question of space' (sad but true this statement is even in this time of advanced geoinformation technologies). Batty's method was employed by e.g. Paszto et al. (2009) in cartographic applications.

A different approach was selected by Gorelick (2006) who introduced a matrix analogue of the Shannon's and Simpson's indices. This procedure is an interesting transfer of *ShI* into 2D space. It can be used in theoretical solving of some problems; however, it is not suitable for practical application related to a territory of a general shape.

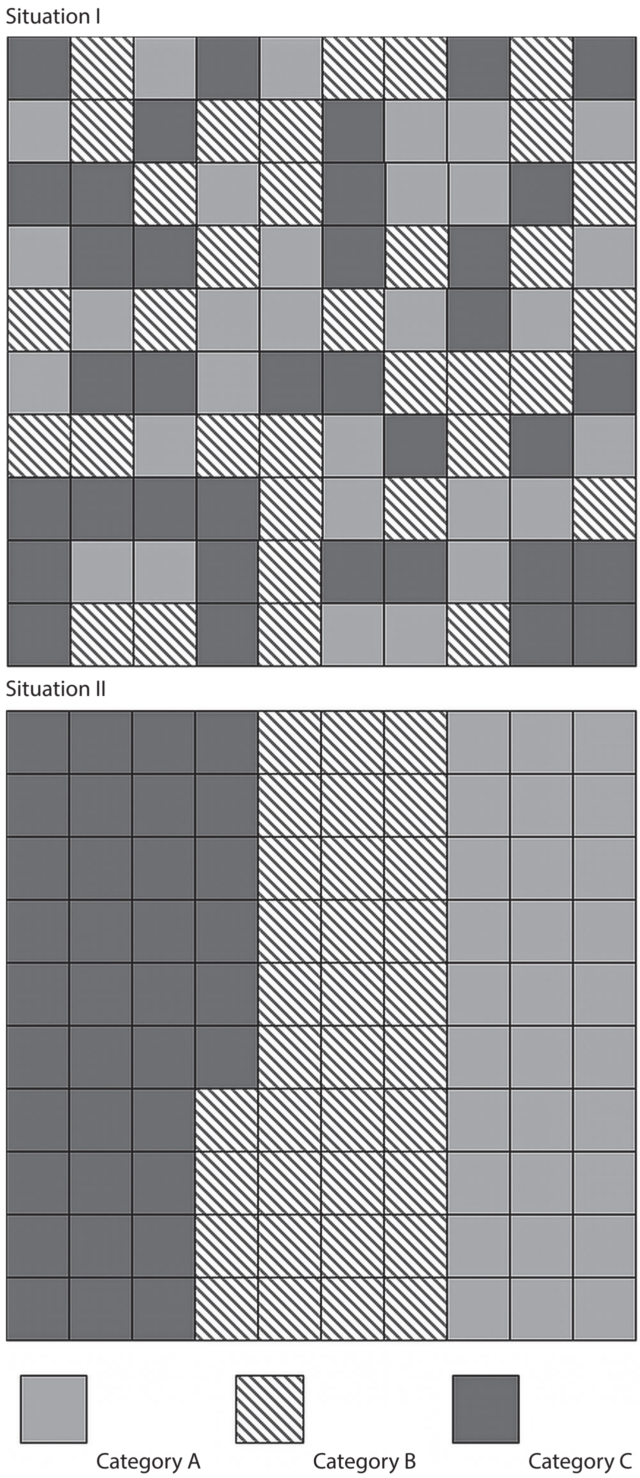

Fig. 4 Two examples of distribution of 3 categories in the area

Spatial distribution was successfully taken into consideration by Claramunt (2005). His method was applied by Li and Claramunt (2006) and Wang and Wang (2011). Its principle is the calculation of average distances between patches of the same category and patches of different categories. The equation (4) was modified into the form

$$ShI = -\sum_{i=1}^{m} \frac{d_i^{int}}{d_i^{ext}}(P_i \log P_i)\ , \qquad (6)$$

where d^{int} is an average distance between areas of the same category ('inner distances'), d^{ext} is an average distance to areas of other categories (the distances relate to gravity centres of areas). The fraction is practically a balance which takes into consideration whether the areas of individual categories are clustered or 'dispersed' all around the territory. Examples of values calculated for the situations in Figure 4 are presented in Tab. 1 and Tab. 2.

Resulting *ShI* values after spatial distribution of individual areas has been taken into consideration:

Situation I: *ShI* = 1.5597.

Situation II: *ShI* = 0.9836.

The original value is equal for both situations: *ShI* = 1.5809.

The results show that these values rather correspond to general notion of landscape diversity. Advantage of this method rests in the fact that it can be used with raster data format in which each raster cell represents a single patch (as shown in Figure 4, Situation II). With regard to regular cell shape, there is no need to determine the distance between areas of a general shape.

Despite interesting results, the method brings a new problem, which is the theoretic base (not connected only with this method, but all *ShI* modifications). *ShI* has an explicit theoretic base and even though its interpretation in landscape assessment is difficult, it is clear what base it stems from and what conditions it complies with. The modification of the *ShI* equation does not mean 'modified Shannon index' but new characteristics with a different theoretic starting point that does not necessarily have to have anything in common with the original Shannon entropy.

Another problem of the calculation according to (6) is the determination of maximum diversity. The complicated parameter of average distances practically makes it impossible to exactly determine maximum possible diversity.

If we use landscape diversity to infer the species diversity, another important indicator, apart from the number of patches and their distribution, is also boundary segmentation and boundary length. However, no information of this parameter is brought by *ShI*. Unlike the spatial distribution of landscape elements, the issue of the boundaries is not solved by means of *ShI* modification, but different landscape metrics such as the total boundary length, boundary density and fractal dimension (McGarigal and Marks 1995).

4.3 Independence of categories

Shannon's derivation of entropy starts from a premise of independent occurrence of individual symbols in a message. This premise is valid for a randomly generated message, but not for a majority of natural systems. An example of non-random occurrence of symbols is a text in English or another language in which some pairs (trios …) of letters are more probable than others. Shannon (1948) presents the following hierarchy:

– zeroth-order approximation … symbols are independent and characterised by equal probability,

– first-order approximation … symbols are independent and characterised by dissimilar probability – it is a model for which entropy or *ShI* are derived,

– second-order approximation … symbols are characterised by dissimilar probability which depends on the previous symbol (some pairs of symbols occur more often that others),

– third-order approximation … symbols are characterised by dissimilar probability which depends on previous two symbols (some trios of symbols occur more often than others),

– etc.

Tab. 1 Values of average distances between categories

	A–A	B–B	C–C	A–B	A–C	B–C
Situation I	2.4635	2.5194	2.7126	2.5085	2.6262	2.6549
Situation II	1.7989	1.8575	1.8343	2.5009	3.8647	2.5903

Tab. 2 Values of the numerator and the denominator of a fraction for individual categories

	Situation I			**Situation II**		
	Category A	Category B	Category C	Category A	Category B	Category C
Numerator	2.4635	2.5194	2.7126	1.7989	1.8575	1.8343
Denominator	2.5690	2.5884	2.6415	3.2023	2.5497	3.1877
Fraction	0.9589	0.9734	1.0269	0.5618	0.7285	0.5754

In case of the second-order approximation and higher-order approximation it is necessary to consider aggregate or conditional probabilities.

Mutual independence of individual categories in landscape diversity assessment is given by a concrete definition of the categories. Commonly used categories are not independent. For example, the categories of arable land, forest and water bodies can be considered independent. On the contrary, the categories of industrial and commercial units and road and rail networks are dependent categories because the occurrence of road and rail networks is closely related to the occurrence of industrial and commercial units. A similar situation holds good for water bodies, water streams and other categories.

If we wanted to preserve entropy as a principle of diversity calculation, we would have to deal with at least the second-order approximation. This would mean being acquainted with estimates of mutual dependences of pairs of categories and applying them in the calculation. Such a method is not unusual and it is equation (4) that is almost exclusively used, even though land cover characteristics do not comply with its demands.

4.4 Maximum diversity

In addition to direct *ShI* calculation used in landscape assessment, we can also use maximum diversity, which is calculated:

$$ShI_{max} = \log m \tag{7}$$

The denomination indicates that it concerns the highest possible value of the Shannon index that can be reached within a given territory. *ShI* reaches the highest values for regular representation of individual categories if the relation (4) is simplified to (7). Almost all authors present *m* as a number of land cover categories. However, a question is if it represents a number of categories occurring in the study area or a theoretically possible number of all the categories. Maximum diversity is generally calculated for the number of categories occurring in a given territory. Although the resulting value has a certain reporting ability, it is not maximum diversity. Maximum diversity can be obtained if *m* represents a number of all potential categories – this number depends on how the categories are defined. For example, the EU CORINE Land Cover (CLC) methodology contains 44 land cover categories.

Arguments for the use of all categories in the calculation of maximum diversity:

1. If we really want to achieve maximum entropy, the use of all categories brings a higher value.

2. In a calculation made on the basis of existing categories we only work with one parameter, which is the distribution of categories. In reality, diversity is dependent on two parameters, neither of which needs to be favoured. Using the existing categories, one parameter is fixed and we try to reach the maximum by changing the other parameter. It is difficult to imagine that we fix the distribution of categories while changing the number of categories because the change in the number of categories inevitably causes changes in the distribution of categories. Still, we can imagine a situation in which the distribution of categories is given and the maximum is reached by means of the number of categories. An extreme but easily understandable example is regular representation of categories. How can maximum diversity be achieved with regular representation of categories? We need to increase the number of categories to its maximum; the maximum is all the categories within used methodology.

3. The unsuitability of calculating maximum diversity using the number of existing categories becomes disclosed for $m = 1$. Then $ShI = 0$ and also $ShI_{max} = 0$. We get into an absurd situation in which the smallest possible diversity is at the same time the maximum diversity.

4. Within the information theory entropy is calculated as a sum made not only over symbols contained in a message but over all the symbols of the alphabet (all possible states). Maximum entropy is then logically calculated from the number of alphabet symbols. If the land area of categories is an analogue of the probability of the symbol (state) occurrence, diversity is calculated over all categories and in the same way maximum diversity should be calculated.

The calculation of maximum diversity is related to the comparison of the existing diversity with its maximum value. A different case is the calculation of Shannon's Evenness Index (*ShEI*) which also contains 'maximum' diversity in the denominator: *ShEI* is supposed to express the regularity in the representation of individual categories, which is why the denominator is logically calculated from the existing categories. In this case it is not suitable to use the term 'maximum' diversity for the denominator. Instead of the equations $ShEI = \frac{-\sum_{i=1}^{m}(P_i \log P_i)}{ShI_{max}} = \frac{-\sum_{i=1}^{m}(P_i \log P_i)}{\log m}$ it would be more suitable to use:

$$ShEI = \frac{-\sum_{i=1}^{m}(P_i \log P_i)}{ShI'} = \frac{-\sum_{i=1}^{m}(P_i \log P_i)}{\log n}$$, where

n is a number of categories occurring in the territory, $n \leq m$.

5. Recommendation and conclusion

'A model of reality is created emphasizing certain connections, while (inevitably) neglecting others,' present Guiasu and Shenitzer (1985) in connection with the maximum entropy used for solving mathematical models of reality. This statement precisely depicts the situation in which *ShI* tries to express very complex landscape characteristics using a single figure. Despite the fact that the Shannon index is the most popular diversity index (McGarigal and Marks 1995), its application is connected with a number of problems that a majority of users are unaware of or fail to deal with. Mechanical application of *ShI* is not suitable since the resulting values can bring distorted characterisation of the studied locality. From the above mentioned we can derive the following recommendations for the application of *ShI*:

1. be aware of the origin of the equation,
2. avoid overestimating the *ShI* value – it does not represent universal characteristics of landscape diversity,
3. avoid presenting the resulting numeric value only; include parameters that are essential for further comparison of the results – logarithm base and the number of categories,
4. be aware of insufficient information related to spatial distribution; use *ShI* modification that takes spatial distribution into consideration,
5. express maximum landscape diversity advisedly.

5.1 Conclusion

As it is necessary to approach the application of Shannon's diversity index critically, it is also necessary to pay close attention to other concepts and procedures related to landscape diversity. With regard to the fact that on one hand, diversity is a very complex feature and, on the other hand, it is a very popular phenomenon, there are many other improper simplifications. For example, the statement that higher diversity leads to higher landscape stability is completely misleading if the type and quality of patches are disregarded. Therefore, the understanding and characterisation of landscape diversity require a more complex approach which avoids using a single figure or a simple term but focuses on capturing diversity from a complex perspective, for example La Rosa, Martinico, Privitera (2011), Fahrig, Baudry, Brotons et al. (2011).

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RÉSUMÉ

Teoretický pohled na Shannonův index při hodnocení diverzity krajiny

Příspěvek se zabývá teoretickými aspekty používání Shannonova idexu při hodnocení diverzity krajiny a rozebírá problémy, které s sebou přináší jeho formální aplikace. Základním východiskem je původní teoretický základ vzorce, který vychází z principů výpočtu informační entropie. Analyzována je závislost numerické hodnoty indexu na dvou parametrech, kterými jsou počet sledovaných kategorií a rovnoměrnost plošného zastoupení vyskytujících se kategorií. Vzhledem k tomu, že pro více způsobů rozdělení zájmového území může být výsledná hodnota Shannonova indexu stejná, je nutné při hodnocení výsledku přihlížet k počtu kategorií i k rovnoměrnosti plošného zastoupení jednotlivých kategorií. Proto je doporučeno uvádět u výsledné hodnoty Shannonova indexu také počet kategorií.

Základním nedostatkem Shannonova indexu je skutečnost, že nevyjadřuje prostorové uspořádání ploch kategorií v území, ale pracuje pouze s celkovými velikostmi kategorií. Je uveden přehled a provedeno zhodnocení existujících modifikací indexu, které se snaží prostorové uspořádání zohlednit. Jako nejvhodnější se jeví využití koeficientu, který zohledňuje vzdálenosti mezi plochami stejných a odlišných kategorií. Tato modifikace je podrobně představena na modelovém příkladu.

Na základě argumentů vycházejících z teoretického základu vzorce pro výpočet Shannonova indexu a z praktických aplikací tohoto vzorce je také představen nový pohled na pojem maximální diverzita krajiny.

Při užívání Shannonova indexu je zcela opomíjeno, že původní vztah pro výpočet entropie předpokládá nezávislost vyskytujících se stavů (v případě hodnocení krajiny např. kategorií krajinného pokryvu). Vzhledem k tomu, že běžně definované kategorie ploch nejsou nezávislé, měl by se pro výpočet Shannonova indexu užívat vztah zohledňující podmíněné pravděpodobnosti výskytu kategorií.

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MODELLING SNOW ACCUMULATION AND SNOWMELT RUNOFF – PRESENT APPROACHES AND RESULTS

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ABSTRACT

The aim of the article is to give a review of methods applied for modelling the snow accumulation and snowmelt and to give a description of main processes governing the runoff from the snowpack. The progress in the understanding of processes running in the snowpack is documented both by worldwide results presented in many studies and by the results achieved by the authors in the selected small experimental catchments in the Czech Republic. The research is focused on 1) measuring the snowpack and analysing its spatial and temporal distribution, 2) assessing the role of different physical-geographical factors on snow accumulation and melting, 3) testing methods for interpolation of measured point data into area, and 4) modelling the snow accumulation and snowmelt in the local and regional scale. The main findings of the research show various ways of behaviour of snowpack accumulated in the forest and open areas in experimental catchments and show the most suitable interpolation methods taking into account one or more independent variables (slope, aspect, altitude, vegetation) for calculating the dependent variable (snow water equivalent, snow depth). The presented results also confirm the known problems with applying temperature-index snowmelt model, mainly for modelling the situations when the air temperature fluctuates near zero and for modelling the diurnal fluctuation of the snowmelt runoff.

Key words: snow accumulation, snowmelt, spatial interpolation, hydrological modelling, energy balance, degree-day method

1. Introduction

The snow melting caused by higher temperature, accompanied with precipitation, is a frequent cause of floods in the Czech Republic. Possibilities of runoff forecast in monitored profiles significantly improved thanks to mathematical modelling. For an accurate prediction it is necessary to enter catchment characteristics and also initial conditions representing altogether the catchment status at the beginning of the simulation. The most important initial condition for the flood forecast caused by snow melting is the snow layer status, mainly snow depth and snow water equivalent (SWE).

Numerous studies indicate various effects of both natural and anthropogenic factors on runoff formation (Jost et al. 2007; Váňová and Langhammer 2011) especially the role of the landscape and different land cover (forest, meadows, arable land). The majority of studies are focused on floods caused by liquid precipitation (Čurda et al. 2011; Jeníček 2009) or they assess the runoff on a long-term scale (Özdogan 2011; Kliment et al. 2011). Many physical-geographic factors are important in the course of accumulation and melting of snowpack in winter and in spring. The effects of altitude and air temperature are significant for large areas that exhibit high variability in terms of elevation (Essery 2003; Jost et al. 2007), while the effect of vegetation predominates locally, namely the presence of forests and open areas in the river basin (Jost et al. 2009; Tanasienko et al. 2009). Jeníček and Taufmannová (2010) has used the HEC-HMS model including the temperature-index snowmelt model for the runoff simulation from various vegetation covers (forest and open areas). The results indicate an applicability of temperature-index method for variant simulations of the rainfall-runoff process, especially for "rain-on-snow" events.

Numerous studies show that slower snow melting in the forest is caused by lower short-wave radiation (Verbunt et al. 2003). The forest also affects wind speed, interception and density of the snowpack (Holko et al. 2009). Essery (2003) tested the distributed MOSES model in high mountainous areas. This author indicates that a significant increase in accuracy was achieved by dividing the river basin to multiple zones based on elevation above sea level. Even better results were obtained by incorporating the effect of vegetation. Pobříslová and Kulasová (2000) applied the balance hydrological HBV-ETH model in experimental river basins in the Jizerské Mountains in order to simulate snow deposition and melting in the forest and in open areas. The results of direct observations confirmed markedly faster snow melting in deforested areas than in forests partly due to higher snow accumulation and partly due to higher short-wave radiation amount in the open areas. Weigert and Schmidt (2005) pointed to another problem by modelling the runoff in winter conditions. Their research was focused on infiltration processes under frozen soil by means of EROSION 3D model. The role of the frozen soil was investigated also by Bayard et al. (2005).

Concerning possible long-term changes in climate conditions there is a question of climate change impact

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on the runoff regime in the regional and local scales (Jain et al. 2011; Teutschbein et al. 2011). An important part of the research in mountain areas is therefore the issue of possible future changes in snowpack and glacier regimes. The main problem is evident; spatial and temporal distribution changes of the snowpack and glaciers will cause the changes in runoff regime (both seasonal regime changes and hydrological extremes changes) with consequences on the water and energy supplies (Janský et al. 2011).

Nevertheless, the modelling activity itself indicated a high level of mutual relationships among individual factors, which makes more difficult the proper identification of the model parameters and its calibration. Precisely, such identification and proper estimation of hydrological model parameters is one of important spheres of current research.

2. Models based on energy balance of the snowpack

Physical approach to modelling the runoff from snowpack is based on energy balance. This method considers and quantifies energy flux on the interfaces of atmosphere–snow–soil. Energy balance could be defined by (formula 1):

$$Q_m = Q_{nr} + Q_h + Q_e + Q_p + Q_g + Q_q \quad (1)$$

where Q_m is the energy balance accessible for snow melting [W m^{-2}], Q_{nr} is the radiation balance, Q_h and Q_e are turbulent sensible heat and latent heat fluxes on the interface of snow – atmosphere, Q_p is the heat supplied by precipitation, Q_g is the heat supplied by soil a Q_q is the heat change inside snowpack [W m^{-2}].

According to Singh and Singh (2001) it is possible to calculate the water volume from melting snow (formula 2):

$$M = 0.0031 \cdot Q_m \quad (2)$$

where M [mm d^{-1}] is the amount of melting water and Q_m [kJ m^{-2} d^{-1}] is the daily output of energy balance (only positive values). The value 0.0031 is determined for ripe snow and liquid water content equals 3%. The snowpack can be represented as one layer in the computation, but it is possible to derive the energy balance for more snow layers taking into account the stratification of the snowpack.

2.1 Shortwave and longwave radiation

Total radiation balance of the snowpack Q_n is possible to compute according to formula 3 (Singh and Singh 2001):

$$Q_{nr} = (1 - \alpha) \cdot S_i + (L_i - L_o) \quad (3)$$

where Q_{nr} is the total radiation, α is the albedo, L_i is the incoming radiation and L_o is the outcoming longwave radiation. S_i introduces the incoming shortwave radiation and it is sometimes replaced with global radiation G. The global radiation involves both direct and diffusive shortwave radiations. The amount of shortwave radiation captured by snow depends on several factors, mainly the slope, aspect, season, latitude, atmospheric diffusion and land cover, which can prevent the direct radiation into the snowpack.

The sources of the longwave radiation (6.8–100 μm) are the atmosphere and the Earth surface (Singh and Singh 2001). The radiation of surface is largely absorbed by the atmosphere, above all due to carbon dioxide and water vapour. An exception is the radiation within the interval 8–12 μm (infrared atmospheric window). The last two items of the formula 3 represent the radiation longwave balance of the snowpack. Based on Stefan-Boltzmann law using emissivity ε and snowpack temperature T_s [K] it is possible to express the relation between the incoming and outcoming longwave radiations (formula 4):

$$L_o = \varepsilon\sigma T_s^4 + (1 - \varepsilon) \cdot L_i \quad (4)$$

where σ refers to the Stefan-Boltzmann constant (5.67 · 10^{-8} W m^{-2} K^{-4}). The energy of incoming longwave radiation for sky without clouds is possible to derive by (formula 5):

$$L_i = (0.575 \cdot e_a^{1/7}) \cdot \sigma T_a^4 \quad (5)$$

where e_a [mbar] refers to the water vapour tension and T_a refers to the air temperature. Considering the sky without clouds, air temperature 2 °C, snowpack temperature 0 °C, snowpack emissivity 1 and relative air moisture 50% and using formulas 3–5, we obtain the longwave radiation balance of the snowpack equal −92 W m^{-2} (DeWalle and Rango 2008).

2.2 Sensible and latent heats

A convective sensible heat transfer is running between the air and the snow in case of different air and snowpack temperatures due to turbulent atmospheric circulation. The direction and the amount of energy flux depend on temperature differences, wind speed, snow surface roughness and atmospheric stability (stability of dry air). Large snow and air temperature differences in spring and early summer caused energy gain of snowpack. However, the snowpack temperature is often higher than the air temperature in the spring nights. This situation represents snowpack energy loss (DeWalle and Rango 2008).

The latent heat transfer represents the transfer of water vapour between the atmosphere and the snowpack. The water vapour flux and its direction are determined by the vapour pressure gradient and the intensity of the turbulence. The snowpack energy loss represents the evaporation and the sublimation from the snow, the snowpack energy gain represents the condensation and the desublimation of the water vapour on the snow surface (DeWalle and Rango 2008).

2.3 Energy supplied by precipitation

In the case of liquid precipitation on snow (so called rain-on-snow events) the precipitation is cooled to the snow temperature. The heat supplied to the snowpack equals the difference of snow energy before the precipitation and after the achievement of temperature stability. Formula 6 expresses the daily amount of transferred energy Q_p [kJ m^{-2} d^{-1}] depending on the precipitation P_r [mm d^{-1}] and the temperature difference (Singh and Singh 2001).

$$Q_p = \frac{(\rho_w c_p \cdot (T_r - T_s) \cdot P_r)}{1000} \quad (6)$$

where ρ_w refers to the water density, c_p refers to the specific heat capacity of water (4.20 kJ kg^{-1} °C^{-1}), T_r is the temperature of liquid precipitation and T_s is the temperature of snowpack.

2.4 Ground heat flux

This part of energy balance usually plays a minor role because of the small heat conductivity of the soil and, in case of higher snow depth, the lack of solar radiation supplied to the soil. The soil heat causes the slow ripening of snowpack during the winter and may cause slow snowmelt.

2.5 Change of internal energy of the snowpack

The internal energy of the snowpack depends on snow temperature and can be expressed as the sum of internal energy of three snowpack parts – ice, water and water vapour. The internal energy of the snow equals the internal energy of the ice in case of snow temperature below zero. The change of internal energy doesn't play a significant role in the whole energy balance and thus it is possible to neglect this part of energy balance (Singh and Singh 2001).

The advantage of methods based on energy budget is their broad possibilities of use in several climatic conditions. It is possible to describe precisely the physical nature of snow accumulation, transformation and melting processes using the energy budget method. The main disadvantage of the energy budget method is the difficulty to obtain the input data necessary for parameterization, calibration and validation of the model (Ohmura 2001). Selected research areas of snow processes made by several authors using the energy balance method are listed in the table 1.

3. Models based on temperature index method

The task of determining individual items of energy balance is quite complex, therefore the so called index methods are often used. These methods make use of the connection between the snow melting and an easily available magnitude that is related to energy balance (air temperature, precipitation). The temperature index method and its various modifications are most widely used. The air temperature is a broadly used magnitude in hydrological modelling, as it provides a simplified description of energy exchange at the atmosphere – snowpack – ground surface interface. The SWE decrease M [mm d^{-1}] is calculated according to formula 7:

$$M = a \cdot (T - T_C) \quad (7)$$

where a [mm °C^{-1} d^{-1}] is the melt factor, which is the SWE decrease in a day caused by the air temperature change T of 1 °C compared to the critical value T_c in which the melting process begins. T is the mean air temperature. The value of T_c varies mainly from 0 to 2 °C. The value of temperature factor is not constant and varies depending on physical characteristics of snow or global radiation. Values vary from 1 to 7 mm °C^{-1} d^{-1}. The temperature index method was defined for the daily time step, but it is possible to use a shorter or longer temporal resolution.

Tab. 1 Research areas solved by the means of energy balance method

Research area	*Reference*
Snow accumulation and snowmelt modelling, model development and calibration, operational hydrology	Garen and Marks (2005); Herrero et al. (2009); Ohara and Kavvas (2006); Walter et al. (2005); Fierz et al. (2003); Franz et al. (2008); Sensoy et al. (2006)
Effect of vegetation	Jost et al. (2009); Koivusalo and Kokkonen (2002); Burles and Boon (2011)
Glacier melt modelling	Magnusson et al. (2011)
Climate change modelling	Dankers and Christensen (2005); Özdogan (2011); Strasser and Marke (2010); Uhlmann et al. (2009)

The temperature index method was derived and firstly used by Finsterwalder and Schunk (1887) in the glaciological study in the Alps; nowadays it is still the most widely used snowmelt method among hydrologists. Hock (2003) summarises the advantages of the temperature index method as 1) the good availability of air temperature data, 2) the relatively simple spatial distribution of the air temperature and its predictability, 3) the simplicity of computation procedure, and 4) satisfactory results of the model despite of its simplicity. Beven (2001) formulated shortcomings of this method as 1) the accuracy of the method decreases with the increasing temporal resolution, 2) the intensity of the snowmelt has a big spatial variability depending on topographic conditions, mainly the slope, aspect and land cover. This variability is very difficult to express using temperature index method.

The temperature index method comes from the linear dependence of snowmelt on the air temperature. Incoming longwave radiation and sensible heat represent 3/4 of total energy balance of the snowpack (Hock, 2003). Shortcomings of the models based on the temperature index method with daily time step are apparent mainly in cases of air temperature fluctuations near zero (Jeníček and Taufmannová 2010; Kutláková and Jeníček 2012). The mean daily air temperature indicates no snowmelt; however, the positive air temperature which occurs during day could cause the snowmelt (Hock 2003). In mountain areas it is necessary to consider the change of the air temperature depending on the altitude; therefor the basin is usually divided into several elevation zones.

The melt factor a is the key parameter in the formula 7. Martinec (1977) derived an empirical relation between the melt factor and the snow density as (formula 8):

$$a = 1.1 \cdot \frac{\rho_s}{\rho_w} \tag{8}$$

where a is the melt factor (mm °C^{-1} d^{-1}), ρ_s is the snow density (mass of snow divided the bulk volume of the snowpack) and ρ_w is the water density. Formula 8 points to the increasing tendency of the melt factor in the spring together with the increasing snow density due to the ripening process. Kuusisto (1980) derived a relation between the melt factor and the snow density separately for forest and open areas (formulas 9, 10):

$$\text{forest: } a = 0.0104 \cdot \rho_s - 0.7 \tag{9}$$

$$\text{open areas: } a = 0.0196 \cdot \rho_s - 2.3 \tag{10}$$

Forests cause the decreasing of the direct solar radiation and therefore the snowmelt in the periods without precipitation. Different melt factors derived Federer et al. (1972) for the northwest of the USA. He experimentally derived the melt factor 4.5–7.5 mm °C^{-1} d^{-1} for open areas, 2.7–4.5 mm °C^{-1} d^{-1} for deciduous forests and 1.4–2.7 mm °C^{-1} d^{-1} for coniferous forests (approximate ratio 3 : 2 : 1). Kuusisto (1980) expressed varying of the melt factor in dependence on the cover density of coniferous forests (formula 11):

$$a = 2.92 - 0.0164 \cdot C_c \tag{11}$$

where C_c is the rate of treetop cover. Coniferous forests reach the values from 0.1 to 0.7. Table 2 contains the list of factors which have an influence on melt factor.

Tab. 2 Factors influencing melt factor (DeWalle and Rango 2008)

Factor	*Cause*	*Influence on melt factor*
Seasonal influence	Decrease of cold content and albedo, increasing of shortwave radiation and snow density	Melt factor increases
Open area vs. forest	Shading and wind protection	Lower melt factor and its spatial variability in the forest
Topography (slope, aspect)	Variability of shortwave radiation and wind exposure	Higher melt factor in south hill slopes
Snow cover area	Spatial snowmelt variability	Melt factor decreases in the basin with larger snow cover area
Snowpack pollution	Dust and other pollution causes lower albedo	Higher melt factor
Precipitation	Rainfall supplies sensible heat, clouds decrease solar radiation	Generally lower melt factor in rainy days due to lower radiation. But precipitation itself cause higher melt factor.
Snow vs. ice	Glacial ice has lower albedo than snow	Higher melt factor in glaciated basins
Meteorological conditions for certain air temperature	Higher snowmelt in case of higher wind speed, higher radiation or higher moisture by the same temperature	Higher melt factor

Tab. 3 Research areas solved be the means of temperature-index method

Research areas	*Reference*
Snow accumulation and snowmelt modelling, model development and calibration, operational hydrology	Walter et al. (2005); Brubaker et al. (1996); Hu et al. (2006); Kutláková and Jeníček (2012)
Effect of vegetation	Federer et al. (1972); Kuusisto (1980); Jeníček and Taufmannová (2010); Pobříslová and Kulasová (2000)
Glacier melt modelling	Finsterwalder and Schunk (1887); Magnusson et al. (2011)
Climate change modelling	Steiger and Mayer (2008)
DDF derivation	Federer et al (1972); Kuusisto (1980); Martinec (1977); Hasa (2010)

Table 2 shows the increasing melt factor due to the precipitation, which could be described by formula 12 (Singh a Singh 2001):

$$a = a' + 0.0126 \cdot P \tag{12}$$

where a is the melt factor with precipitation influence, a' is the melt factor without precipitation influence and P (mm) is the precipitation.

The temperature index method is widely used in numerous variants for modelling snow accumulation and melting. Selected research areas of snow processes made by several authors using temperature-index method are listed in the table 3.

4. Summary of results from the Krušné Mountains

Periodical measuring of the snow depth and SWE in the Department of Physical Geography and Geoecology (Faculty of Science, Charles University in Prague) started in 2006 in the Šumava Mts. (Jeníček et al. 2008). Snow measurements are more intensively made in the spring time in order to describe the relation between snow melting and stream hydrographs in the experimental catchments.

The snow monitoring in the Bystřice River basin (stream gauge Abertamy, 9.0 km^2) and the Zlatý Brook basin (stream gauge Zlatý kopec, 5.5 km^2) in the Krušné Mts. began in the winter 2008/2009 (Fig. 1). In the regional scale the research is carried out in the Bystřice River basin upwards stream gauge Ostrov (127.6 km^2). The aim of the research is 1) to assess the effect of selected physical-geographic factors on snow accumulation and snowmelt runoff dynamics; 2) to develop methods for snow measuring and spatial interpretation of snow data and; 3) to model the snow accumulation and the snowmelt including snowmelt runoff scenarios under changing conditions (effect of vegetation, effect of climate change).

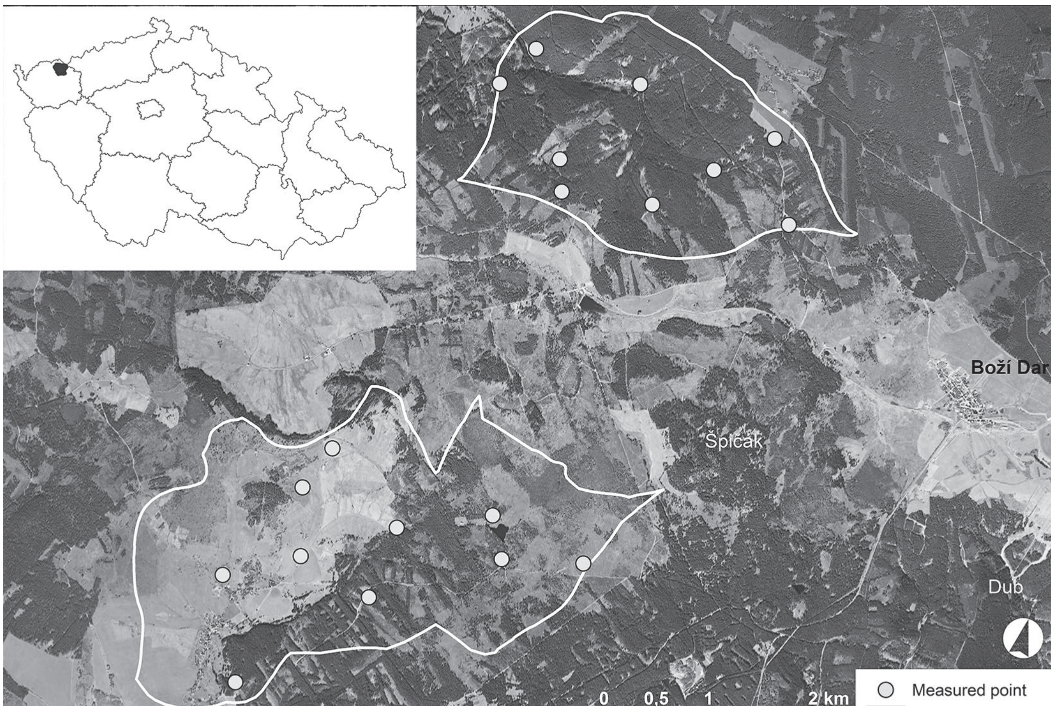

Fig. 1 Location of experimental catchments Bystřice River (south, stream gauge Abertamy) and Zlatý Brook (north, stream gauge Zlatý kopec) with measured points and the location of Bystřice River basin (stream gauge Ostrov, overview map of the Czech Republic)

Both of the studied headwater river basins belong to the highest elevated basins in the Krušné Mountains (750–1050 m a.s.l.) and there is an assumption of high amount of the water accumulated in the snowpack and thus a spring flood risk. The Bystřice River basin and the Zlatý Brook basin represent not only two different basins in terms of vegetation (95% of forest cover in the Zlatý Brook basin, 46.5% of forest cover in the Bystřice River basin), but they differ also in terms of orography, especially the windward and leeward effects. Differences between the snow accumulation and the snowmelt in the forest and open areas documented with the average of point measurements in both catchments are evident from the figure 2.

The main aim of the study performed by Kučerová and Jeníček (2011) was to asses selected interpolation methods in terms of their prediction capability of snow water equivalent (SWE) in unknown points. The study was carried out in the Bystřice River basin (127.6 km^2, figure 1). Point data measured in the basin were transferred into grids with resolution of 60 × 60 metres using nine interpolation methods which belong to deterministic, geostatistical and global methods.

The prediction of SWE in unknown points was assessed by means of cross validation. Differences between estimated values and measured values were evaluated by several parameters (figure 3). The best prediction quality of SWE in unknown points was achieved by means of geostatistical methods (ordinary kriging, cokriging and residual kriging) and global methods (linear regresion) compared to deterministic methods (Thiessen polygons, inverse distance weighting, global and local polynomial and radial basis functions). The linear regression using the altitude as an independent variable was the best evaluated interpolation method according to the most parameters (Kučerová and Jeníček 2011).

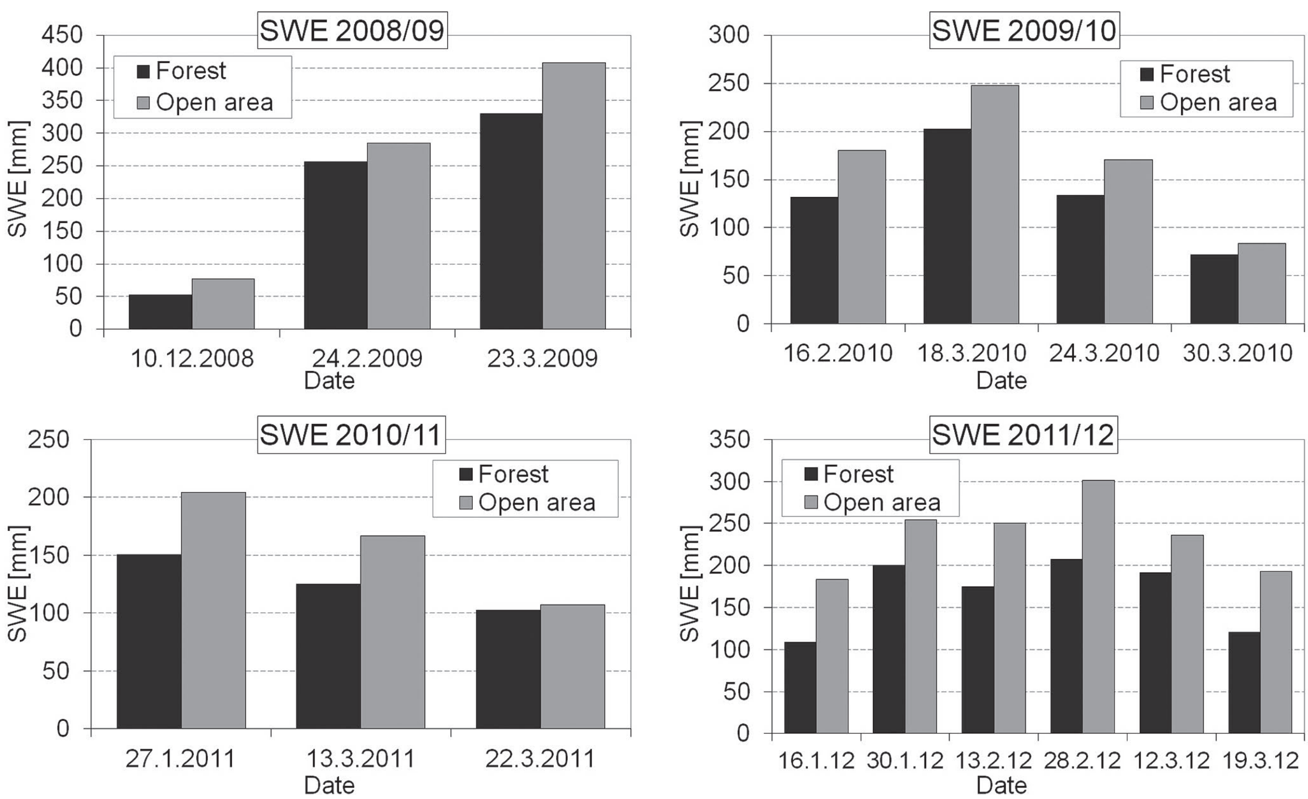

Fig. 2 Snow water equivalent (SWE) in the forest and in open areas during the winters 2008/09, 2009/10, 2010/11, and 2011/12 in the Bystřice River basin and in the Zlatý Brook basin

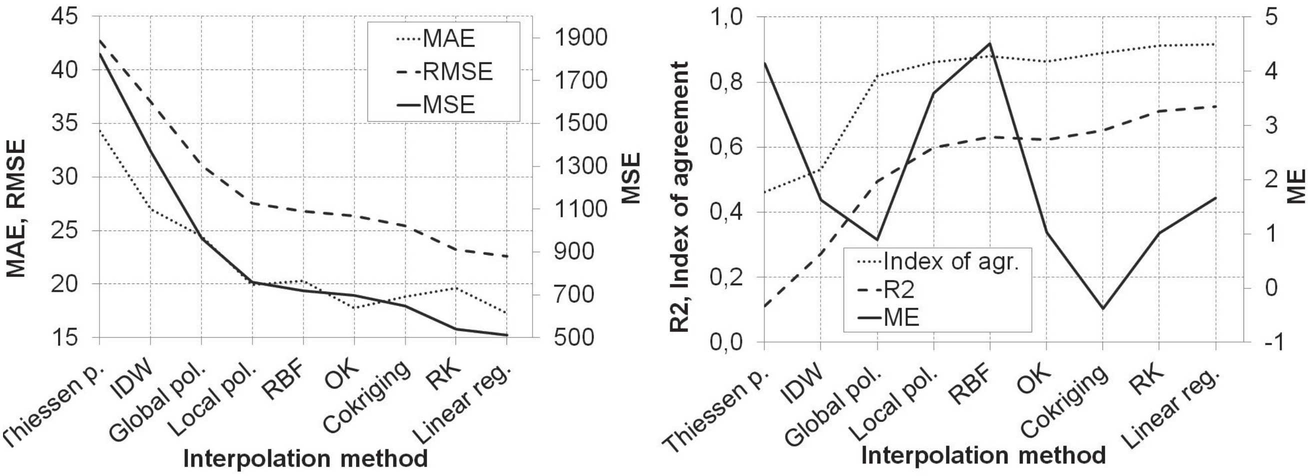

Fig. 3 Parameter values evaluating interpolation methods in terms of quality of their prediction of dependent variable (SWE) in unknown points (MAE – mean absolute error, RMSE – root mean square error, MSE – mean square error, Index of agreement, ME – mean absolute error, R2 – coefficient of determination)

The findings of the study are in agreement with the results achieved by others authors. According to the study, the global and geostatistical methods give a generally better prediction of climatic variables in unknown points compared to deterministic methods (e.g. Carrera-Hernández and Gaskin 2007; Haberlandt 2007; Lloyd 2005). Moreover, the prediction quality may be enhanced by including one or more independent variables in the calculation of the dependent one – slope, aspect, altitude, vegetation (Erxleben et al. 2002; López-Moreno and Nogués-Bravo 2006).

The temperature index approach was used in order to derive degree-day factors (DDF) in the headwater part of the Bystřice River basin (Hasa 2010). Degree-day factors were calculated by using the air temperature and flow rates in the stream gauge Abertamy for spring snowmelt periods 2009 and 2010. The snow water equivalent of melted snow was simplified to the runoff depth derived from the continual monitoring of the flow rates in the stream gauge Abertamy. The air temperature was measured at the climatological station Hřebečná located in the middle of the catchment. The degree day factor was calculated for each snowmelt period; 1.40 mm °C^{-1} d^{-1} and 1.48 mm °C^{-1} d^{-1} for years 2009 and 2010, respectively. Derived values are markedly smaller comparing to those derived by Martinec (1977), Kuusisto (1980) and Federer et al. (1972) using the land cover data and measured snow density (table 4). The DDF analysis was also made in the Ptačí Brook experimental catchment (Bohemian Forest, southwest of the Czech Republic). This analysis was based on point measured data of SWE and the monitoring of precipitation, air temperature and discharge during winters 2010/11 and 2011/12. The derived DDF varies between 2.77 mm °C^{-1} d^{-1} and 3.28 mm °C^{-1} d^{-1} according to assessed year and season. The results correspond better with the results of above mentioned studies. Computed degree day factors are applicable for modelling the runoff from the melting snow in the experimental catchment.

Jeníček and Taufmannová (2010) have used the HEC-HMS model with the temperature-index snowmelt model for the runoff simulation from different vegetation covers (forest and open areas). Table 5 shows all methods used for simulation the runoff from the Bystřice River basin in the HEC-HMS model.

Tab. 4 Empirical degree day factors (DDF) in the Bystřice River basin

Method	*DDF (mm °C^{-1} day^{-1})*	*Required data*
Derived from point measured data (Hasa 2010)	1.40–1.48	SWE, discharge, air temperature
Martinec (1977)	3.85	snow density
Kuusisto (1980)	4.12	snow density + land cover
Federer et al. (1972)	4.92	land cover

Tab. 5 The list of HEC-HMS components used for runoff simulation

HEC-HMS Component	*Applied method*
Snow accumulation and snowmelt model	Temperature index (DeWalle and Rango 2001)
Runoff-volume model	SCS CN - Soil Conservation Service Curve Number (Feldman 2000)
Direct-runoff model	Clark Unit Hydrograph (Feldman 2000)
Baseflow model	Exponential Recession (Feldman 2000)
Channel model	Muskingum-Cunge (Feldman 2000)

The results indicate an applicability of temperature-index method for scenario simulations of the rainfall-runoff process, especially for "rain-on-snow" events. Similar results were achieved by Kutláková and Jeníček (2012) by the application of the lumped HEC-HMS model in the Bystřice River basin (stream gauge Ostrov, 127.6 km^2). The model provided good results in the higher elevations with high amount of the snow without partial thawing (above 800 m a.s.l.). However, problems were recognized in the lower parts of the basin (300–600 m a.s.l.), where air temperatures fluctuated near zero. In those parts the model sometimes wrongly differentiated between the rain and snow. One of the conclusions of the study was to use better spatial description of the basin (more elevation bands) or to use the energy balance method in order to accurate the air temperature representation and thereafter the simulation of the snow accumulation and snowmelt.

5. Discussion and conclusions

Main hydrological uncertainties are associated with the collecting and analysis of input data and with the modelling of rainfall-runoff process using the chosen snowmelt runoff method. The hydrological uncertainty is the result of 1) the uncertainty of inputs (measured data), 2) the uncertainty of the hydrological model and 3) the uncertainty of model parameters.

Regular measurements of the snow depth and SWE in experimental river basins in the Šumava Mountains and the Krušné Mountains have been going on at the Department of Physical Geography and Geoecology since the winter 2006/2007. Performed measurements have confirmed a number of important facts. In particular, the spatial characteristics of the snowpack exhibit a high variability level in mountainous conditions, while this variability can be described only with difficulty by point measurements at meteorological stations (Egli et al. 2009). In general, the biggest differences may be found when comparing snow amounts deposited in forests and in open areas (Burles and Boon 2011; Jeníček and Taufmannová 2010; Jost et al. 2009; Pobříslová and Kulasová 2000). The above mentioned conclusion works for explorations done within the framework of a local scale of the selected area. Globally, the amount and nature of snowpack accumulation is most likely decided upon the elevation above sea level (Kutláková and Jeníček 2012; Essery 2003).

The snow model that uses the temperature index method for calculations is the main component of the HEC-HMS model applied in author's studies. The method is relatively sophisticated; nevertheless, it applies several simplifications of real processes that occur during the snow accumulation and melting. The processes still remain largely unknown and their satisfactory description has not been developed yet. One of the factors, that are difficult to involve in modelling, is the frozen ground. In the model applied in the studies by Jeníček and Taufmannová (2010) and Kutláková and Jeníček (2012) it is not possible to take into account the spatial variability of frozen ground, which is the problem especially on the regional scale in the areas with higher variability of altitude. The complex nature of infiltration in the frozen ground is also apparent in other studies (Bayard et al. 2005; Weigert and Schmidt 2005).

The undertaken simulations (Jeníček and Taufmannová 2010; Kutláková and Jeníček 2012) are associated with the disadvantage of impossibility to take into account the diurnal process of snow melting due to an insufficient number of time series of air temperature with the step of 1 hour. The above mentioned fact did not cause any significant deviations in case of rain-on-snow events. However, in the case of high flows caused by the high short-wave radiation without the liquid precipitation, the simulations didn't capture diurnal deviations of the observed flow. In this case, the use of the energy balance model is advisable instead of the temperature-index method.

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RÉSUMÉ

Modelování akumulace a tání sněhu – přehled současných přístupů a výsledků

Tání sněhu způsobené vysokými teplotami vzduchu doprovázené kapalnými srážkami je v České republice častou příčinnou vzniku povodně. Cílem příspěvku je popsat hlavní procesy, které ovlivňují odtok ze sněhové pokrývky a poskytnout přehled o metodách, které jsou v současné době používány pro modelování akumulace a tání sněhu. Pokrok v pochopení procesů probíhajících ve sněhové pokrývce dokumentují jednak četné zahraniční výzkumy, jednak výzkumy, které byly provedeny autory textu na malých experimentálních povodích v horských oblastech České republiky a jejichž souhrn je v textu uveden. Výzkum autorů se zaměřuje na 1) měření charakteristik sněhové pokrývky a analýzu její prostorové a časové distribuce, 2) hodnocení role vybraných fyzicko-geografických faktorů na akumulaci a tání sněhu (sklon a expozice svahu, typ vegetace), 3) testování metod prostorové interpolace bodově měřených charakteristik sněhu a 4) modelování akumulace a tání sněhu v lokálním a regionálním měřítku.

Ve sledovaných povodích ukazují hlavní výsledky výzkumu na rozdílné chování sněhové pokrývky akumulované v lese a na otevřených plochách, kdy v lese dochází k nižší akumulaci sněhové pokrývky a také k jejímu pozvolnějšímu tání než v případě otevřených ploch. Pro interpolaci bodových měření sněhu se ukazuje jako nejvhodnější použití metod, které do výpočtu neznámé závislé proměnné (výšky sněhu, vodní hodnoty sněhu) zahrnují jednu nebo více nezávislých proměnných, například nadmořskou výšku. Dosažené výsledky také potvrdily známé problémy s aplikací metody teplotního indexu (degree-day), především obtížnost modelování vodní hodnoty sněhu a odtoku ze sněhu v podmínkách teploty vzduchu kolísající kolem 0 °C. Problémy také nastávají při modelování denního chodu tání sněhu způsobeným vysokým úhrnem krátkovlnného záření a výrazným denním chodem teploty vzduchu (přes den kladná teplota vzduchu, v noci záporná teplota vzduchu). V těchto případech by bylo přínosnější použití metod založených na výpočtu energetické bilance sněhu. Metoda degree-day naopak uspokojivě modeluje situace s pozvolným přibýváním sněhu bez častých oblev a následné tání sněhu způsobené vysokými teplotami vzduchu a kapalnými srážkami.

GEOMORPHOLOGY AND NATURAL HAZARDS OF THE SELECTED GLACIAL VALLEYS, CORDILLERA BLANCA, PERU

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ABSTRACT

Field reconnaissance geomorphologic mapping and interpretation of satellite data was used to prepare geomorphological maps of the selected glacial valleys in the Cordillera Blanca Mts., Peru. The valleys are located about 5 km apart, but show important differences in geology and landforms presence and distribution. Above all, the presence of small glacial lakes near the ridge tops is typical for the Rajucolta Valley, whereas no such lakes occur in the Pumahuaganga Valley. Detailed field assessment of possible hazardous geomorphological processes on the slopes around the Rajucolta and Uruashraju Lakes was performed. Shallow landslides and debris flows often channeled by gullies are the main dangerous processes possibly affecting the glacial lakes. In the case of the Rajucolta Lake, evidences of shallow landslides were also found. Mapping showed that newly formed small glacial lakes and moraine accumulations located on the upper part of the valley slopes may be source of dangerous debris flows and outbursts floods in the future. In some cases, those processes may affect glacial lakes on the main valley floor, which often store considerable amount of water. Thus the possibility of triggering large glacial lake outburst flood should be carefully evaluated.

Key words: geomorphologic map, natural hazards, glacial lakes, Peru, Cordillera Blanca

1. Introduction

The study area is located in the department of Ancash within the Cordillera Blanca Mts. (Huascarán, 6768 m a.s.l.) elongated in the NW–SE direction. This mountain range runs for 170 km limited by the Santa River on its west side and Maraňón River on its east side (Figure 1). This mountain range is part of the Cordillera Occidental forming continental divide among Pacific (Santa River) and Atlantic Oceans (Maraňón River). Glaciers of the Cordillera Blanca Mts. represent world's largest glaciated region in the tropics. The Santa River valley has been subject to many natural hazards in the past (Zapata 2002) as well as during recent years (Vilímek et al. 2011). Many of them originated in the high parts of the mountains and caused damages and fatalities in the densely inhabited valley floors. Glacial lake outbursts floods (GLOFs, Vilímek et al. 2005; Carey et al., in print) and earthquake triggered slope movements (Klimeš et al. 2009) are the most dangerous types of natural hazards occurring in the Cordillera Blanca during last decades. The most devastating GLOF is the flood from the Palcacoccha Lake in 1941, which devastating large part of the province capital city of Huraz. The rock avalanche from the Huascarán Mt. from 1970 claimed between 5,000 (Evans et al. 2009) and 23,000 lives (Plafker et al. 1971) devastating towns of Yungay and Ranrahirca. Intensive research following those events showed that morphological properties of the moraine dams and old morphological features preserved in the relief provide basic and valuable information for landslide and GLOF susceptibility assessment.

Geomorphological map of two glacial valleys along with detailed expert assessment of hazards identified in the valley heads around glacial lakes is presented. Rajucolta Valley with large glacial lake is important for the safety of the regional capital city of Huaraz since it stores considerable amount of water (17,546,151 m^3 in 2004, personal communication N. Santillán, National Water Authority, Lima). The Pumahuaganga Valley located in the SE part of the mountain range has significantly different geological and geomorphological properties than the valleys in the north and central part of the Cordillera Blanca.

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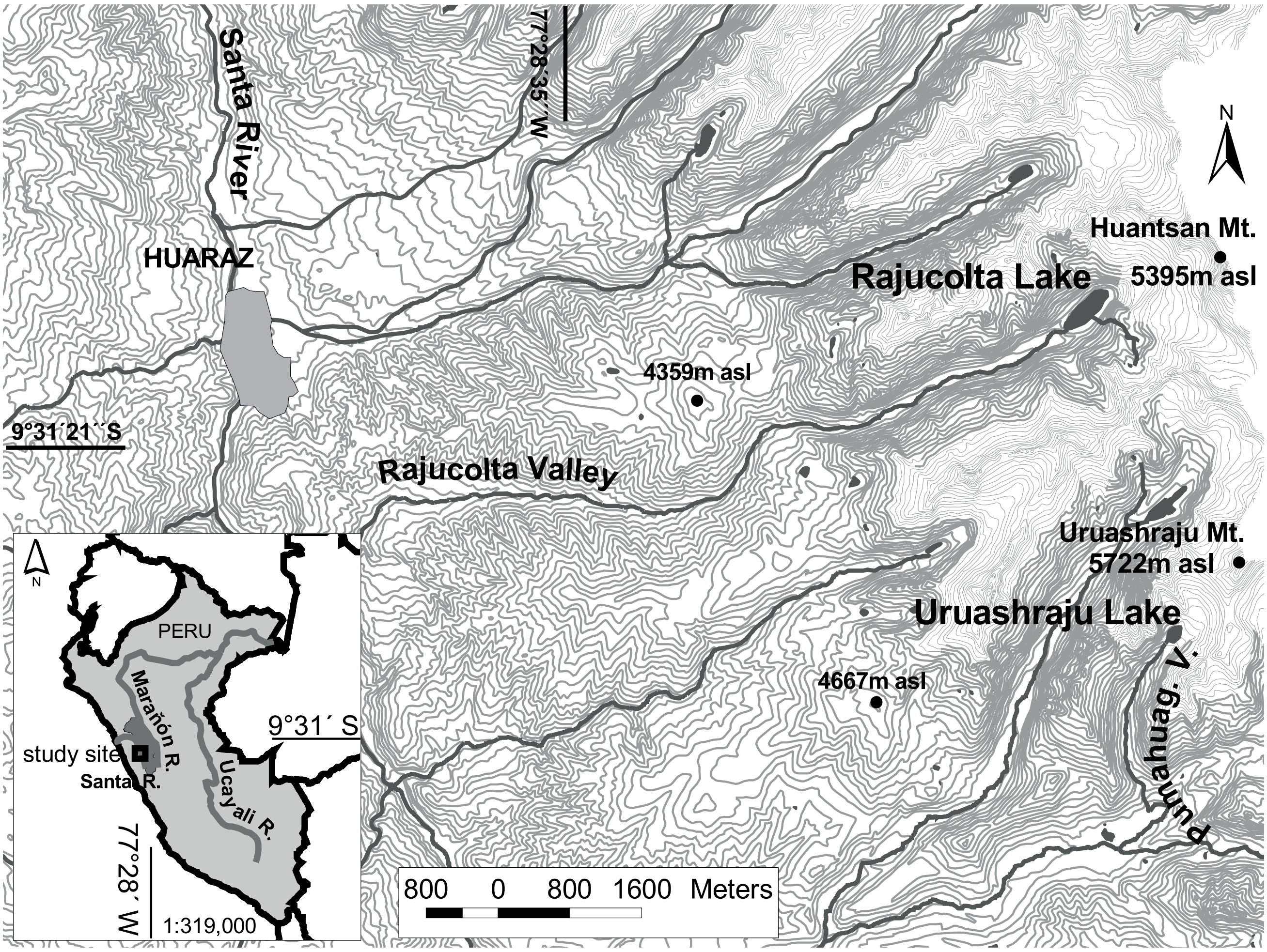

Fig. 1 Orientation map of the study area

1.1 Geology

Major part of the Cordillera Blanca Mt. constitutes of the batholith with total length of 200 km and width between 12 and 15 km. It is predominantly made of coarse grained granodiorite and tonality rocks (Figure 2) which are strongly foliated. In certain locations of the batholith, intrusive rocks gradually change to amphibolites. Dikes and sills of quartz-porphyry occur frequently in many locations of the batholith which is in contrast to the scare occurrence of the basic rocks dikes. The age of the batholith is estimated shortly after Paleogene volcanism or in the Mio-Pliocene Era with K/Ar age calculated 16 to 2.7 ± 0.4 M.A. (Wilson et al. 1995).

The highest summits of the SE section of the Cordillera Blanca Mt. are overlaid by sedimentary (sandstones and shale) and extrusive volcanic rocks (dacitic, andesitic and basaltic lavas, tuffs and breccias). They represent erosive remnants of sedimentary rocks (Mesozoic to Tertiary age), which primarily overlaid the Cordillera Blanca batholith (Morales 1967) and form area around it.

Main structural features of the batholith are controlled by pronounced foliation and system of vertical fractures. Two main directions of fractures are NW–SE and NE–SW. The third fracture system is sub horizontal. Evidences of tectonic movements can be found on many faults and show apparent striations. The main regional fault is the Cordillera Blanca normal fault running for some 210 km along west margin of the batholith. Estimations of its slip rate vary depending on exact location from 0.86 mm up to 3 mm/year (Wise and Noble 2003). Some authors also describe left lateral component of its movement (Wise and Noble 2003), which has been also detected by direct movement measurements (Košťák et al. 2002).

Variety of metallic and non-metallic raw deposits is located within the Cordillera Blanca Mt. They have been known and used since colonial times (Wilson et al. 1995). Polymetallic-wolfram-molybdenum zone of the Cordillera Blanca is found on the contact between igneous rocks of the batholith and overlying older formations along the NW slopes.

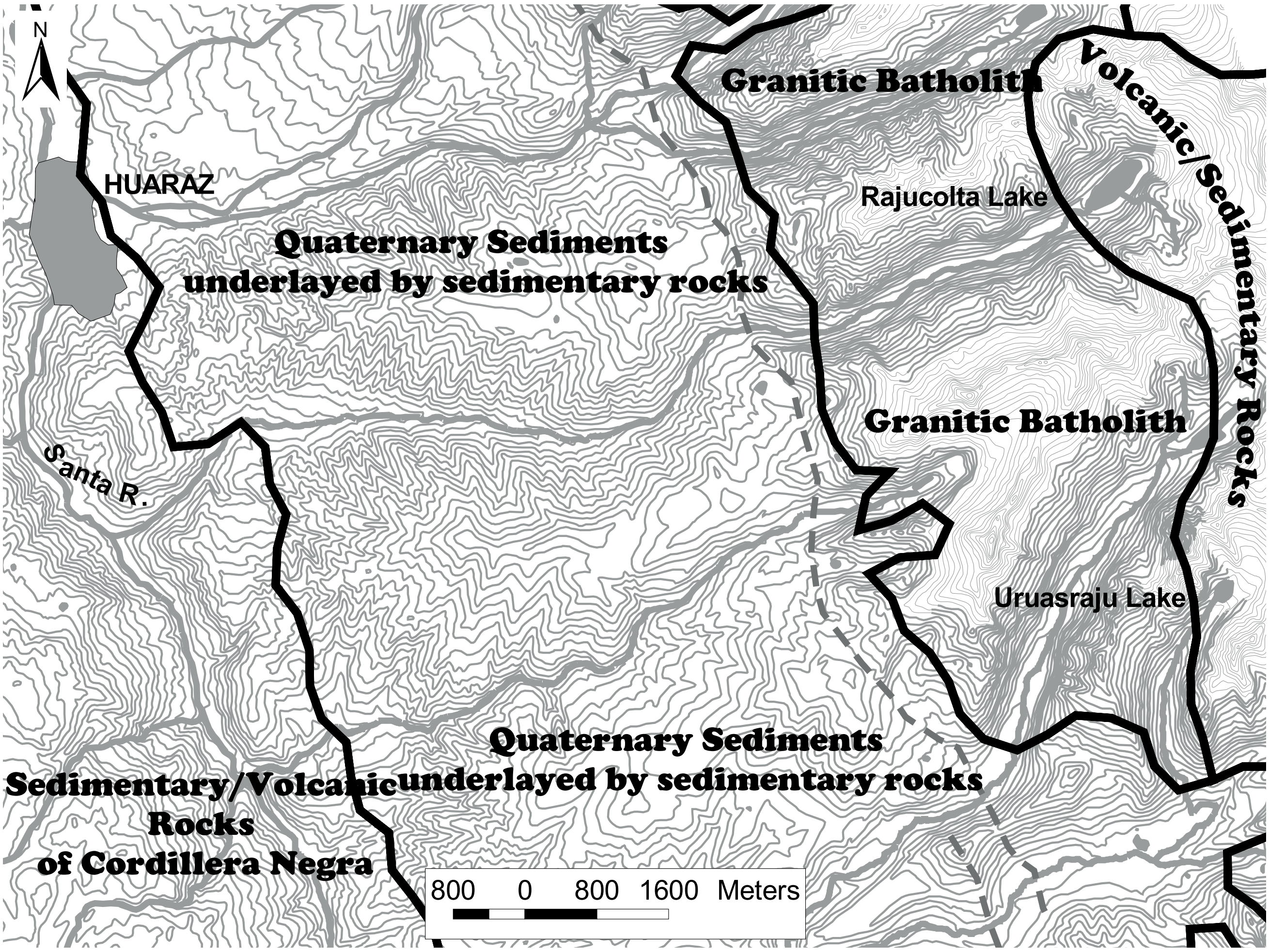

Fig. 2 Geology of the study area. Limits of the geological units are in black solid line, gray dashed line shows Cordillera Blanca normal fault

1.2 Geomorphology

Cordillera Blanca has the average altitude of over 4000 m with several peaks exceeding 6000 m (e. g. Huascaran 6768 m a.s.l., Huandoy 6395 m a.s.l.). Highest parts of the mountains are covered by mountain glaciers which reached extend of 721 km^2 in 1970, but retreated to 600 ± 61 km^2 in 1996 (Silverio and Jaquet 2005). There were 402 glacier lakes known in 1970 (Ames ed. 1989), but it is expected that its number increased due to glacier retreat, which is often accompanied with lake formations. Along the west limit of the mountains, lay undulating, deeply dissected foothills formed in glacial or fluvioglacial sediments underlay by Mesozoic and Tertiary rocks. The foothills are situated in the altitude between 3050 m and 3850 m forming belt 3 to 12 km wide. The glacial sediments consist of gravel and sand layers which may contain also isolated blocks of rocks up to several tens of meters of size. Massive lateral and terminal moraines extends from the glacial valleys to this area.

The Santa River Valley is located between the foothills of the Cordillera Blanca on east and the Cordillera Negra Mt. range on the west. Upper part of this graben valley (Wise and Noble 2003) is wide and opened with gradient between 0.9% and 1.6%. Whereas, its lower course is rather narrow with gradient not smaller than 3.5%. In the place where the river changes abruptly its direction from NW to WSW, very narrow canon formed leading its waters to the Pacific shore.

The Cordillera Negra Mts. lays west of the Santa River. Its highest altitudes are about 5000 m a.s.l. and it is intersected with many deep and narrow valleys formed in sedimentary and volcanic rocks. Recently the mountain range is not glaciated, but there were identified 16 glacial lakes which formed during the Pleistocene glaciations (Concha 1974). Rich deposits of polymetallic ore are being exploited in this region.

1.3 Glacial lakes

Majority of the lakes in the Cordillera Blanca Mt. are of glacial origin. They formed either in deepened bowel like basins in the base rock carved by glaciers or behind moraines (terminal, recessional or lateral moraines). Moraines are formed by unsorted or poorly sorted sediments showing certain degree of compaction. The moraines have often asymmetric triangular cross sections with steeper inner slopes. Dip of the outer slopes ranges between 30° and 40° and total high sometimes exceeds 70 m. According to Concha (1974), there are 52% of glacial lakes dammed by moraines. The rest of the glacial lakes is dammed by base rock or combination of the base rock and moraines. Only small part of the lakes in the Cordillera Blanca (6.5%, Concha 1974) formed behind dams consisting of rockslides, rock avalanches and debris flows deposits.

Level of hazard of a lake to produce dangerous GLOF can be assessed based on the type of dam and its slope, distance of the lake from the glacier and probability of major ice or rock fall into the lake (Concha 1974). Complete overview of the characteristics important for the lake dam stability gives Emmer (2011). The most dangerous are considered those lakes with direct contact to the glaciers and dammed by moraines with steep slopes. On the other hand, the safest glacial lakes are those with base rock dams since their rapid erosion or breakage due to sudden increase of water level is almost impossible. Evolution of the glacial lakes and their safety conditions are very dynamic, thus repeating evaluation of the level of hazard for given lakes should be performed, to maintain reasonable safety level of the local inhabitants.

2. Methods

Field mapping and interpretation of the remotely sensed data (satellite images – SPOT, LANDSAT 1999 and WorldView 2010) were used to map basic geomorphological features of the studied areas. The mapping focused only on the valley parts within the Cordillera Blanca Mts., their foothill sections were omitted since the mapping focuses primarily on glacial valley forms. Detailed description and assessment of the terminal parts of the valleys around the glacial lakes was performed during field mapping in 2003 and 2011.

Genetic type of the material and morphology were used to define geomorphological classes. Among the landforms directly associated with glaciations are recessional and terminal moraines. In many cases these moraines have triangular cross-profile, forming asymmetric ridges. Presence of this morphology was one of the major attribute necessary to map moraines on satellite images. Glaciofluvial and glaciolacustrine deposits were identified during the field work. Among the other landforms covering valley bottom and lower parts of the slopes are talus deposits and dejection cones. Sediments on slopes, which were not attributed to any of the above mentioned class, were identified as colluvial deposits. It is possible that in some parts these are formed by moraine material, but this could not be determined based on field mapping constrained to the valley floor and information extracted from the satellite images.

3.Results

3.1 Geomorphology of the Rajucolta and Pumahuaganga Valleys

The Rajucolta Valley starts with glacial cirque bellow Huantsan Mt. (6395 m a.s.l.) and runs south-west entering the foothills of the Cordillera Blanca at the altitude of 4000 m a.s.l. (colour appendix Figure I). It has form of narrow (320–500 m), U-shaped valley modeled by repeating mountain glaciations (Rodbell and Seltzer 2000). Five hanging valleys are connected to the main valley which floor is 150 m to 300 m lower. The Rajucolta glacier is still connected with the lake, which formed behind its terminal moraine at elevation of 4272 m a.s.l. The lake is 1.5 km long, 0.5 km wide with volume of 17,546,151 m^3 as measured in 2004 (personal communication N. Santillán, National Water Authority, Lima). In total the mapped valley part is 8.8 km long and majority of its floor is covered by glaciofluvial material. In several regions it gradually transforms into lacustrine deposits showing areas of older lake basins. In two cases, they are found upstream from remnants of recessional moraines, which are probably responsible for damming the old lake basins and reached up to 2.2 km from the moraine dam. Surface of the deposits is flat or gently rolling with often well developed deep gullies carved by the streams in soft lacustrine deposits. Foots of the valley slopes on both sites are covered by almost continuous band of talus deposits with slope dip between 30°–45°. The talus is deposited bellow rock slopes and rock faces outcropping in the lower and steepest part of the valley sides where the slope exceeds 50°. In several places, dejection cones formed instead of the talus deposits. They resulted probably from repeating debris flows which transported colluvial and moraine material from the upper and also less steep parts of the ridges and hanging valleys located in general above 4750 m a.s.l. In this region, the slopes vary between 20°–35° and are mainly covered by moraine accumulations with typical, triangular morphology. Many glacial lakes are being formed behind those moraines often formed bellow horns of the mountain peaks. Length of the lakes does not exceed 350 m, but typically is around 60 m. According to the 1999 LANDSAT image, there were 11 such lakes. The rest of the slopes are either covered by colluvial deposits which could not be further specified or is formed by the outcropping base rocks.

The Pumahuaganga Valley begins with the Uruashraju glacier named after 5722 m a.s.l. high mountain on which southwest slopes it evolved. The lake is situated at 4600 m a.s.l. and is 210 m long and 108 m wide. It is dammed by bedrock dam with some moraine sediments on top of it. Total length of the mapped valley is 4.2 km. It vents into the over deepened valley which floor is about 200 m bellow the Pumahuaganga hanging valley floor. Distribution of the main geomorphological units varies significantly from the Rajucolta Valley (colour appendix Figure III). Sediments are dominated with almost 2 km long side moraine which is well developed mainly on the southeast side of the valley below the glacier. The opposite site of the valley is covered by slightly stratified colluvial sediments without moraine form. These consolidated sediments form very steep, erosional slope where stones are rolling down almost at all times. Denudated remnants of moraine accumulations were identified at the east side of the valley mouth. Moraine accumulations are almost entirely missing on the higher elevations bellow the horns of the mountain peaks. There are also no glacial lakes on the mountain ridges. Large part of the valley floor is filled with lacustrine deposits of old lake now forming marsh. Talus deposits rim only part of the valley slopes. Dejection cones are entirely missing in the valley, suggesting that there was not enough material on the upper parts of the slopes to be transported down the valley floor in form of debris flows.

3.2 Natural hazards of the Rajucolta and Pumahuaganga glacial valleys

The rock slopes of the glacial valleys underwent repeating compression and unloading during the advances and retreats of the mountain glaciers. It is reflected by many opened cracks visible on the rock cliffs and several rockfall/rock slides which occurrence could be related to stress relaxation after the glacial retreat. These rather large rockfalls/rock slides are in both valleys located near their lower end (letters A on Figures I and III – colour appendix). The accumulations are formed by large angular rock blocks often exceeding 2 m in size and in some cases reaching up to 4.5 m. Dense forest of the Polylepis sp. trees covers all of the identified accumulations (compare to Cáceres 2007). Other identified landslides (rock slides) within the Rajucolta Valley originated from the highest parts of the ridges and have narrow elongated shape. In the Pumahuaganga Valley, debris flows are concentrated to the northwest slope near the lake, where the moraine sediments are exposed in very steep slope.

Other possible source of natural hazardous events represents gullies connecting side hanging valleys or upper parts of the valley slopes with the main glacial valleys. Recently, these channels are mainly eroding the talus or dejection cone sediments. Nevertheless, it is clear that they were responsible for deposition of some of the dejection cones in the past. Thus potentially dangerous debris flows accumulating moraine material from the upper parts of the ridges on the valley floor may occur in the future.

3.3 Natural hazards around Rajucolta and Uruashraju glacial lakes

The moraine dam of the Rajucolta Lake is covered by dense vegetation (herbs and shrubs) preventing the water erosion of its surface. Its outflow was dammed by 13.6 m high earth filled dam in 2003. At the same time, water conduct was constructed to lower the lake level by some 7 m. It resulted in lowering total water volume (by 5,000,000 m^3 personal communication N. Santillán, National Water Authority, Lima) and added additional protection from outburst floods. The potential displacement wave now needs to overcome the constructed dam. Despite of this safety improvement, there were identified several potentially hazardous sites on the inner slopes of the lake dam.

On the N part of the Rajucolta Lake banks, several gullies with small dejection cones developed. The slope is covered by colluvial sediments, which are underlay by base rock in shallow depth. The sediments come from moraine deposits in the hanging valley above where a small lake is also located. This geomorphological setting may impose high danger if larger amount of moraine material would be mobilized either due to extreme precipitations or outburst of the glacial lake. Further west on the moraine slope, a prominent terrain step is forming head part of temporarily inactive landslide, which accumulation area is situated bellow the water level. Remobilization of this landslide may cause displacement wave and subsequent flood. Southeast and south parts of the slopes above lake are again characterized by small glacial lakes in the cirques of the hanging valley. They are connected with the lake by small stream. The lakes are possible sources of GLOF which may increase its volume by mobilizing water of the Rajucolta Lake. Southwest of this stream, the slopes are very steep and long, covered by loosened colluvial deposits without vegetation. So far only small gullies and soil slips were identified on this section of the banks. Nevertheless, high inclination (35°–44°) and the length of the slope make this area susceptible to landslide or debris flows formation, which may have potential of triggering significant displacement wave and GLOF from the Rajucolta Lake.

The southwest slopes of the Uruashraju Lake possess high hazard due to very steep inclination, which is far from angle of repose of the forming material. Source areas of several debris flows were mapped there (colour appendix Figure II). The falls (rolling) of boulders were witnesses many times during several days of the field work. Nevertheless, the field evidences suggest that usually only relatively small amount of material is involved in each event. More intense precipitations or seismic shaking may mobilize much larger amount of material. Northeast and north slopes are formed by moraine sediments, which keep steep inclinations in their upper part, whereas the lower portion of the slope is rather shallow with strong limonite cementation of the sediments (personal communication Jan Novotný, Arcadis Geotechnika, a.s., Prague). There have been identified no lakes on the slopes above the Uruashraju Lake. This fact decreases probability of GLOF being triggered from the lake. Also its small dimensions make it much less dangerous than the Rajucolta Lake.

4. Discussion

The mapped glacial lakes show common geomorphological features, but differ significantly in the presence of moraine sediments on the upper part of the valley slopes, which are missing in the Pumahuaganga Valley. Such moraine sediments are abundant in the Rajucolta Valley where also considerable number of so far small glacial lakes is being formed. Similar moraine sediment distribution was identified in the Cojup Valley (Vilímek at al. 2005). Debris flow originated from moraine located bellow the Huandoy Mt. transported considerable volume of material to dejection cone in the Llanganuco Valley (Zapata 1995; Vilímek et al. 2000). The moraine sediments were mobilized due to intense precipitation and also probably due to melting of buried ice blocks located bellow the moraine surface. Similar events may occur also in the Rajucolta Valley imposing certain degree of hazard to the mapped dejection cones. Also any gullies connecting the upper valley slopes with the valley floor should be considered as potential conducts of dangerous debris flows. Even in the cases when erosion processes prevail during recent times.

The outflow of the Rajucolta Lake is reinforced by regulation dam with the purpose of improving the Santa River flow during the dry seasons to supply sufficient water for electricity generation in the Cannon del Pato power plant. The dam added additional space to retain possible displacement waves caused by potential ice or rockfalls to the lake. At the same time, if significant and quick changes of the water level due to the dam operation may occur, stability of the inner slopes could be lower possibly resulting into the landslide generation. Such event could also cause GLOF with unknown magnitude. Flood caused by landslide occurred in the Palcacocha Lake causing only minor damages down the Cojup River stream (Vilímek et al. 2005).

Recent GLOF events show (Bouška et al. 2011), that glacial lake characteristics previously thought to define safe lakes (Concha 1974) should be carefully revised. For example, considerable distance of glacier tongue from the lake and base rock dam type seems not to be sufficient to consider the lake safe with respect to the GLOF origin. As proved by the 2010 Lake 513 GLOF. Its glacier terminates 190 m above the lake, which is dammed by base rock and its water level was lowered by drainage tunnels. Despite of that, ice and rock fall to the lake caused GLOF damaging several houses and causing unrest within the local population. It seems to be necessary to carefully reconsider levels of GLOF hazard for all lakes within the inhabited watersheds. Hazard and risk assessment for the potentially flooded areas would be of great importance. Its results may be beneficial for development planning and civil defense. Implementation of the hazard assessment requires strong and long term interest of the local politicians with respect to the natural hazards. Unfortunately, local experiences show that the local authorities are not motivated to do so (Klimeš and Vilímek 2011).

5. Conclusions

Geomorphological mapping with the aid of satellite images enabled to characterize basic land forms and associated forming processes along their degree of hazard in selected glacial valleys. Field investigation was necessary to obtained detailed information about slope stability conditions important for reliable hazard assessment of respective glacial lakes. Areas which need further field investigation to ascertain possible degree of hazard were identified around the small glacial lakes located high above the Rajucolta Lake and also along the sides of its valley above altitude of 4750 m a.s.l. These small lakes and moraine accumulations located mainly in the hanging valleys may be source of dangerous debris flows or GLOFs in the future. Also their affect on much larger glacial lakes in the main valleys needs to be carefully evaluated and consider during the future research of the natural hazards. Recently documented GLOFs considerably hampered validity of the used glacial lake safety criteria formulated some 40 years ago. Thus new approaches evaluated the glacial lake hazards are necessary.

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RÉSUMÉ

Geomorfologie a přírodní nebezpečí vybraných ledovcových údolí v pohoří Cordillera Blanca, Peru

Pohoří Cordillera Blanca leží ve středním Peru a tvoří kontinentální rozvodí mezi Atlantským a Tichým oceánem. Nejvyšší hora Huascarán (6768 m n. m.) je zároveň nejvyšší horou Peru. Pohoří je budováno převážně granodiority a tonality třetihorního stáří, které jsou v nejvyšších partiích překryty erozními zbytky druhohorních sedimentárních a vulkanických hornin. Ze západní strany je pohoří omezeno výrazným zlomem, který je odděluje od údolí řeky Santy. To je vyplněno čtvrtohorními glaciálními a fluvioglaciálními sedimenty překrývajícími druhohorní sedimentární horniny.

Geomorfologické mapování bylo provedeno na základě interpretace satelitních snímků a ověřeno v terénu. Tomu byla také přizpůsobena legenda přehledné geomorfologické mapy. Byla zpracována dvě ledovcová údolí v jihovýchodní části pohoří, jejichž zdrojové oblasti jsou vzdáleny pouhých 5 km. Údolí Rajucolta je 8,8 km dlouhé a v jeho závěru je stejnojmenné jezero s rozměry 1,5 km a 0,5 km a s objemem 23 260 000 m^3. Jezero je hrazené ústupovou morénou. Druhé údolí – Pumahuaganga – je dlouhé 4,2 km a pod horou Uruashraju je (5722 m n. m.) je situováno jezero s rozměry pouhých 210 m a 108 m. Jeho hráz je z větší části tvořena podložní horninou.

Geomorfologické mapování ukázalo, že pro povodí Rajucolty jsou typické morény a malá morénová jezera v horní části svahů v nadmořské výšce nad 4750 m n. m. Jezera vznikají většinou ve visutých údolích se směrem S–J. V celém povodí bylo zjištěno 11 takovýchto morénových jezer. Jejich maximální rozměr nepřesahuje 350 m, ale většinou se pohybuje kolem 60 m. Na tato vysutá údolí navazují na dně hlavního údolí četné výplavové kužele. V povodí Pumahuaganga jsou morény v horních částech hřebenů výjimečné a jezera tam nebyla zjištěna žádná. Nejvýraznějším morfologickým tvarem v údolí je velmi rozsáhlá morénová akumulace v jeho závěru, která je situována výhradně na jeho jižním svahu. Na rozdíl od údolí Rajucolty zde nebyly identifikovány žádné dejekční kužely. V obou údolích byly zjištěny rozsáhlé skalní sesuvy situované v blízkosti jejich ústí. Na jihovýchodním svahu nad jezerem Uruashraju byla identifikována celá řada zdrojových oblastí drobných přívalových proudů. Ty vznikají na velmi prudkém erozním svahu v nevytříděných svahových sedimentech. Díky malému množství vody v jezeře tyto procesy nepředstavují výraznější nebezpečí. Jiná situace je u jezera Rajucolta, na jehož březích byly také zjištěny dočasně uklidněné, drobné přívalové proudy. Navíc je ve vysutých údolích nad jezerem situováno několik ledovcových jezer, u kterých není možné vyloučit vznik ledovcových povodní, které by ovlivnily jezero Rajucolta. Velký objem vody v tomto jezeře představuje potenciální nebezpečí pro níže položené osady včetně krajského města Huarazu.

AN INTEGRATED APPROACH FOR MANAGEMENT OF AGRICULTURAL NON-POINT POLLUTION SOURCES IN THE CZECH REPUBLIC

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ABSTRACT

We report a new, integrated approach to the identification and localization of potential critical areas of non-point agricultural water pollution in the Czech Republic. The methodology is presented in model catchments of IV. order, namely the Hrejkovický and Bilinský brooks in the water reservoir Orlík watershed. The risk rate of non-point source pollution is evaluated with the help of GIS tools, integrating the assessment of geomorphology, land use and soil conditions within a territory in conjunction with the agricultural tile drainage systems. Besides the areas prone to erosion and 'direct protection localities' along water courses, spots with increased potential of nutrient leaching into groundwater and drainage water are delineated, based on a synthetic map of shallow groundwater vulnerability. These spots are classified using analysis of the Valuated Soil Ecological Units (VSEU) code, while agricultural drainage systems are identified according to the documents of the former Agricultural Water Management Authority of the Czech Republic. Results from geographical analysis show differences between intrinsic parameters of model catchments, which influence the vulnerability potential towards diverse types of non point pollution. The potential pollution thread of surface and groundwater by leaching is relatively high in both catchments, in the Bilinský brook catchment due to prevailing arable land on first and second vulnerability classes within the tile drainage subcatchments and in the Hrejkovický brook catchment due to dense occurence of first and second vulnerable clasess in the catchment area, though comprised from a third by grassland. Water erosion potential jeopardy is bigger within the Bilinský brook catchment with 10% of arable land having the average soil loss 4–10 t ha^{-1} y^{-1}, contrary to 2% within the Hrejkovický brook catchment. Presented approach can help in prioritizing protective measures and management strategies in a catchment to curtail the negative impacts of non point agricultural pollution in water bodies and in the whole environment.

Key words: water vulnerability, infiltration areas, tile drainage, erosion, non-point pollution sources, GIS

1. Introduction

The quality of surface and groundwater is significantly influenced by pollution from point sources (settlements, waste-water treatment plants, fish ponds and industrial or agricultural works) and also by non-point pollution sources from prevailingly agricultural activities, causing elevated leaching of nutrients into waters and increased erosion (Macleod et al. 2007). The significance of non-point pollution sources will probably grow with continually decreasing pollution from the point sources (Haygarth and Jarvis 2002; Langhammer et al. 2009). Its contribution is important especially in the case of nitrogen and phosphorus, varying in the regions of the Czech Republic according to the land use, farming intensity and methods, morphological and hydrological characteristics of the territory, and the level of atmospheric deposition. While assessing the contribution of individual pollution types by evaluating the solute loads based on the data acquired by non-continuous monitoring approaches, however, the amounts of phosphorus fractions, originating from erosion or re-suspension of e.g. stream bed sediments, as well as for nitrogen compounds, which are not detectable by point monitoring of water with monthly (or fortnightly) periodicity, are probably strongly underestimated (Kronvang et al. 2005; Hejzlar et al. 2008, Fučík et al. 2010a).

The causality between land use in a catchment and quality of surface and ground water represents a principle documented by many authors (Haygarth and Jarvis 2002; Žížala et al. 2010) with larger or smaller impacts and differences, this principle is valid for various types and scales of catchments. The main factors influencing the nitrogen burden in waters , in conditions of the (not only) Czech Crystalline Complex, are the percentage of arable land within an area and the artificial drainage systems (Lexa et al. 2006; Fučík et al. 2008; Kvítek et al. 2009; Wade et al. 1998). Agricultural land drainage together with ploughing causes a general change in oxidation-reduction conditions in the soil profile; mineralization of organic nitrogen is accelerated and denitrification activity decreases. In contrast to permanent grasslands (further referred to as PGL), arable land lacks nitrogen-reducing vegetation, so that especially in winter and spring months nitrogen is leached into lower soil horizons, vadose zone, drainage and groundwater (Haberle et al. 2009; Kvítek and Doležal 2003).

Export of phosphorus compounds from non-point agricultural sources, occurring mainly through surface runoff, erosion processes and partly also via subsurface runoff, e.g. tile drainage (see e.g. Buczko et al. 2007; Deasy et al. 2008), is generally dependent on the slope gradients and their lengths in catchments, rainfall intensity, crop rotations, agronomical practices, soil types (namely soil

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texture, soil profile depth) and their actual conditions (wetness, bypass flow) and on the percentage of arable land in a catchment as well (Ekholm et al. 2000; Kronvang et al. 2003; Janeček 2007).

In recent years, research in the Czech Republic and abroad has focused on the effects of fluctuating ratio of various runoff components on pollutant loads from non-point sources (e.g. Hermann et al. 2008; Tomer et al. 2010; Zajíček et al. 2011). The validity of the hypothesis postulating the dominant effect of land use in the 'source areas' on surface and shallow groundwater quality in the conditions of Czech Crystalline Complex (Doležal and Kvítek 2004), has been verified experimentally. So far, this hypothesis has only been validated for nitrates (Fučík et al. 2010b) and thermal regime of different drainage runoff components (Zajíček et al. 2011); however, the hypothesis may be applied more extensively, namely to the pollutant-transporting medium – water; to its behaviour in the soil and hydro-geologic environment of the unsaturated zone of the Crystalline Complex. While testing this hypothesis it has been found that the drainage systems situated in the soils with crystalline bedrock and built in slopes only rarely receive water infiltrated directly from rainfall or ground water accumulated under the drainage system (Zajíček et al. 2011). In such cases the drainage system is often connected to a distant spring effluent or a shallow aquifer supplied from a source located outside the drainage system itself (Kvítek and Doležal 2003). The total runoff of the Bohemio-Moravian Highlands consists in ca 40% of shallow interflow and in ca 30% of baseflow (Doležal and Kvítek 2004).

By 1990, more than 1,078,000 ha have been drained in the Czech Republic (Kulhavý et al. 2007). Investigation of non-point pollution sources was therefore focused on the drainage systems that could significantly contribute to the nutrient load of surface waters. The presence of drainage systems modifies the natural pathways of water circulation and runoff – depending on soil characteristics and morphological conditions of a locality, weather course and parameters of the drainage system, the drainage usually shortens water cycle and retention time in the soil-rock environment (Doležal et al. 2000). Due to the characteristic shallow pattern of water circulation in the Crystalline Complex, the morphologically higher situated localities are hydrologically connected with the drainage system and have essential impact on the formation of runoff and the quality of drainage water. The soils located in upper parts of the landscape are typically shallow with little sloping, and so prone to accelerated infiltration (Kvítek and Doležal 2003). It is therefore reasonable to expect that the landuse within the most vulnerable enclaves due to infiltration – critical source areas of the catchments – will significantly influence the hydrology and hydrochemistry dynamics of tile drainage systems built on the territory of the Czech Crystalline Complex.

Although transformation processes of both major nutrients (nitrogen and phosphorus) occurring in agriculturally exploited land have been relatively well documented, it is difficult to predict and quantify the loss of nutrients from agricultural non-point pollution sources and precisely localize their origin. A number of studies have confirmed the validity of the method of identifying the 'critical source areas' in a catchment as an appropriate approach to the description of nutrient loss pathways. This principle has been recognized and used in various modifications worldwide (see e.g. Pionke et al. 2000; Heathwaite et al. 2005; Lyon et al. 2006; Srinivasan et al. 2005; Strobl et al. 2006).

There are several ways of perception and usage of the term „vulnerability" across the scientific field, very often being addressed exclusively to vadose zone, aquifers or groundwater (Gogu et al. 2000) or to a whole environment, as a result of all factors which may mutually affect the dynamics of surface and groundwater quality in an area. The definition of the latter interpretation describes the Intergovernmental Panel on Climate Change (IPCC 2001) as a function of exposure, sensitivity and adaptive capacity, where exposure means a system's degree of exposure to external impacts, sensitivity is the degree to which a system responds to external impacts and adaptive capacity is defined as "the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate" (IPCC 2001). In this study, vulnerability is considered as a fusion of exposure and sensitivity, being expressed in a qualitative (shallow groundwater vulnerability and direct protection) and quantitative (erosion) conception.

The main goal of this work is to document the methodology of defining the three types of critical source areas on the example of two closely situated, but different catchments of the Water Reservoir Orlík, with the purpose to reduce the nutrient leaching into surface and groundwaters.

2. Study area

The model catchments of the Hrejkovický and Bilinský brooks in the watershed area of Water Reservoir Orlík (Fig. 1) were selected as both best representing and distinctive the land cover species and built tile drainage systems. Both the catchments also contained monitoring objects (profiles).

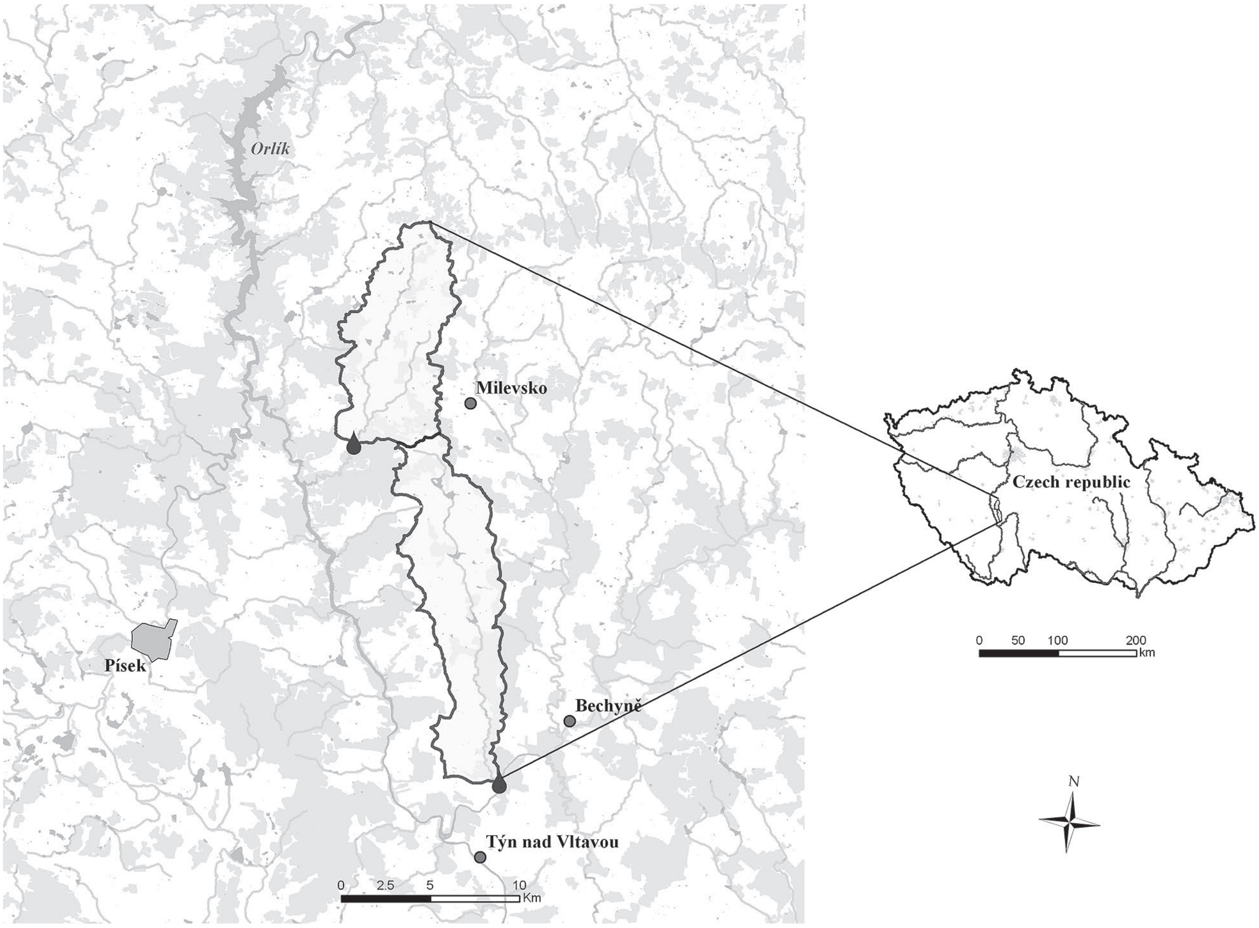

Fig. 1 Study area

Hrejkovický Brook

Profile number 211 008
Catchment area – 58.21 km²

Slope:	average – 3.63°	
	maximum – 28.43°	
Altitude:	minimum – 420.30 m a.s.l.	
	maximum – 608.32 m a.s.l.	

The dominant evaluated soil types were mesobasic and eubasic modal Cambisols on coarse weathered rocks (30.33%), weakly gleyic Regosols and Cambisols (24.16%), and brown Gleysols (16.85%).

Hydrogeological region – Crystalline complex in the catchment of the central Vltava River

By its geomorphologic distribution, the southern part of the catchment belongs to the Milevsko Hills and its northern part to the Kovářov Uplands. The Milevsko Hills display broken topography, sitting mostly on granitoids of the Central Bohemian Pluton, with articulated erosion-denudation relief broken by structural ridges and monadnocks. The Kovářov Uplands are flat uplands sitting on granitoids of the Central Bohemian Pluton with articulated erosion-denudation relief.

The brook is a right-hand affluent of the Vltava River.

Of demographic importance in this catchment is the Hrejkovice municipality with 465 inhabitants.

Bilinský Brook

Profile number 211 064 (211 063)
Catchment area – 71.46 km² (211 064)

Slope:	average – 2.97°	
	maximum – 40.15°	
Altitude:	minimum – 379.41 m a.s.l.	
	maximum – 570 m a.s.l.	

The dominant soil types were arenic, weakly gleyic Regosols and Cambisols (23.33%), modal eubasic to mesobasic Cambisols, medium-textured (14.58%), and modal Luvic Pseudogleys and gleyic Cambisols (12.91%).

Hydrogeological region – Crystalline complex in the catchment of the central Vltava River

By its geomorphologic distribution, the catchment belongs to the Bechyně Hills, represented by an erosion-denudation relief disturbed by faults in the N-S direction, with structural monadnocks displaying remnants of tabulated surfaces and deeply cut valleys.

The brook is a right-hand affluent of the Lužnice River.

Sources of geographical data used in this work:

– Valuated Soil Ecological Units (VSEU) – graphical and numerical database of soil data in original mapping scale 1 : 5000; these data were originally intended for soil pricing

– Land Parcel Identification System (LPIS)
– CORINE Land Cover
– Digital Elevation Model (DEM 10 ×10 m)
– Digital Base of Water Management Data (DIBAVOD)
– Principal Base of Geographic Data 1 : 10,000 (ZABAGED)
– Synthetic map of ground water vulnerability (Novák et al. 2010)

As an additional source we used information of the drainage systems placement from the mapping documentation of the former Agricultural Water Management Authority of the Czech Republic scaled 1: 10,000 on the Basic Map of the Czech Republic.

3. Methods

Critical source areas of non-point agricultural pollution are generally represented by agricultural land enclaves with high potential risk associated with fast export of nutrients and pollutants or soil particles (Pionke et al. 1996). In our work, the critical source areas were classified using three criteria. First, they represent source areas of increased potential leaching of pollutants into drainage and groundwaters, determined according to the vulnerability of ground water with shallow circulation (Janglová et al. 2003; Novák et al. 2010); second, they represent areas prone to erosion defined by the USLE method (Wischmaier-Smith 1978) in combination with DEM analysis; and third, they are defined as direct protection localities of water courses, represented by districts closely associated with the embankment zones of water courses. The classification of critical source areas of non-point agricultural pollution was done in the ARC GIS environment.

The initial analysis of LULC (Land Use Land Cover) development was done using the CORINE Land Cover data layer, recording the representation of land cover species in the model catchments in 1990, 2000, and 2006. The classification system assigns individual categories to the land type groups (211 – non-irrigated arable land, 231 – meadows and pastures, 243 – agricultural areas with natural vegetation, 312 – coniferous forests). The impact of LULC on the quality of surface water is reflected mainly in the proportion of arable land and PGL in the total area of agricultural land. Due to the 1 : 200,000 scale of the background source, the classification of some land types into categories in this background suffers a certain extent of bias and ambiguity (Hanzlová et al. 2007).

A more detailed LULC background is provided by the LPIS 2010 system (colour appendix Figs IV–V) operated by the Czech Ministry of Agriculture. This is a system of graphic records of farming sections based on cadastral records, with links to complex information including data on the land type (culture). This material keeps records of only registered land users receiving various fundings within the State agricultural policy, so that the system leaves uncovered areas. It is the faithful representation of the current situation of agricultural land fund containing information on the allocation of agricultural State funding. The only disadvantage of its use is the difficulty of obtaining retrospective data. Data are distributed in the *.shp format.

3.1 Definition of shallow groundwater vulnerability

The layer of shallow groundwater vulnerability was generated using an analysis of VSEU codes. The graphical and numerical VSEU database is unique by the precision of its processed data scale – 1 : 5000 (Mašát et al. 2001). To assess the infiltration process we used the last four code digits – main land unit, slope, exposure, skeleton content and soil depth, which were classified into categories 1–5 (category 1 = highest infiltration capacity, 5 = lowest infiltration capacity). The individual code elements were then assigned weights expressing the significance of particular criteria for the infiltration process. Multiplication of category values by weight of the criterion and their mutual addition gave five categories of vulnerability in relation to the potential infiltration of precipitation water into the soil and rock environment (Figs 2–3), where categories 1 and 5 express the maximum and the minimum infiltration rates, respectively (Janglová et al. 2003). The method is protected by Utility Model No. 20352 registered with the Office of Industrial Property of the Czech Republic.

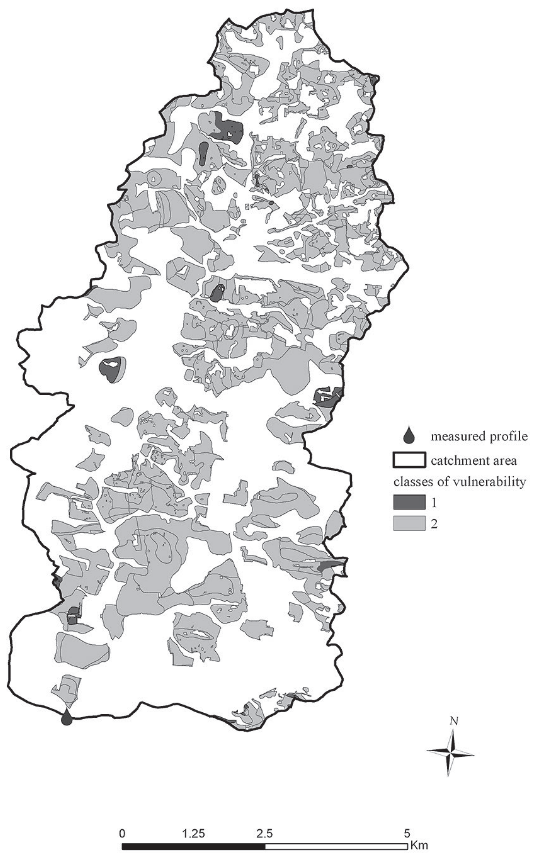

Fig. 2 Categorization of shallow groundwater vulnerability (Hrejkovický brook)

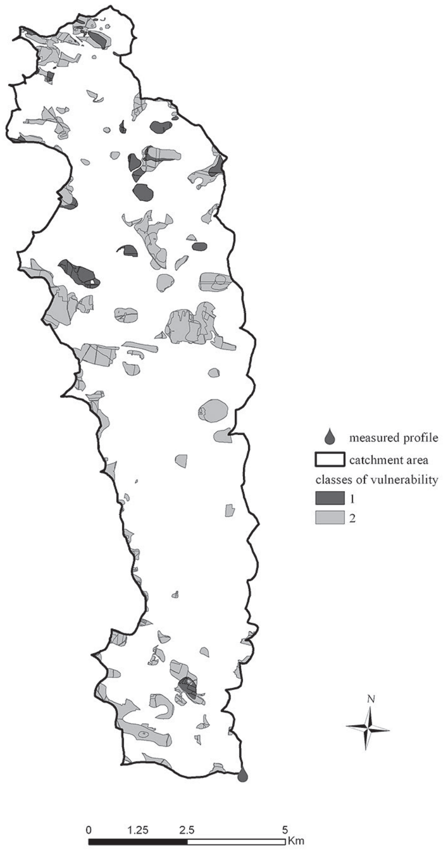

Fig. 3 Categorization of shallow groundwater vulnerability (Bilinský brook)

To obtain information about hydrological connectivity between the enclaves with different vulnerability levels of shallow groundwater and the agricultural drainage systems we used the GIS layer of the former Agricultural Water Management Authority of the Czech Republic with locations of the built drainage systems scaled 1 : 10,000, to which we generated subcatchments taking into account the local soil conditions and morphology using DEM. In the ARC GIS environment we then intersected the vulnerability categories 1 and 2 with these subcatchments and subsequently delineated the areas most vulnerable to leaching of risk compounds into shallow groundwater (Figs 4–5).

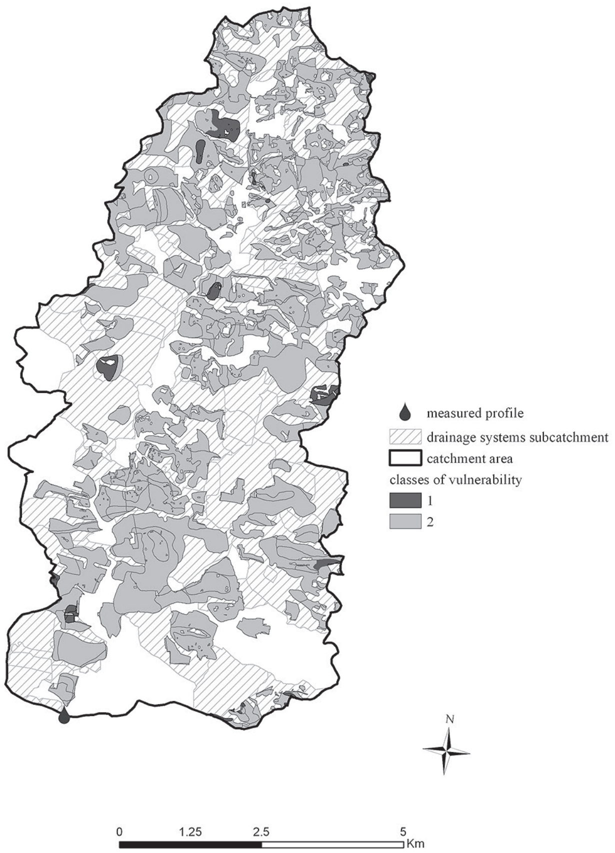

Fig. 4 Drainage systems subcatchment (Hrejkovický brook)

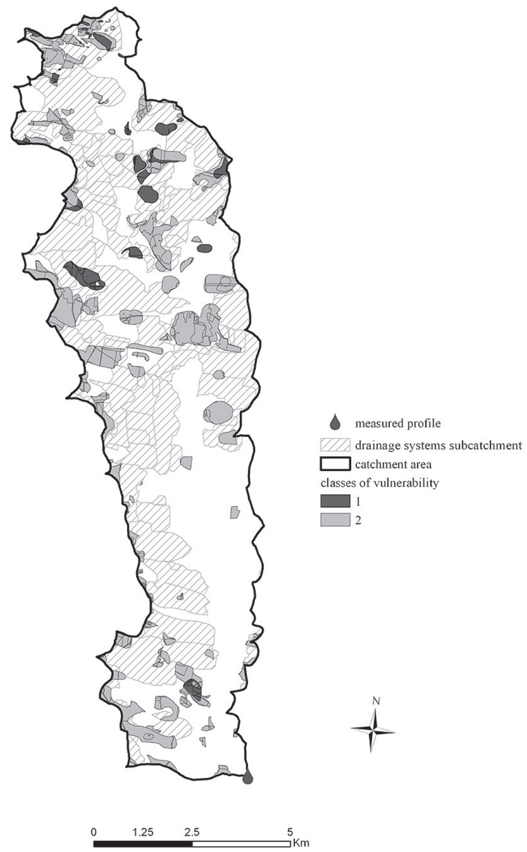

Fig. 5 Drainage systems subcatchment (Bilinský brook)

3.2 Definition of vulnerability to erosion

Selection of the risky localities due to erosion was done based on the long-term average soil loss using the Universal Soil Loss Equation, USLE (Wischmeier et al. 1978).

A = R · K · L · S · C · P
G = Computed soil loss per unit area ($t\ ha^{-1}\ year^{-1}$)
R = Rainfall factor
K = Soil erodibility factor
L = Slope length factor
S = Slope gradient factor
C = Cropping management factor
P = Erosion control management factor

The map of long-term average soil loss is presented as a raster layer with 10 m pixel resolution, containing the computed values of long-term soil loss per unit area (Novotný et al. 2010).

The erosive effect of a rain is determined by qualitative characteristics of the rainfall (kinetic energy, intensity, or their combination). For computing we used the recommended average value for the Czech Republic $R = 20\ MJ\ ha^{-1}\ cm\ h^{-1}$ (Janeček et al. 2007).

The soil erodibility factor represents the vulnerability of soil to erosion, i.e. the ability of soil to resist the erosive factors (precipitation, surface runoff). For computing we used the VSEU data scaled 1 : 5000, which were assigned updated values of K factor (Vopravil 2006).

To determine the LS factor we used GIS tools, establishing the LS factor separately for each square of the raster digital terrain model (DTM). The uninterrupted slope length was substituted with the runoff source area in square meters (micro-catchment) established separately for each land point (DTM square) (Desmet et al. 1996). The input data for computing were digital terrain model at the resolution corresponding to the scale and the layer of land use. These data serve to determine the slope and the area of a subcatchment substituting the length of runoff pathways. The S factor value is established for each point separately based on its local slope according to McCool approach (1987, 1989).

The cropping management factor (C) was defined based on the climate regions (Kadlec, Toman 2002).

The value of P was set 1, expressing the absence of any erosion-protective measures. Identification of land vulnerable to erosion was done by overlaying the map of long-term average soil loss with the LPIS database and selection of the areas with above-limit erosion (over $4\ t\ ha^{-1}\ year^{-1}$) in general conditions. In this way the land is assessed in relation to the long-term average soil loss – according to its area, slope gradient, morphology (convergence of surface runoff), local precipitation effect, soil characteristics, and protective cover effect (colour appendix Figs VI–VII). For selected soil sections we identified the relevant landowner plots.

When applying the methodology for selecting vulnerable areas relevant to protection of drinking water sources these limits are stricter, and the values of $0.5–2\ t\ ha^{-1}\ year^{-1}$ were considered as safe soil loss depending on the catchment characteristics (Janeček et al. 2007).

3.3 Definition of vulnerability from the aspect of direct protection

The areas for 'water course direct protection' are defined using generated soil representatives typical for alluvial localities, predominantly the Fluvisol soil group. Genetically, this soil group just corresponds to the area of recent floodplains, i.e. long-term and repeatedly waterlogged areas (Němeček et al. 2001). Sections of this vulnerability group are defined in more detail using the DEM data. The resulting information layer provides sufficient data to establish inundations, as 'direct protection localities of water courses' from the aspect of the water protection integrated system. In the flood plains, if not represented by natural floodplain forest, the proposed measures in the form of grassing or forestation must be strictly observed (including appropriate management) because of potential intensive leaching of risk compounds associated with fluctuations of groundwater level or presence of surface runoff (Kvítek et al. 2009). Flood plains are defined by the law as important landscape elements (Act No. 114/1992 of the Collection of Czech Laws).

3.4 Integrated approach to the definition of critical source areas

Combination of the three types of critical source areas defined in sections 3.1., 3.2., and 3.3. enables identification and global delineation of all potential source localities of non-point agricultural pollution. Their subsequent association with the LULC layer provides a current survey of the use of areas with potential non-point agricultural pollution in the territory of interest. The priority in this system poses an application of targeted grassing.

4. Results

Using the ArcGIS 10 software we evaluated the land use based on the CORINE layers and LPIS 2010 system. The investigated catchments were categorized according to CORINE classification in all stages of data processing (1990, 2000, 2006). Analysis of representation of the individual CORINE classes in the agricultural land fund (further referred to as ALF) in the particular years of data processing shows that both investigated catchments undergo gradual reduction of arable land proportion at the expense of PGL, and that in the Hrejkovický brook catchment the growth of PGL is more pronounced compared to the Bilinský brook, which shows a slower increase (Table 1).

Tab. 1 Development of arable land vs. PGL ratio in the catchments – CORINE

Hrejkovický brook [%]					Bilinský brook [%]							
CORINE	Profile No.	arable	PGL		Profile No.	arable	PGL		Profile No.	arable	PGL	
		211	231	243		211	231	243		211	231	243
1990	211 008	57.02	1.22	16.60	211 063	69.34	0.85	2.09	211 064	68.64	0.99	3.27
2000	211 008	53.85	4.39	16.60	211 063	69.34	0.85	2.09	211 064	68.52	1.10	3.27
2006	211 008	50.09	10.59	13.67	211 063	65.59	2.21	3.64	211 064	65.33	1.90	4.80

4.1 Assessment of shallow groundwater vulnerability

The proportions of arable land and PGL were analysed within the shallow groundwater vulnerability classes 1, 2 according to the LPIS and CORINE classifications, see Tables 2 and 3. LPIS data showed the proportions of arable land and PGL to be 49.5% and 33%, respectively. CORINE classification showed the following ratios in the Hrejkovický brook catchment: in 1990, the proportion of arable land was 73.97% vs. 21.36% PGL, in 2000 the ratio changed to 69.75% vs. 25.58% at the expense of PGL, and in 2006 the ratio was 65.27% vs. 30.35%, which around 9% decrease of ploughed land ratio compared to the initial situation. A similar analysis was performed for the Bilinský brook catchment, with the proportion of arable land 80.13% vs. 6.44% of PGL according to LPIS. More detailed analysis based on the CORINE classification did not bring such marked differences in these land proportions in the investigated years as in the Hrejkovický brook catchment, but the changes of landuse in vulnerability classes 1, 2 – from arable land to PGL – was also noticeable.

In the second phase of data processing, using the methodology for definition of shallow groundwater vulnerability, we performed an intersection of the areas with vulnerability classes 1, 2 with drainage system subcatchments to define the surfaces most vulnerable to leaching of risk compounds into surface and groundwater.

The analysis of vulnerability classes 1, 2 in drainage system subcatchments of the Hrejkovický brook shows that the vulnerability classes 1, 2 are present in the surface area of 18.89 km^2, representing 56.92% of ALF. In contrast, the drainage system subcatchments of the Bilinský brook show the presence of these vulnerability classes only in the surface area of 8.16 km^2, the percentage of vulnerability 1, 2 in ALF being 22.31% (Table 5).

We also analysed the proportion of arable land and PGL in vulnerability classes 1, 2 according to LPIS classification (Table 5). In drainage system subcatchments of the Hrejkovický brook we found the proportion of arable land and PGL to be 57.84% vs. 28.56%. A similar analysis was performed for the drainage system subcatchments of the Bilinský brook, showing that the proportion of arable land vs. PGL according to LPIS is 83.68% vs. 6.63%.

Tab. 2 Proportions of arable land and PGL within groundwater vulnerability classes 1, 2 (LPIS 2010)

LPIS				
Stream name	Profile No.	% vulnerability in ALF	Ratio arable x PGL [%]	
			arable	PGL
Hrejkovický brook	211 008	57.44	49.50	33.07
Bilinský brook	219 063	21.97	79.76	6.52
Bilinský brook	219 064	22.01	80.13	6.44

Tab. 3 Development of arable land and PGL ratios in groundwater vulnerability classes 1, 2 (CORINE)

Hrejkovický brook 211 - 008			Bilinský brook 219 - 063		Bilinský brook 219 - 064	
CORINE processing	Ratio arable x PGL [%]		Ratio arable x PGL [%]		Ratio arable x PGL [%]	
	arable	PGL	arable	PGL	arable	PGL
1990	73.97	21.36	94.97	0.59	94.16	0.78
2000	69.75	25.58	94.97	0.59	93.96	0.98
2006	65.27	30.35	91.34	3.86	90.95	3.66

Tab. 4 Area of drainage system subcatchments and the area of ALF in drainage system subcatchments

Stream name	Profile No.	Subcatchment area [ha]	ALF in subcatchment [ha]	% ALF in subcatchment
Hrejkovický brook	211 008	4139.67	3319.40	80.19
Bilinský brook	219 063	3629.20	3152.27	86.86
Bilinský brook	219 064	4153.08	3661.03	88.15

Tab. 5 Proportion of groundwater vulnerability classes 1, 2 on arable land and PGL (LPIS 2010) within drainage system subcatchments

LPIS				
Stream name	Profile No.	% vulnerability in ALF	Ratio arable x PGL [%]	
			arable	PGL
Hrejkovický brook	211 008	56.92	57.84	28.56
Bilinský brook	219 063	22.91	83.46	6.89
Bilinský brook	219 064	22.31	83.68	6.63

4.2 Assessment of land vulnerability to water erosion

The assessment of land vulnerability to water erosion based on computing the acceptable soil loss by water erosion brought different results for the investigated catchments (Table 6). While in the Hrejkovický brook catchment the situation corresponded with the results of slope gradient determination, and land plots with G value exceeding 4 t ha^{-1} year^{-1} included only 2% of arable land, in the Bilinský brook catchment these land plots comprised 10% of arable land due to the higher length of uninterrupted slopes.

4.3 Assessment of vulnerability related to direct protection

The results of direct protection analysis corresponded with the hydro-morphology of the investigated catchments. While in lateral profiles the Hrejkovický brook catchment shows features typical for flat catchments, and thus higher representation of floodplain soils, the Bilinský brook catchment is characterized by lower mean width of the catchment, reflected in lower proportion of floodplain soils in the catchment. The proportion of the floodplain soil group in the Hrejkovický brook catchment is 3.15% vs. 1.43% in the Bilinský brook catchment.

5. Discussion and Conclusions

The potential source areas of agricultural non-point pollution were defined by combining all the three described principles of delineating critical source areas, while subsequent association with the LULC layer led to determination of the current extent and distribution of the source areas of non-point agricultural pollution in the territory of interest.

Concerning the distribution of land use types, both catchments showed a high proportion of agricultural land, Hrejkovický brook with 72.76% and Bilinský brook with 74.25% (CORINE 2006). Detailed analysis based on LPIS revealed the current ratio of PGL vs. arable land to be 33.07% vs. 49.50% in the Hrejkovický brook catchment and PGL vs. arable land to be 6.44% vs. 80.13% in the Bilinský brook catchment (the remaining percentage excluding LPIS), while in the long-term perspective we can notice a reduction of arable land compared to PGL growth in both investigated catchments.

Assessment of shallow groundwater vulnerability brought very diverse results for the particular catchments, which is mainly due to the second criterion for vulnerable area definition, i.e. an interaction with drainage systems.

Tab. 6 Percentage of classes of acceptable soil loss by erosion in individual types of land use

Acceptable soil loss – G – percentage [%]									
Hrejkovický brook 211-08				Bilinský brook 211-063			Bilinský brook 211-064		
G [t ha^{-1} year^{-1}]	Arable land	PGL	Soil sections total	Arable land	PGL	Soil sections total	Arable land	PGL	Soil sections total
Less than 1	59	98	73	50	99	59	45	97	54
1–2	27	1	17	26	1	21	24	1	20
2–4	12	1	9	18	0	15	20	1	16
4–10	2	0	1	6	0	5	10	1	9
Over 10	0	0	0	0	0	0	1	0	1

Much higher occurrence of tile drainage is found in the Hrejkovický brook catchment with 56.92% of ALF within drainage subcatchments being situated in first and second vulnerability clasess, but only by about 58% covered by arable land. In comparison, the Bilinský brook catchment had the ratio of ALF within drainage subcatchments on first and second vulnerability clasess 22.31 and 22.91%, respectively, used nearly by 84% as arable land.

Analysis of the potential soil loss due to erosion in Hrejkovický and Bilinský brook catchments corresponded to the slope characteristics and land use. The Bilinský brook catchment thus showed relatively high vulnerability to erosive effects namely in the lower part of the catchment, where as much as 10% of arable land was found in the interval 4–10 t ha^{-1} $year^{-1}$. Contrary to that, the Hrejkovický brook catchment may be characterized as significantly less threatened by erosion, in accord with its geographic characteristics.

The vulnerability associated with direct protection of water courses is defined according to the soil types in the immediate environment of the water courses. Its extent directly correlated with the morphology of alluvial location of these catchments. The direct protection should be implemented in 3.15% of the area of Hrejkovický brook catchment compared to 1.43% in the Bilinský brook catchment.

The described methodology serves for detailed definition and delineation of individual types of critical source areas of non-point agricultural pollution in the particular catchment zones. It is an appropriate tool for proposing measures to reduce the proportion of non-point sources of surface and shallow groundwater pollution with nutrients and risk compounds. A great advantage is that protective measures can be proposed for the particular landowner plot. There is a range of various methods which deal with the assessment of potential of non point pollution sources in agricultural catchments of different scales. However, predominance of these approaches usually do not encompass all the possible runoff pathways and potential contaminants in a landscape; they either focus separately on leaching (nitrate) or on overland flow and erosion processes (suspended solids and phosphorus). The most widespread approach for evaluation of groundwater vulnerability is the DRASTIC model (Aller et al. 1987; Murray and Rogers 1999), even though a number of other techniques have been developed and used in this field (Civita 2010).

Compared to other approaches, the originality of presented method is provided by the precision of the used data, scaled 1 : 5000 for pedology data and the layer of production sections representing landowner plots integrated into higher units with uniform culture. The generally used scales for pedology data are in the range of 1 : 50–200,000.

This work was aimed to document the differences in results obtained by the used methodology for definition of the critical source areas at two closely situated catchments with different natural conditions and land management. Our future efforts will be oriented towards collection of hydrological and water quality data for verifying the accuracy and applicability of the described approach using hydrology and nutrient balance, or optionally mathematical modelling in the field of hydrology and hydrochemistry in the territories of interest.

The presented methodology for defining the critical source areas of non-point agricultural pollution has been employed during designing of projects dealing with water protection, particularly in protection zones of water supply reservoirs, and by its complex approach is applicable to the large practice of natural resource preservation. The approach is further elaborated and modified in ongoing research projects.

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RÉSUMÉ

Integrovaný přístup k řešení problematiky plošného zemědělského znečištění v ČR

Příspěvek popisuje nový, integrovaný přístup v metodách identifikace a lokalizace potenciálních kritických zdrojových oblastí plošného znečištění povrchových vod dusíkem a fosforem, který je představen na modelových povodích IV. řádu Hrejkovického a Bilinského potoka v povodí vodní nádrže Orlík. Ohroženost vod plošným znečištěním je posuzována geografickou analýzou, která hodnotí geomorfologii, způsob využití a půdní podmínky území, ve vazbě na stavby zemědělského odvodnění. Vedle ploch podléhajících erozi a lokalit tzv. přímé ochrany podél vodních toků, jsou vymezovány oblasti zvýšeného potenciálního vyplavování živin do podzemních a drenážních vod, stanovené na základě syntetické mapy zranitelnosti mělkých podzemních vod. Tyto oblasti jsou klasifikovány na základě analýzy kódu bonitovaných půdně ekologických jednotek (BPEJ) a zemědělské odvodnění podle podkladů bývalé Zemědělské vodohospodářské správy (ZVHS).

Z výsledků geografické analýzy vyplývá rozdíl mezi dvěma sousedními povodími a jejich potenciálem k působení plošného zemědělského znečištění. Z výsledků analýzy LULC je patrný zhruba stejný podíl zemědělské půdy pro obě povodí ovšem struktura základních dvou druhů pozemků (orná půda x trvalé travní porosty) je odlišná. Vyšší podíl zatravnění je v povodí Hrejkovického potoka oproti Bilinskému, kde je zastoupení TTP relativně nízké. Z hlediska zranitelnosti vyplavování rizikových látek do povrchových a podzemních vod jsou náchylná obě povodí; povodí Bilinského potoka z důvodu převahy orné půdy na plochách se zranitelností 1. a 2. kategorie v mikropovodích drenážních systémů, povodí Hrejkovického potoka pro velmi častý výskyt ploch s 1. a 2. kategorií zranitelnosti (58% ZPF). Z hlediska potenciálního rizika výskytu eroze na zemědělské půdě je ohroženější Bilinský potok, zejména v dolní části povodí.

THE POTENTIAL OF CULTURAL EVENTS IN THE PERIPHERAL RURAL JESENICKO REGION

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ABSTRACT

Peripheral rural regions are looking for new development strategies in the face of interregional competition for qualified labour, tourists and better image. Rural areas usually suffer from a number of socio-economic problems such as depopulation, ageing and negative educational structure. This article deals with the analysis of selected soft factor, cultural offer and its institutional arrangements and a possible impact on the socio-economic development of the peripheral rural Jesenicko Region. It is argued that culture economy approach to rural development is in line with the emerging theory that development activity of peripheral rural regions consists of both endogenous and exogenous forces using new forms of governance. The description of the types of actors and their interrelationships is the starting point for understanding and evaluating the actors' role in regional development. Realization of semi-structured in-depth interviews, literature review and observation were the main methods of data collection. Many cultural and sports events of local character are held in the Jesenicko Region. Cultural offer, however, does not reflect the requirements of local residents and visitors. The participation of local inhabitants on the production of cultural activities is also very low, which can hinder further development of the region. The desired strategic connection of culture and tourism remains, with few exceptions, underused. This article suggests some possible directions of culture economy approach for further development of the Jesenicko Region.

Key words: periphery, rural, culture, event, region, development

1. Introduction

Culture is an important factor in human society supporting its overall integration (Heřmanová, Chromý 2009). Culture includes literature and arts as well as people's way of life, value systems and traditions. Local culture comprises tangible (monuments, arts, artifacts, cultural landscapes, cultural organizations, institutions, traditional gastronomy, products and production processes) and intangible elements (a way of life: i.e. folklore, customs, dialects, songs, dances, living culture and cultural events) (Patočka, Heřmanová 2008). In other words, social structures and cultural factors form a specific "regional culture" (Amin, Thrift 1992). Local culture reinforces the local identity of residents and helps to create the image of the area. Particularly in rural areas it is often a strong integrating element of communities in today's globalized world, where there is a widening gap between successful and unsuccessful regions. That is why the sites look for innovative development strategies that lead to increasing their own competitiveness (Rumpel et al. 2011). Current European neoregionalism assumes that optimal reduction of regional disparities and the territorial development (of "problematic regions") cannot be achieved by supporting the "top-down" approach, but by the mobilization of the endogenous potential (bottom-up approach), strengthening the local identity and by supporting the improvement of the human (creative class, Florida 2002) and social capital (Falk, Kilpatrick 2000; Jančák et al. 2010). According to Asheim (1996) building of local networks and the interconnection of local actors (endogenous resources) are one of the options of solving the problems of economically weak and rural regions. This strategy corresponds with the New Rural Paradigm (OECD 2006).

Involving the local community in the decision-making process instead of leaving the responsibility for rural regeneration on the state is the principle of new rural governance (Woods, 1998: 170). One of the possibilities of enhancing the growth in community spirit and cooperation is to involve local inhabitants in event planning and production (Allen et al. 2006). Special events (cultural, sports), social environment, regional specifics, the image of the region, environmental quality and cultural landscape can create, by their broader reflection, the opportunity and one of the factors and premises of further development of the territory. The presence of these amenities can decide about where people want to live and spend their leisure time and where they establish their entrepreneurial activities (Rumpel et al. 2008: 9). Blažek and Netrdová (2009) call the mentioned soft factors "key differentiating factors", while culture is a phenomenon that tends to have intensely local characteristics thereby helps to differentiate places from one another (Scott 2000). The attempt by rural areas to (re)valorise place through its cultural identity is called the "culture economy approach to rural development" (Ray 1998). The word "economy" signals that one deals with the relationships between resources, production and consumption. The culture economy thus consists of strategies

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to transform local knowledge into resources available for the local territory (Kneafsey 2000: 4). Economy is culturalised and culture is economised (Klaus 2006). From the tourism perspective, destinations develop, facilitate and promote events of all kinds that meet multiple goals: to attract tourist (and increase culture consumption), to contribute to general place marketing, to increase the infrastructure and tourism capacity and to animate specific attractions or areas (Getz 2007). Some of the local and regional events may have tourist potential that can be developed but some are primarily community-oriented so there is no need to exploit them. As Quinn (2005) states, festivals/events are arenas where local knowledge is produced and reproduced, where the history, cultural inheritance and social structures that distinguish one place from another, are revised, rejected or recreated. Festivals provide rural communities with coping mechanisms at times of economic hardship (Gibson, Stewart 2009). Allen et al. (2010) emphasise the role that festivals play in promoting social cohesion and reproducing social relations.

This article deals with the analysis of selected soft factor, cultural offer, its institutional arrangements and a possible impact on the regeneration/development of the peripheral rural Jesenicko Region. In terms of Czech geography this topic is only insignificantly reflected (see Patočka, Heřmanová 2008; Heřmanová, Chromý 2009; Chromý, Skála 2010). This paper attempts to bring in the impulse to the debate in the framework of regional development and economic geography.

2. The Role of Culture in Peripheral and Rural Regions

In literature, rural regions are often identified with the peripheral and vice versa (Perlín et al. 2010). In the framework of the polarization of space the periphery is seen as a poorly integrated area into the given place, time, processes, systems and structures (Schmidt 1998). The peripheral areas are the result of uneven development in the area while this development is influenced by different historical, political, economic, social, cultural and natural conditions (Havlíček et al. 2005). A common feature of large peripheral areas is their location near regional (i.e. inner periphery, Musil, Müller 2008) and state boundaries (Čermák 2005: 49). Peripheral rural regions are forced to face a number of socio-economic problems, such as depopulation and out-migration of skilled labour (Temelová et al. 2011), ageing, negative educational structure, reduced numbers of community organisations and volunteers and reduced service infrastructure (Falk, Kilpatrick 2000: 26). The declining quality of life in rural and peripheral areas associated with the above mentioned socio-economic phenomena is considered to have been one of the most important processes of socio-spatial differentiation in the Czech Republic in the transition period (Novák et al. 2007).

Culture has not been taken as one of the factors in the practice of regional development for a long time. Policy reports in the United Kingdom have signalled the importance of arts and crafts to rural competitiveness (Hunter 2006; Matarasso 2002, 2004, 2005), and championed the potential of rural cultural industries in contributing to local and regional development strategies. Any evaluation of the economic contribution of culture to the local economy is difficult without the existence of statistical data and their evaluation in the Czech Republic. According to Kunzmann (2002) culture may affect the development of territorial units as follows:

A. Culture creates the identity

Residents of towns, cities and regions are primarily identified with the cultural heritage and cultural traditions of their locality. This is the reason why local people try to preserve this heritage. Chromý and Skála (2010) argue that regional (i.e. destination) identity ensures regional competitiveness on the tourism market. The key issue is also the choice of appropriate regional brands and symbols that highlight the uniqueness of the area (the "economy of symbols"). According to Cloke (1992) the countryside becomes a commodity that can be bought and sold. Birth houses of famous personalities (such as Martinů's house in Polička, Freud´s house in Příbor) can become major tourist attractions. The major natives are often associated with various cultural events held at their birthplaces (e.g. Smetana's Litomyšl, Šrámek's Sobotka and others) (Heřmanová, Chromý 2009: 102).

B. Culture creates the image

Culture has become an integral part of the city and regional marketing. Destinations try to differentiate themselves through their unique heritage, traditions, as well as festivals (event marketing). Organizing various events (cultural, sports, educational) in order to attract media attention and thus create a specific external image (Richards, Wilson 2007) is a partial component of a complex regional marketing (Rumpel 2011). As Getz (2007) acknowledges, events have many partners and proponents and many important societal and economic roles to play. Events are seen as an important motivator in tourism (Getz 2007), and as an effective enhancer of a destination image. Image is defined as the sum of subjective impressions and ideas that people have about a specific territory (Kotler 1994). Image is a simplification of objective reality and is composed of partial information and associations connected with the territory, and thus with the culture of the region while the same spatial image can be evaluated differently by various persons (Ježek et al. 2007).

C. Culture creates new jobs

Culture can create new jobs under the condition of the existence of local and regional strategy to promote cultural industries. Cultural industries are a "new" market segment which gains increasing importance and might, in some cases, help to revitalize economically weak regions (Kunzmann 2002). Cultural industries include all activities that are directly related to initiating, creating, preserving, disseminating and ensuring arts and culture. The concept of cultural industries refers to those institutions in the society which employ the characteristic modes of production and organisation of industrial corporations to produce and disseminate symbols in the form of cultural goods and services (Garnham 1987). The development of the cultural potential of the region means specifically the diversification of local economic structure. For example, events are an expanding industry, providing new and challenging job opportunities (project managers, technicians, graphic artists, publicists, photographers, entertainers etc.) for people entering the field (Allen 2010: 23).

3. Cultural Governance in Peripheral Rural Regions

In connection with culture and regeneration of traditional cultural communities and regions in the European Union the concept of governance is practiced (Heřmanová, Chromý 2009). New local governance (Woods 1998) has emerged, characterized by self-organizing networks embracing the state, private and voluntary sectors. The concept of governance is used for the description of changing of decision-making structures of government (public administration) to governance (processes and relationships in the network of cooperating actors). The description of the types of actors and their interrelationships is the starting point for understanding and evaluating the actors' role in regional development, or rather for identifying problems that are associated with ensuring organizational processes of territorial development (Rumpel et al. 2011: 36).

The concept of cultural governance is used to analyze the interactions between different stakeholders (actors) who aim to enhance the quality of cultural offer in the city/region. The functionality of the concept of cultural governance depends primarily on the strategic coalition between cultural actors and public administration and on ensuring stable funding mechanisms (Moon 2010: 450). Application of the concept of governance provides guidance on how to understand the economic, social and political changes in rural areas (Little 2001: 97). Quinn (2005) and Reverté and Izard (2011) suggest that the cultural development of the region depends mainly on strong personalities (leaders) who possess visions and are able to accomplish their ideas. The role of the state and local government lies primarily in the creation of financial, conceptual, legislative and, to some extent, institutional and organizational preconditions for the citizens' participation on culture. The involvement of local people into public life is an important prerequisite for creating a suitable social environment and a sense of belonging to a place of residence. It may also prevent any potential brain drain from the region. Particularly in peripheral areas the mobility is enhanced by the lack of opportunities for self-fulfilment and by the fact that the central area attracts the skilled labour (Heřmanová, Chromý 2009: 124). An inspiring example of the involvement of local residents in the development of cultural offer in the region and thus strengthening the regional identity is the foundation of an alternative multi-genre festival in Galway (see Quinn 2005) which is based on the specific local culture. It has developed from an independent festival of regional significance into a professionally-managed event of national importance.

4. Methods and the Brief Outline of Jesenicko Region

This article is based on literature review, internet sources and observations. In order to complement the current information qualitative research tools – i.e. interviews (face-to-face in-depth interviews) were used. Interviews were conducted with Miroslav Hrdlička (the director of the Cultural Facility of the Jeseník city, Městská kulturní zařízení Jeseník, MKZJES), Tomáš Hradil (the head of the non-governmental organization Brontosaurus), Jarmila Chovancová (the owner and program director of the club Plíživá Kontra) and Marcel Šos (the director of the Jeseníky Information Centre).

The main objective of this article is to analyze the cultural offer in the Jesenicko Region in the context of culture economy approach to rural development. The indicative summary of the most important regular cultural and sports events in the Jesenicko Region was created in order to assess its cultural potential according to Kunzmann's methods (2002). There are held around 32 regular cultural and sports events per year of which the most important 16 are presented in this article (see Table 1) and evaluated according to their impact on Identity (1 = high impact, 3 = low), Image (1 = high impact, 3 = low), and Target group (1 = residents, 2 = tourists). The main cultural actors involved in the organization and management of the events were identified in the course of the research. In order to fulfil the main objectives of this article the following research questions need to be answered:

1. What are the trends in the development of cultural activities in peripheral regions?

2. Who are the main producers of cultural life in the Jesenicko Region?

3. What is the target group of the local cultural offer and can this soft localization amenity be used for further development of the region in the context of the culture economy approach to rural development?

The Jesenicko Region is defined as the administrative district of Jeseník for the purpose of this text. In 2010, 41.255 inhabitants lived there in 24 municipalities. The Jeseník district lies in the very north of the Olomouc Region near the border with Poland, in the south adjacent to the district Šumperk. In the east it shares a border with the Bruntál district. With the total area of 719 km^2 it is the smallest district of the Olomouc Region. The region is defined by the Hrubý Jeseník Mountains, the Rychlebské hory mountains and the Zlaté Hory mountains. Nearly half of the Jesenicko Region belongs to the protected landscape area of the Jeseníky mountains (Balík 2008: 19).

The district Jeseník belongs to the economically weak regions as stated in the Resolution of the Government of the Czech Republic of 17 May 2006, defining the region with concentrated state support for the period 2007 through 2013 (§ 4 of Act No. 248/2000 on regional development) (Novák et al. 2007: 9). The unemployment rate in the region is among the highest in the Czech Republic. The influence of the current peripheral status of the Jeseníky region has its historical development associated with the German settlement that was forcibly interrupted after the Second World War (Popelka 2009 In: Rumpel et al. 2009). Along with the displacement of indigenous people resettlement by new inhabitants ensued in consequence. Heřmanová and Chromý (2009) call Jesenicko "the region with lost identity" in terms of the loss of indigenous people (bearers of identity). The largest share of the resettlement of the border region comprised of Czech inhabitants of inland regions, but simultaneously a lot of newcomers were foreigners (Slovaks, Romani people, Hungarians and Greeks). The results of all these factors are manifested in visual arts, literature and music of the region. The differences and cultural diversity can be prerequisites for further development of the region (Bennett 2001).

5. An Analysis of the Current Cultural Offer and Cultural Governance in the Jesenicko Region

This chapter presents the situation analysis of the cultural offer in the Jesenicko Region and provides the assessment of the current role of culture in the development of the region according to Kunzmann (2002). The Jesenicko Region has historically been an important spa centre but this tradition is not significantly reflected in the character of the cultural offer of the region. The name of a world famous native son, founder of the first hydropathical institution Vincenz Priessnitz, is associated with a regional product (herbal liqueur), with a local gastronomic event (the Priessnitz's Cake confectionary competition) and the rock music band Priessnitz. The exhibition devoted to Vincenz Priessnitz and the development of the spa tradition in the region is located in his birth house in the Jeseník town.

Although the cultural traditions of the region were historically forcibly severed, there are devices and proactive individuals who try to promote cultural development of the Jesenicko Region primarily with the aim to strengthen the identity of the local population. The main operators of the cultural life are cultural facilities of the municipalities (Jeseník, Javorník, Zlaté Hory) and organizations funded from the budget of the municipalities. The City Jeseník serves as the cultural centre of the region where most cultural events take place. The Cultural Facility of the Jeseník town (Městská kulturní zařízení Jeseník, MKZJES) operates a single regional Petr Bezruč Theatre, the Pohoda cinema, the cultural centre Katovna and the building called Pentagon. MKZJES supports local amateur artists and actively tries to involve local people in the cultural life. MKZJES cooperates with other cultural entities in the region, such as the club Plíživá Kontra, the civic association Virtus and the non-governmental organization (NGO) Brontosaurus. The financial support for organizing cultural events in the region can be obtained from municipal budgets, grant schemes of the Olomouc Region, the Ministry of Culture, a number of various cultural funds, the Euroregion Praděd (specifically for organizing events in cooperation with Polish partners) and other EU programmes.

The private club Plíživá Kontra focuses on the implementation of independent artistic production in the Jeseník town. The club operates mainly from its own resources and sponsorship. Plíživá Kontra defines itself as "a space for self-realization"; it cooperates with MKZJES by means of mutual renting places, sharing the cost of promotion of individual events etc. MKZJES and Plíživá Kontra try to establish a long-term cultural cross-border cooperation with neighbouring Polish towns. A joint product of the club, MKZJES and the Polish town of Nysa was the organization of the interregional music festival "Jeseníky-Nysa Clubbing" focusing on the genres of hip hop, jazz and rock. The organization of the festival did not meet the expectations of the local inhabitants (mainly the people who live in the house where the Plíživá kontra club is located) and the festival had to be moved to another location promptly.

The NGO Brontosaurus tries to revive the historical ties of the Jesenicko Region. Its members mediate the communication among different actors of public life in the region. The main activities of Brontosaurus include the restoration of cultural monuments (mainly springs), nature conservation, restoration and interpretation of sacred sites, the involvement of local residents and creating the inhabitants' relationship to the region. A specific project of Brontosaurus is thus called Folklorní kosení (Folklore Mowing). In this event, young volunteers work on a meadow, they listen and play local music, eat local gastronomic specialities and go to the church mass. About 70 volunteers have already participated in this event. Besides Brontosaurus there exists the Virtus NGO which attempts to involve local people in cultural and social events in the region. Virtus, the Centre for Creativity, organizes the festival of creativity and the festival of regional theatre. According to the festival organizer, Ludmila Liberdová, the festival attendance is not high, but it keeps acquiring its supporters over time. The festival of creativity brings in a wide range of cultural and educational activities (theatre, music, dance, arts and others) and is held in co-operation with the MKZJES, the music school of Jeseník and the leisure centre Duha (Rainbow). The organization is located in the former premises of Moravolen (a textile factory), where a community centre for the residents of the Jeseník town is being established.

The extinct tradition of Podzimní sklizeň (Summer harvest) which was held annually in September, has been restored and incorporated into the current cultural life of the village Bělá pod Pradědem. The Czech-Polish harvest festival is very popular not only among Czech population, but also among Polish visitors. The symbol of the festival is a wreath entwined with flowers and grains. The local people walk in procession in local costumes and the event thus helps the residents to identify with the border region and their lost cultural traditions.

Successful international music festivals using the names of emblematic persons from the history of the region, the International Music Festival of Karel Ditters from Dittersdorf and the International Schubert's Competition for Piano Duos, attract a specific group of local and foreign visitors who look for "highbrow culture". Schubert's mother, Elisabeth Vietz, came from Zlaté Hory (Schubertova soutěž 2005). Schubert's competition originates in the 1970s thanks to the initiative and enthusiasm of the Lejska family (Adámek 2009) and to subsequent support by major actors in the field of classical music. The festival has became world famous and acknowledged, it is reflected mainly in foreign media. The number of participating competitors is rising (in 2005, 27 duos competed, among them there were representatives from Armenia and Japan) (Schubertova soutěž 2005). Laureates of the competition perform at numerous international festivals and spread the image of Jeseník not only as a spa centre but also a classical music destination.

The municipality of Mikulovice, on whose territory the electronic music festival Breakfest was held in 2008, took an inspirational approach in the implementation of innovative events. The festival took place in the former barracks in the brownfield area behind the village with the approval of the authorities. The event interrupted the otherwise mainstream offer of music production provided by local cultural facilities. At this type of event (the so-called hidden), it is very difficult to trace the organizers due to the fact that such events take place on the basis of semi-underground. This is a crucial fact for the participants in order to visit similar-type events. The festival, despite the negative media image of analogous events (see e.g. CzechTek), attracted more than thousand devotees of alternative subcultures to the region. The event took place without any major incident and the local retailers welcomed the increased sales of their goods. Breakfest indicated the direction of possible re-use of brownfield sites for the needs of major cultural festivals, sports events and events with intensive space demand away from residential areas of towns and villages (such as motorcycles and veteran reunions).

Tab. 1 Periodic Cultural and Sports Events in the Jesenicko Region

Name	Description	Identity	Image	Target group
AZ pneu Rally Jeseníky	Car racing	3	2	2
Czech-polish summer harvest	Restored tradition	1	2	1
Theater harvest	Local theater festival	1	3	1
Festival of Creativity	Creative workshops	1	3	1
Folklore mowing	Event for volunteers	1	3	1
Giro di Rejvíz	Bike racing	2	3	2
Music Festival of Karel Ditters from Dittersdorf	Festival of classical music	2	1	2
Rockfest in Javorník	Music festival	3	3	1
Jeseník's nugget	International family music festival	3	3	1
Klasika Viva	Festival of classical music	3	1	2
International Schubert's Competition	Festival of classical music	2	1	2
Mikulovický škrpál	Regional theater festival	1	3	1
Priessnitz's cake	Confectionary competition	1	3	1
Rallye Rejvíz	International rescue competition	3	1	2
Golden days	International competition in gold-washing	1	1	2
Trekking in Zlaté Hory	Trekking	2	3	2

Source: Marková, 2012

In terms of tourism the most important event in the region is the competition in gold washing, Zlaté dny ve Zlatých horách (Gold Days in Golden Mountains). This event was established sixteen years ago due to the occurrence of gold in the region and its historical use in the vicinity of Zlaté Hory. In the organization of the competition the municipality of Zlaté Hory along with the Club of Moravian-Silesian gold-diggers are involved. After the successful organization of the European Championship in 1996 and the Championships of the Czech and Slovak Republic in 2001, 2005, and 2009, a week-long World Championship in gold washing took place in 2010. This event was attended by 500 competitors from 21 countries and it was met with great response from the audiences and media interest, which helped to raise the awareness about the region and contributed to the attraction of visitors.

6. Conclusion

Many sports events are held along with cultural events in the Jesenicko Region. These events concentrate mainly on trekking and cycling (see Table 1), however, they are of a rather local character, analogously to the cultural events. They bring only minimal external impulses to the region. Thus, the identity of local residents needs to be primarily created/strengthened because the identity was forcibly severed after the Second World War. The Festival of Creativity, Folklore Mowing and the Czech-Polish summer harvest festival seek to fulfil the objective. However, these events hardly contribute to the creation of the external regional image. On the other hand, the competition in gold washing, Zlaté dny ve Zlatých horách (Gold Days in Zlaté Hory), has much greater media attention; it has been growing annually in sense of increased number of competitors and audiences. The contest AZ Pneu Rally Jeseníky Car Racing also manifests increased media coverage.

There is no evidence of creating new jobs in cultural industries in the Jesenicko Region. In the organization and implementation of cultural activities there is involved only a small number of same actors, the participation of local residents is very weak, which may generate a barrier for further regional development. According to Leber and Kunzmann (2006) it is necessary to use a specific endogenous potential of rural regions (territorial capital) in designing strategies for sustainable development of the quality of life in these locations.

The visitors' survey (Havrlant 2008 In: Rumpel et al. 2009) shows considerable dissatisfaction with the cultural and social activities in the Jesenicko Region. Based on the carried-out interviews and literature one can assume that the cultural offer of one-time cultural events is relatively extensive in the region. The overlapping of individual events is often the case when four regular sports and cultural events take place monthly in the region. As mentioned above, the organizers struggle with low public interest. Communication policy of cultural events either shows significant deficiencies or the supply does not meet the expectation of the locals (declared low attendance) or visitors (see Havrlant 2008 In: Rumpel et al. 2009). Individual events are characterized by their isolation, they are organized by small groups of enthusiasts (often the same actors, which documents the low civic participation in the region). Education in connection with the population structure is a specific problem in the Jesenicko Region where there is a significant under-representation of population with tertiary education. This barrier prevents the development of cultural activities and thus any further regional development. The level of education of the population is one of the most important factors in the development of every area, "both in the context of the technological and cultural globalization, and in the context of regional social and economic development" (Heřmanová, Patočka 2009: 31). The unfavourable economic situation of local residents and the low level of education significantly reduce the numbers of visitors of cultural and sports events.

The absence of market research about the visitors' requirements and the expectations of the locals could be another negative factor and missing pieces of information for the cultural development of the region. There is a lack of statistic data about visitor numbers, which greatly hinders the assessment of the economic impact of the events. Marketing strategies and their monitoring and evaluation, coherent communication and cooperation of cultural actors with the operators of tourist facilities and public administration should be the key in reducing development barriers. For completeness, it must be said that MKZJES has recently introduced a new marketing tool – sending text message alerts about upcoming cultural events in the region to registered users. However evaluation of this tool is not known at the time of writing this paper.

According to the analysis of the Jesenicko Region it is obvious that there is no cultural event of national importance which attracts more local and foreign visitors to the destination and thereby positively influences tourism and thus the overall economic development of the locality. There is a market niche for a specific event which would build on the rich history of the Jesenicko Region in the field of cultural activities. Particularly the town of Jeseník has an 800-year-long rich history connected to a long tradition of textile production and witch-hunt (new museum was opened recently). The potential of the names of the famous native Vincenz Priessnitz (his birth anniversary in 1999 was enrolled in the UNESCO cultural anniversaries) or celebrity patients of world-famous Priessnitz's and Schroth's spa (Nikolai Vasilievich Gogol, Franz Kafka) (Šprincová 1969) remains unexploited for the development of cultural and tourism activities in Jesenicko. An interesting opportunity for development of economic activities in the region and creating new events is the marketing of local gastronomic products while focusing on the popularity of farmers' markets in many Czech towns. Bessiére (In: Woods 1998: 153) also observes that regional food and gastronomy have become important in rural tourism. An interesting trend has occurred in the world in connection with destination marketing – places where famous blockbuster movies were made attract many tourists (e.g. *The Lord of the Rings* – New Zealand countryside, *Harry Potter* – the countryside in Scotland etc.) (Cloke 2007 In: Richards, Wilson 2007: 42). The opportunity for development of similar activities is the introduction of the movie *Alois Nebel* which was made in the Jesenicko Region and was bidding for the Oscar award.

In conclusion, it can be stated that the desired strategic linking of culture with tourism does not happen in Jesenicko while the cultural potential of the region for its further development remains, with few exceptions, unused. In the specific regional conditions of Jesenicko, culture and tourism can be taken only as additional development elements linked to the support of regional small and medium enterprises and the education of local inhabitants. The public administration in the Jesenicko Region should focus on strengthening the local identity using the local potential.

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RÉSUMÉ

Potenciál kulturních events v periferním rurálním regionu Jesenicko

Článek je zaměřený na analýzu měkkého lokalizačního faktoru – kulturní nabídky – v zájmovém regionu Jesenicko, a její vliv na socioekonomický rozvoj rurálních peri-ferních regionů. Hlavními metodami pro sběr dat bylo realizování hloubkových rozhovorů s organizátory kulturního života na Jesenicku, internetové rešerše, kompilace odborné literatury a metoda pozorování. Na základě získaných dat lze konstatovat, že se na území Jesenicka koná řada kulturních i sportovních akcí, které jsou spíše lokálního charakteru a do regionu přináší jen minimální externí impulsy. Kulturní nabídka však nereflektuje požadavky místních obyvatel ani návštěvníků regionu. Z hlediska governance lze participaci místních obyvatel na tvorbě kulturních aktivit označit za velmi nízkou, kdy kulturní a sportovní eventy organizuje nízký počet stale stejných aktérů. K žádoucímu strategickému propojení kultury s cestovním ruchem na Jesenicku nedochází, přičemž kulturní potenciál regionu pro jeho další rozvoj zůstává až na pár výjimek nevyužitý. Článek ve svém závěru naznačuje možné směry dalšího rozvoje jesenického regionu v oblasti kultury.

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A STUDY OF THE USER FRIENDLINESS OF TEMPORAL LEGENDS IN ANIMATED MAPS

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ABSTRACT

Among other topics related to the visual aspect of cartographic products, current research addresses the problem of user friendliness. The most significant research concerns those products that evolve most rapidly, a typical example being interactive dynamic maps. This group of cartographic works includes products that are relatively challenging for users with respect to their temporally fluid content and the possibility of interactive manipulation.

The article begins with a basic discussion of user-friendliness in cartographic products; in this context it addresses the historical development of the notion of cartography as a science, as well as the evolution of the ways in which it has been defined and of its subjects of interest. It demonstrates that, aside from notions of cartography as a technical discipline, it is also of interest from a linguistic point of view for its role as a mean of communication between cartographer and map user. Still greater emphasis is placed on the design aspects of cartographic production. The study offers the example of recent developments in Czech cartographic production, in which the last twenty years have seen a significant differentiation between published cartographic products and amateur cartography generally. This applies to creation as well as user base.

Next the article describes a study on the user-friendliness of temporal legends, which are very common in animated maps. The goal of this study, which was conducted during the summer of 2010, was not only to evaluate the given temporal legends, but also to investigate the extent to which users were able to work with temporal variables (with time) in a cartographic product. Among the tools for collecting data was a form of online test. This test posed questions to respondents and automatically measured the amount of time it took them to find their answers. This method was based on the assumption that, given two cartographic works containing similar content, the work which enables the user to find information more quickly is the more user-friendly of the two. The results of the test were then analyzed on the basis of an objective standard for comparing qualities in a cartography work. The authors conclude by suggesting future directions for research on the subject.

Key words: cartography, study of user friendliness, temporal legend, time, cartographic animation

1. Introduction

Through most of the twentieth century cartographic works in the Czech lands were produced primarily in two main sectors – the civilian (e.g. for land-surveying purposes) and the military. These cartographic works were often created for a narrow group of specialists, and the public did not have free access to a large portion of them. Of course, there were also high-quality cartographic works for schools and the public (e.g. school atlases, also the rare collection of maps entitled "Poznáváme svět" ["Getting to Know the World"]), but the market contained far fewer titles and was more generally less complex than it is today.

After 1989, a fundamental change occurred. With the arrival of the "Velvet Revolution," the problem of concealing map data ceased to be a priority (Maršíková and Maršík 2007) and the domain of cartography was gradually opened to the average consumer. Geodetický a kartografický podnik, n. p. (Geodesic and Cartographic Company), which arose in 1983 with the consolidation of Geodetický ústav v Praze, n. p. (Geodesic Institute of Prague) and Kartografie Praha, n. p. (Cartography Prague) – see Šíma 2004 – ceased to function as the lone publisher of cartographic literature and in 1992 its legacy was assumed by Kartografie Praha, a. s. Other manufacturers began to appear at around the same time, including SHOCart, s. r. o., which was formed in 1991.

The 1990s saw the gradual diversification of published cartographic works. With the development of the travel industry and free access to information, the wider public became more familiar with maps and their use. Meanwhile, notions about cartographic production began to change among cartographers themselves. While it goes without saying that accurate and up-to-date content remains the most important criterion when evaluating a map's quality, design aspects of cartographic production – notably the idea of "user friendliness" – have asserted themselves to an ever greater extent over time. Unlike in the previous era, the overall conception of a map's contents and legend must now conform to the needs of users, who often have no prior experience reading maps. Contributions from fields such as psychology, pedagogy and graphic semiology (Bertin 1983) are making inroads in what has until now been considered a purely technical discipline.

This trend is visible in changes in the very way cartography is defined: "CARTOGRAPHY is the science

To be quoted as:
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AUC Geographica, 47, No. 2, pp. 53–61

of making any map, embracing all phases of work from surveying to map printing." (source: UN, Department of Social Affairs, 1949, In Konečný et al. 2005).

If we may call the above a "traditional" definition, the following definition demonstrates cartography's shift into other disciplines: "CARTOGRAPHY is a unique and instinctive multi-dimensional facility for the creation and manipulation of visual (or virtual) representations of geospace (maps), to permit the exploration, analysis, understanding and communication of information about that space." (source: Wood 2003, In Konečný et al. 2005).

This shift in the meaning of cartography has led to an increase in the attention given to the problem of user friendliness. Cartographers are aware that users require maps that they can understand and easily read.

The problem of user friendliness as presented above is addressed in the following chapters, which describe the conception, execution and assessment of the study, the goal of which was to test in practice the user friendliness of three temporal legends (for the definition of "temporal legend" see Chapter 4) of animated maps.

2. User-friendliness in cartography

Use of a cartographic work entails the transmission of information between the work itself and its user (Koláčný 1967, In Pravda 2003). After the transmission occurs, an image of reality conveyed by the map should be present in the mind of the user. The quality and effectiveness of the transmission of cartographic information corresponds to the degree to which this image resembles the depicted phenomena.

One may thus identify the effectiveness of cartographic communication with the user friendliness of a given cartographic work (Novotná 2010), i.e. with the ease and speed with which that work allows the user to solve a concrete problem. The goal is to minimalize the work's demand on the mental labor of the user (Zipf 1935, In Bertin 1983). Thus, given the availability of two cartographic works containing identical content, the work which enables the user to ascertain the correct and complete solution more quickly is, from the standpoint of cartographic communication, the more effective one (Bertin 1983).

Effectiveness is usually classified within the broader category of usability and, together with practicability, ease of memorization and satisfaction, it is one of its sub-pillars (Nielsen 1999; Rubin 1994). Krug (2005: 4–5) defines usability thus:

"What we mean by usability is that a thing, whether it's a web page, a fighter jet or a revolving door, works well and that someone with average (or even below-average) ability and experience can use it for its intended purpose without becoming frustrated."

3. User friendliness and modern cartographic products

Research concerning user friendliness in cartography is not a new affair. Serious scientific research in this field was already taking place in the second half of the 20th century (e.g. Castner 1983 and Phillips 1984). The technology employed, as well as the methods of assessment and, in particular, the subjects of the research itself, have all changed over time.

Currently the focus of research has shifted from analog maps (traditional maps, most often on paper) to digital maps, i.e. maps stored on a hard drive which may be rendered on an output device, most often a monitor, or transferred to analog by printing. Digital maps are most often distributed through the internet.

In contrast to the communicative means of analog maps, which seldom change, the tools employed by maps on the internet transform very quickly, thus calling for constant improvement (Mitbø 2007).

Internet maps can provide the user with a range of functions that traditional analog maps cannot. With this, however, come greater demands on the mental exertion of the user. Maps on the web can be categorized by various critieria, and it is noteworthy that there are many concepts and typologies, of which several are mutually inconsistent or even incompatible. As far as demands on the user are concerned, the two most important aspects are the dynamic characteristics of the maps and their interaction with the user. The diagram below (Figure 1) provides an overview of the situation (Kraak and Brown 2001, modified). The diagram illustrates the scale of difficulty for the user and simultaneously the sophistication with which an active and curious user may take advantage of the possibilities inherent in the cartographic work. Individual groups of maps are connected to the most frequent types of interactivity a user may employ (Crampton 2002). The diagram has been simplified and, in addition to the literature cited, is based on the authors' personal experience.

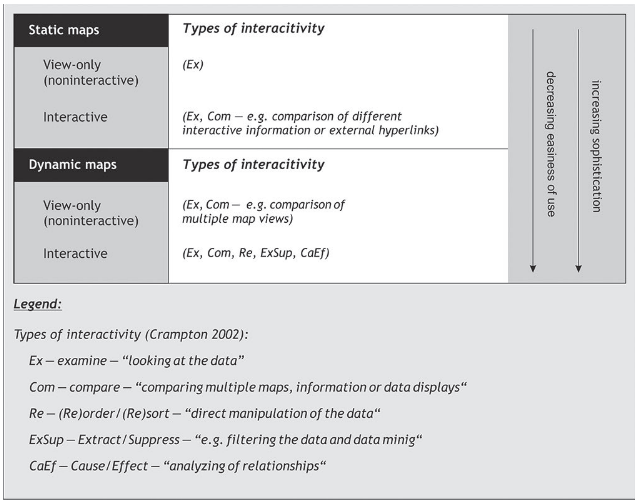

Fig. 1 Internet maps – demand on user and types of interactivity

The simplest form of internet map to use is the "static view map" which is simply an analog map transferred to web, most often in the form of a scanned image. The most challenging cartographic works on the internet are interactive maps, which communicate with the user on a certain level and react to his activity. The difficulty of using a cartographic work also increases with its dynamic characteristics. "Static" maps always represent the same spatial data, but in "dynamic" maps the map fields change in real time (Konečný et al. 2005), the displayed data loads in a dynamic fashion. We may consider the most challenging cartographic works as those that fulfill the demand for interactivity as well as dynamically generated content. Thus this area is an appropriate focus for research into user friendliness in the context of contemporary cartography.

As a sub-category of dynamic maps we might underscore cartographic animation (animated maps), which may be defined as "animation with a map field" (Vít 2010). The term "animation" itself signifies a sequence of frames which, when displayed in rapid succession, create the illusion of fluid motion or change (Harrower and Fabrikant 2008). Among the first animated maps was one that indicated the movement of German armies on Warsaw during the Second World War (Peterson 2000). This map was presented in a form that more closely resembled an animated film than a cartographic work. Cartographic animation has seen significant changes since then, most of all in creative technology and in the medium of distribution to the user. In spite of this qualitative advance, they retain their similarity to cartoons or animated films.

4. Representation of time in animated maps

4.1 The temporal legend

As mentioned in the preceding chapter, cartographic animation is often understood as a subcategory of dynamic maps. It is helpful to remember the analogous nature of animated maps and cinematographic products when considering the following. As in film, wherein single frames depict the sequence of events in time, the purpose of many animated maps is to portray action. In such a case, the map wishes "to tell some kind of story" (Turchi 2004) and it is often spoken of in this context in terms of "temporal animation" (Kraak and Ormeling 2003).

Temporal animation generally depicts action which is played out within the framework of absolutely conceived ("world") time. For example, it could be said that event A happened at time B, while event C took place over d amount of time. In order to connect events with the time in which they take place, it is necessary to supplement the map with a "temporal legend." A temporal legend gives the reader a key to understanding how to properly order within time the thematic matter represented in the map. The map reader is able to say, with the aid of a temporal legend, when the event represented in the map field occurred. It is in this regard that we must qualitatively distinguish an ordinary map legend from a temporal legend. Whereas an ordinary map legend explains the meaning of individual cartographic symbols (or connects a map's symbols to real objects and phenomena), a temporal legend assigns the map's symbols to a moment in time. Temporal legends serve a dual function: Kraak proposes that in many cases they should not just aid in the interpretation of time, but also serve as a navigational instrument, i.e., by interacting with the temporal legend, the user may move freely through the animation (Kraak, Edsall, MacEachren 1997).

4.2 Rate of time

In constructing an animated cartographic work furnished with a temporal legend, the map's creator will inevitably encounter the dilemma of uneven distribution of events within a particular length of time. It may happen that almost nothing occurs on the map field during a certain period, whereas at the other end of the time span several actions must be compressed within a short interval. Because the action is not uniformly distributed, it may be appropriate in some instances to "stretch" world time in certain segments of the animation in order for the reader to observe everything playing out on the map field, and to "shrink" it when no (or almost no) changes are taking place and it would become tedious to follow it. This might have seemed absurd before MacEachren had described time as a cartographic variable (MacEachren 1994). This also opened the possibility to modulate time, just as it is possible to modify the shape, color or size of cartographic symbols (see Bertin 1983).

As long as we accept the possibility of "elastic time", we can discuss rate of time and its modification. In terms of traditional cartography, we may consider rate of time as adhering to a particular "time scale."

Time scale is analogous to scale of distance and can be described as the ratio between real time and depicted time. That is, it concerns the speed of real time as it is captured in animation.

When dealing with a relatively low rate of time, for example, a second in animation may correspond to an hour in reality; with a higher rate, a second may correspond to a day. It is necessary to inform the map's user about the rate of time in various parts of the animation. This may be accomplished in many various ways, depending on the overall construction of the temporal legend.

Below are three varieties of temporal legend that were used in the test of user friendliness that follows (Chapter 5). These particular temporal legends were selected for their mutual dissimilarities – i.e. their methods of depicting time and changes in its speed are based on differing, in some cases even contradictory, concepts. Other possible methods for expressing rate of time (e.g. by means of other graphic variables which can be ordered – see Bertin 1983, such as degree of color saturation) are presented and discussed in a study by Vít (Vít 2010). Most, however, use a graphic permutation of one aspect or another of the temporal legends below.

1/ The temporal legend conceived as a temporal axis

a) Passage of time is typically indicated on a temporal axis by the position of a mobile pointer or "slide bar." The rate of time can be roughly inferred by observing how quickly the slide bar moves. Change in the speed of the slide bar signifies change in the rate of time. When time is stretched (changing to a lower rate of time), the slide bar decelerates; when time is compressed (changing to a higher rate of time), it accelerates. This method functions with the variable rate of motion (see Figure 2).

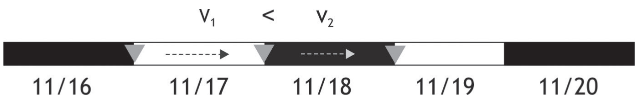

Fig. 2 Temporal legend "1/a)". Rate of time represented by changes in speed of slidebar. For 11/17 the rate of time is slower than for other days (rate of motion of the slidebar v1 is lower than rate of motion v2). Thus this day is represented in greater detail and on a larger time scale
v = rate of motion of the slidebar
11/16, 11/17, etc. = individual days represented by individual sections of temporal axis

While the concept of representing the rate of time is comprehensible and intuitive, there is the problem of the physiological limits of visual perception. In general, the smaller the change in speed of an object, the more difficult it is for the senses to perceive that change (Tremouretto and Feldman 2000, In Fukuda and Hueda 2006). The psychologist Šikl maintains that the lower relative threshold for perceiving acceleration is 20–30% of the speed of the observed motion. That is, as long as the speed of the observed motion changes by at least 20%, the human brain is capable of registering that change (Šikl 2006). The application of these findings to the problem at hand is clear: unless the change in the slide bar's speed on the temporal axis is sufficient (representing a greater contrast in tempo), the user won't be able to notice that change.

b) Another method for dealing with the problem of representing rate of time is to consider the task from the opposite position, i.e. holding the slide bar itself to a constant speed. In order to change the rate of time in this case, it is necessary to modify the size of the units on the temporal axis, using longer graphic units to indicate a slower tempo. In this case, when constructing the temporal axis one is dealing with the variable size (see Figure 3).

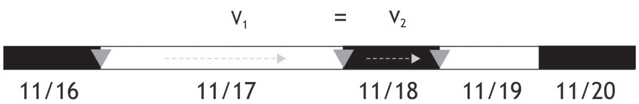

Fig. 3 Temporal legend "1/b)". Rate of time represented by varying the length of units on temporal axis. For 11/17 the rate of time is lower than for other days (the graphic unit for this day is longer, causing the slide bar to take longer to reach the end)

This method has clear advantages over the previous one, the first of which is that it is more easily to read. The user perceives changes in the unit's length on the temporal axis more easily than he does changes in the slide bar's speed. Another advantage is the fact that rate of time is expressed directly by a visible value (the user watches the temporal axis and can immediately note when the rate of time is lower and when it is higher), whereas in the previous case he had to interpolate differences in the rate of time from the various speeds of the slide bar. The fact that the slide bar moves at a constant speed also facilitates the use of the temporal legend as a means of manipulating the animation (i.e. the user may move through the animation by using the mouse to control movement of the slide bar). A disadvantage, however, is lower intuitiveness. For this reason, this method requires that the user receive instruction.

2/ Alphanumeric temporal legend (passage of time expressed textually and numerically)

An alphanumeric temporal legend entails expressing rate of time through the frequency of changes in numbers or text. Identifying changes in rate of time this way, however, is very demanding, because of the extreme difficulty of registering those changes in frequency. Thus it is desirable to express rate of time by yet other means. One possibility is to add to the alphanumeric temporal legend an appropriate graphic tool for informing the user of the rate of time. An ideal tool for this purpose is an arrow, which is commonly associated with direction and motion. Rate of time is essentially a quantitative value (it answers the question How many or how much), and therefore its representation may be achieved by sundry graphic variables that can be arranged in ascending or descending order. The most appropriate of these variables is size. In this case, a direct correlation will exist between rate of time and its graphic representation; that is, the longer the arrow, the higher the rate of time (see Figure 4).

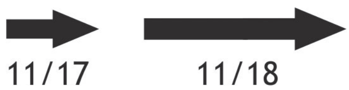

Fig. 4 Temporal legend "2/". Rate of time represented as a quantitative value. The length of the arrow shows the rate of time at a given moment. In this image, the day 11/17 is represented in greater detail (time moves more slowly) than is 11/18

An advantage of this method is the element's distinct visual dominance (the arrow can be made to draw the eye by flashing, for example). As with the previous method, the intuitiveness of this method is debatable.

Each of the three temporal legends described above has its advantages and disadvantages, and it is impossible to say unequivocally which of them is the best, especially since user subjectivity plays an undeniable role. For this reason, it was necessary to compare the proposed methods objectively and to base our conclusions on these results.

5. Studying the user friendliness of temporal legends

5.1 General methods for studying user friendliness in cartography

In studying and assessing user friendliness we may proceed by two basic methods: quantitative or qualitative testing (Krug 2009). When testing quantitatively, a task is defined and assigned to all subjects in precisely the same manner. The goal of a quantitative test is most often to prove a hypothesis (Krug 2009) or to compare two similar products. An advantage of quantitative testing is the possibility of conducting it online and thus reaching a larger pool of subjects. On the other hand, a qualitative test on a smaller number of subjects is better at determining future users' opinions of the object being tested. Common devices used in qualitative testing of user friendliness include structured conversation (Bláha 2005) and analysis of a subject's work with the product.

Testing user friendliness of cartographic works is a complex undertaking, and no method of testing is guaranteed to lead to successful results. Each test is unique and must be tailored to the tested phenomena. We may, however, trace the most common sets of tasks presented to users in studies:

– the user is given a real task, and the researcher measures the amount of time it takes him to successfully complete it,

– the user compares multiple cartographic variants of the same actuality and he evaluates them on a scale between better and worse using a semantic differential (Bláha 2005),

– the user's evaluation employs a point scale or awards "grades,"

– the user draws the mental map that he imagines after studying the cartographic work in question (Kynčlová 2009; Novotná 2010),

– a comparison of the intuitiveness of expressive media on the basis of the length of time it takes for the user to comprehend the meaning of their content,

– a study of the psychological possibilities of expressive cartographic media (the user guesses the meaning of cartographic symbols (Bláha 2010), or the user proposes cartographic symbols for specific phenomena),

– a study of the user's involuntary responses (use of eye tracking to study eye movement while studying a cartographic work – Coeltkin et al. 2009; Ooms et al. 2010); a simpler variant might entail following the movement of the cursor directed by the mouse during the user's interaction with the tested cartographic work,

– a standardized or unstandardized conversation is conducted with the user in which he evaluates the work verbally.

5.2 Methodology

A form of interactive online test was chosen to assess the user friendliness of the three temporal legends described above. While its nature was basically quantitative, in the final stage subjects were given the opportunity to write a commentary expressing their subjective opinions. For the purposes of the test, a model animated map with an American Civil war theme was created using Adobe Flash. This map was created in three variants which differed only in the temporal legend used by each. The test was conducted in the following manner: as he worked with the animated map, the user was presented with several time-related questions of varying types that required him to use the temporal legend. For each question, the subject was given a choice of four possible correct answers. A database registered whether the user had answered the question correctly and how long it had taken him to find it. Each test subject worked with only one variant of the model animated map. The hypothesis was the following: if one variant of the temporal legend is more user-friendly than the others, this will manifest itself in a higher number of correct answers and a shorter average time for those users who work with that variant.

Finally, all results for individual variants of the temporal legend were evaluated using objectivized methods (Miklošík 2005); the result was a numerical value that corresponded with overall user friendliness (see Section 5.5).

When using this method of testing the user friendliness of temporal legends it is necessary to be aware of the test's overall demand on the user. As Figure 1 in Chapter 3 demonstrates, dynamic interactive cartographic works are the most user-difficult of all cartographic production. In the case of animated maps, the user must be able to perceive (and to remember!) a great deal of information that changes over time. In the case of a static cartographic work, the average person is able to simultaneously work with seven different pieces of information (Miller 1956 In Harrower and Fabrikant 2008), but in the case of animated maps this number decreases. With a temporal legend the difficulty grows because the user must perceive not only changes in the map field itself, but also in the changing temporal legend. The very location of the temporal legend can play an important role: it is recommended that the temporal legend is placed as close as possible to the map field so that the user may follow the changes in both the map and the legend. This aspect has been studied by e.g. Mitbø, who suggests incorporating the temporal legend directly onto the map field (Mitbø et al. 2007).

In the test of user friendliness described above, users were asked questions concerning time which required the use of a temporal legend. By requiring users to interact with the legend, the researcher sought to test the following hypothesis: if a temporal legend was too demanding of the user, the user would not successfully perceive the changes in the map field. The basic hypothesis of the overall test of user friendliness was that a failure in the subsequent assessment would manifest itself in one of two ways:

– users working with the temporal legend in question would take longer, on average, to answer the questions,

– their answers would show a higher rate of errors,

or a combination of the two.

5.3 Preliminary phase of test

In the test's preliminary phase, the above-mentioned model animated map was created together with a functional interface (Adobe Flash in conjunction with the MySQL database) in order to produce an automatic testing application for the user. The most important part of the preliminary phase was the formulation of individual questions of varying types to be posed to the user during the test. The questions chosen had just one correct answer (represented in bold type in the following paragraph), and the solution of each one required use of the temporal legend. The questions were as follows:

1) On what day did the first Confederate soldiers cross into the Union territory marked in blue on the map?

a) 6/16, b) 6/18, **c) 6/15**, d) 6/21

In this case, the user was to search for an answer to the question, "When?"

2) How long did it take General Stuart to march from Salem (which he left on 6/25) to York?

a) 6 days, b) 11 days, c) 2 weeks, d) 1 day

Here users searched for an answer to the question, "How long?" in connection with the movement of an object. Searching for the answer required a de facto repetition of the answer to the question "When?"

3) Choose the correct statement about the rate of represented time on the Battle of Gettysburg map.

a) In the interval 8.00–10.00 the rate of represented time is lower than in the interval 18.00–20.00.

b) In the interval 8.00–10.00 the rate of represented time is higher than in the interval 18.00–20.00.

c) In the interval 8.00–10.00 the rate of represented time is roughly the same as in the interval 18.00–20.00.

d) It is not possible to determine the relationship between the rates of time in question.

The purpose of this question, which concerned the determination of rate of time, investigated the user's ability to recognize that variable and consciously employ it. This was the final question because it was determined to be the most difficult.

After answering the final question, the user sent the data and was directed to a webpage with a form on which he could anonymously fill in information about himself and add commentary if he chose. An important component of the form was a section in which the user employed a scale of one to five to "grade" the ease with he was able to work with rate of time and his overall assessment of the temporal legend's intuitiveness (more on this in Section 5.5).

Before testing began, a pilot study was conducted with the purpose of eliminating basic flaws in the application. Nine respondents participated in this phase (three for each variant), some of whom were students of cartography who had experience with cartographic testing. The goal was to elicit as many critical opinions as possible, on the basis of which the application would be revised.

5.4 Running the test

After the elimination of technical and conceptual flaws identified during the pilot study, the test was conducted on May 7, 2010. To recruit users, the author (Vít 2010) sent a link to the testing application to approximately two hundreds of respondents with the request that they pass it on. In this manner, the application reached a wide circle of people of varying ages and levels of education. The testing was officially concluded on June 24, 2010. A total of 216 respondents participated, resulting in 216 entries in the database. The exclusion of "sketchy" entries reduced the data pool to 172 relevant responses, approximately 60 workable responses for each of the tested temporal legends. Of these, 114 were from men and 58 were from women. The average age of respondents was 26.54 years, and the most common level of education attained was post-secondary. While this is not an entirely representative sample, the authors consider it to be acceptable given the nature of the study.

5.5 Assessment of the results

The final phase of the study involved the assessment of temporal legends in two fashions. The first was an attempt to show the relative value of different legends for various temporal questions (Table 1). The second assessed the quality of each legend overall (i.e. their consequent user friendliness – Table 2). Table 3 is an addendum that reflects how the users of the different temporal legends "graded" them (i.e. how they rated them subjectively).

Tab. 1 The effectiveness of the examined temporal legends in relation to individual questions

	1/a)	1/b)	2/
	Correct responses (%)	Correct responses (%)	Correct responses (%)
Question 1 ("when…?")	91.07	85.00	87.50
Question 2 ("how long…?")	85.71	96.67	92.59
Question 3 ("rate of time")	83.93	72.88	71.43

Tab. 2 Consequent user friendliness of the examined temporal legends

	1/a)	1/b)	2/
User friendliness (%)	75.44	68.52	50.04

Tab. 3 Subjective rating of the temporal legends by the users

	1/a)	1/b)	2)
How easy was it for you to work with the rate of time as it is represented here?	1.85	1.84	2.00
How would you rate the overall intuitiveness (comprehensibility) of the temporal legend?	1.66	1.83	1.7

Table 1 shows the effectiveness of the legends as the percentage of respondents' correct answers to time-related questions when using each legend (labeling used in the temporal legends corresponded to the labeling discussed in Section 4.2). When using the alphanumeric temporal legend, for example, 87.5% of the respondents chose the correct answer of the four they were offered for Question 1.

According to the percentage of correct answers, it would seem that for questions of the When type (Question 1) the correct answer is most easily found using the temporal legend 1/a). This was also the case for questions dealing with the rate of time. This is presumably because this method represents rate of time in the most natural and comprehensible way (there is a direct correspondence between the speed of the slide bar and the rate of time). A surprising result was the relative failure of this temporal legend in the case of Question 2 (How long?). Contrary to expectations, for this question the highest favorability went to the temporal legend 1/b). Yet this was the least successful legend for Question 1, in which case users complained of poor readability and intelligibility in general, an inevitable side effect of the various lengths of the units on the temporal axis.

For the question about rate of time, the alphanumerical temporal legend (labeled 2/) met expectations as the least favorable. Rate of time is not inferred from the design itself, but is rather framed as an independent element, and it is debatable whether it makes sense to mention it at all. One user expressed this circumstance thus: "This concept of rate of time is easy enough to grasp, but it seems unintuitive to me."

An important result of the testing of temporal legends was the establishment of their user friendliness on the whole, as expressed by a single numerical value. This was accomplished by determining weighted values for specific criteria and their subsequent aggregation (Mikošlík 2005).

First, three criteria for evaluation were established (here in order of importance):

1) ability of users to correctly answer a question with the help of the temporal legend;

2) users' subjective assessment of the temporal legend (using a grading system);

3) average length of time it takes to find a correct answer.

Next, values were assigned to the criteria according to their importance so that Criterion 1) would figure most heavily in the resulting evaluation. These values were then transferred to a uniform scale and arranged for use in the resulting aggregate function (see below). Our assignment of values for individual criteria is complex and there is no need to delineate it here (it is described in detail in e.g. Miklošík 2005), so here we will only report the resulting values:

– weight of first criterion: p1 = 0.767;
– weight of second criterion: p2 = 0.690;
– weight of third criterion: p3 = 0.614.

The final step was employing the "aggregate function," into which are entered a percentage representing the degree to which individual evaluating criteria were fulfilled and their value. For the purposes of this study, a multiplicative form of aggregate function was chosen in order to strengthen the influence of the first and most important evaluating criteria:

$U = (1) \times p_1 \times [(2) \times p_2 + (3) \times p_3]$, where

U … user friendliness of a given temporal legend (in%),

(1)–(3) … degree of fulfillment of a given criterion (in%, or 0–1),

p_1–p_3 … the weight of a given criterion.

The resulting calculated user friendliness of the studied temporal legends is shown in Table 2. As the table makes clear, from the standpoint of general user friendliness the best temporal legend is 1/a), which fulfilled over three quarters of the evaluating criteria. By contrast, the results for temporal legend 2/ (only 50%) are relatively disappointing and attest to its significant flaws.

Table 3 indicates that users regarded temporal legend 1/a) as the most user friendly. On the other hand, users slightly preferred temporal legend 1/b) for representing rate of time. Here we identify a discrepancy between subjective assessment (impressionistic rating – Table 3) and objective assessment (percentage of correct answers – Table

1), since the largest percentage of correct answers associated with perception of rate of time belongs to legend 1/a).

6. Conclusion

Based on the assessment of the overall user-friendliness of the temporal legends in the study, the best method was found to be the temporal legend with a form of temporal axis, temporal units of consistent length, and the rate of time illustrated by the speed of a movable slide bar – i.e. method 1/a. This temporal legend proved to be favorable in regard to rate of time and response to the question When? This method of representing time is intuitive and commonly used in practice. That is why we must ask whether this temporal legend is truly the best, or whether its familiarity to the users played a role.

The alphanumeric temporal legend (2/), by contrast, failed in most of the indicators evaluated. Its main problem lies in the fact that it does not provide the user a complete image of the time period the cartographic work represents. Use of an additional element (an arrow) to represent rate of time proved to be of debatable benefit.

In the overall evaluation of user friendliness, the temporal legend with units of varying lengths and a slide bar moving at constant speed (1/b) placed second. Lack of clarity was most frequently cited in negative assessments for this legend. On the other hand, it received very positive ratings for the fact that the user is able to use the mouse to manipulate the mobile slide bar. (The other temporal legends used a conventional motion bar located below the map data field.)

This study of the user friendliness of temporal legends represents a beginning in the investigation of this question in cartography. The authors are aware of a number of deficiencies and flaws in the testing described above, the most significant of which was that it was excessively complicated. The results point to certain trends in user friendliness, yet we were unable to establish unambiguous conclusions. For this reason, the authors believe that ensuing research should focus on individual aspects of temporal legends, using a greater number of subjects in each case to examine isolated qualities. A series of such tests might provide a basis for a new set of hypotheses for statistical evaluation. Further research might consider a temporal legend in which the user is able to adjust certain qualities. Of particular interest is the possibility of enabling the user to select a preferred rate of time through the manipulation of a given interactive element (Sieber et al. 2005).

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RÉSUMÉ

Výzkum uživatelské vstřícnosti časové legendy v animovaných mapách

Vedle technické stránky kartografické tvorby se v současnosti stále více diskutuje o její uživatelské vstřícnosti. Výzkum uživatelské vstřícnosti může být vhodným vodítkem pro odlišení vizualizačních technik, které má smysl dále rozvíjet a technik, které jsou z pohledu uživatele neefektivní. Článek navrhuje a diskutuje tři odlišné typy časové legendy, které řeší rozdílným způsobem samotné znázornění času (dvě odlišné formy časové osy × alfanumerické vyjádření času) a také jeho rychlost a její případné změny. První ze zkoumaných legend vyjadřuje rychlost času rychlostí pohyblivého jezdce, druhá grafickou délkou časových jednotek na časové ose. Poslední, alfanumerická časová legenda, používá ke znázornění rychlosti času speciální, uměle přidaný prvek ve tvaru šipky.

Tyto tři navržené časové legendy byly vzájemně porovnány na základě online testu uživatelské vstřícnosti. Do porovnání vstupovaly jak faktory objektivní (jak je uživatel schopen s danou časovou legendou pracovat), tak faktory subjektivní.

Z testu vyplynulo, že nejlepší způsob vyjádření času je formou časové osy, kdy je rychlost času vyjádřena proměnnou rychlostí pohyblivého ukazatele („jezdce“). Tento způsob je však v praxi nejběžněji používaný a zůstává proto otázkou, nakolik jsou výsledky testu ovlivněny faktorem zvyku uživatelů. Pro stanovení jasných závěrů by bylo třeba provést větší množství elementárních testů.

SUMMARY OF PAPERS BY CZECH PARTICIPANTS AT THE XVIIITH INQUA CONGRESS IN BERN

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ABSTRACT

The review paper presents the main research topics of the XVIIIth INQUA Congress from selected sessions with contributions from the Czech participants. The results of Czech papers are highlighted and discussed in relation to progress in Quaternary research. Discussed are advances in topical subjects of international studies of Quaternary palaeoenvironments and climate change.

Key words: the Quaternary, the XVIIIth INQUA Congress, palaeoenvironments, climate change

1. Introduction

The International Union for Quaternary Research (INQUA) was founded in 1928 with the basic objective of developing collaboration and interdisciplinary communication in all aspects of Quaternary research. INQUA is a full member of the International Council of Scientific Unions and collaborates with related associations as well as long-term research projects such as the Past Global Changes Programme, the International Geosphere – Biosphere Programme and the International Geological Correlation Programme. It organizes many international workshops and conferences (compare http://www.inqua.org/) and also regular congresses every four years involving a broad range of specialists in basic and applied subjects of Quaternary research.

INQUA Congresses were held in Copenhagen (1928), Leningrad (1932), Vienna (1936), Rome (1953), Madrid (1957), Warsaw (1961), Boulder (1965), Paris (1969), Christchurch (1973), Birmingham (1977), Moscow (1982), Ottawa (1987), Beijing (1991), Berlin (1995), Durban (1999) Reno (2003), Cairns (2007), and Bern (2011). The next INQUA Congress will be organized in Nagoiya, Japan. The organization of the sessions at the XVIIIth INQUA Congress in Bern (20–27 July 2011) were mostly prepared by commissions, committees, and working groups of the INQUA with the main emphasis on reviewing recent research results, and to discuss activities for the next congress. The motto of the congress was "Quaternary Science – the view from the mountains", which also emphasized the wonderful environment as a substantial source of prosperity and the hospitability of the people of Switzerland.

Contributions of the Czech participants presented during several sections of the XVIIIth International Union for Quaternary Research (INQUA) Congress in Bern (July 20–29, 2011) were in a harmony with the majority of topics specified by the INQUA interdisciplinary commissions. The restored commisions of the INQUA for the period 2011–2015 are: Stratigraphy and chronology, Palaeoclimate, Terrestrial processes, deposits and history, Coastal and marine processes, Humans and biosphere. Advances in the Quaternary research were also expressed by the structure of the XVIIIth INQUA Congress (for details see http://www.inqua2011.ch/ or http://www.inqua.org/). The research programme was mainly realized in the framework of specialized sessions (originally marked from No. 1 to 110, however, 22 of them were not realized) and discussion meetings, plenary talks, general assembly and pre-, mid- and post-congress excursions. Papers of the registered Czech participants were placed and presented in research sessions summarized in Table 1. The original sources of all papers and their relation to specialized sessions are available at http://www.inqua2011.ch/.

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Tab. 1 Research sessions of the XVIIIth INQUA Congress in Bern with the contributions of the Czech participants (Note: names of presenters are printed in bold, for details see chapters 2 and 3)

No 11: The Palaeorecords of fire in the Earths' System: Climate or Humans?
Přemysl Bobek: *Soil charcoal distribution in sandstone landscape. (Charles University in Prague)*
No 34: Geoarchaeology: Paleoenvironments and Human Interactions
Eva Jamrichová, *Vlasta Jankovská: Natural environment of human societies in Poprad Basin (NE Slovakia) from the Late Palaeolithic to the Mediaeval Period: landscape character and vegetation changes. (Masaryk University in Brno)*
No 42: Ecological Responses to Climatic Change at Decadal to Millennial Timescales: From Genes to Biomes
Lydie Dudová, *Barbora Pelánková: Central European vegetation of the Early and Middle Holocene as seen from the Southern Urals. (Masaryk University in Brno)*
No 53: Palaeohydrological archives, fluvial environments and surface-groundwater flow processes
Renata Kadlecová, *František Buzek, Jiří Bruthans: The Jizera River terraces - a vulnerable source of water for Prague (the Czech Republic). (Czech Geological Survey in Prague)* ***Pavla Žáčková***, *Libor Petr, Lenka Lisá, Jan Novák: Analysis of vegetation and environmental changes since 11.5 ky BP from an extinct oxbow lake of the flood plain of the Elbe River, the Czech Republic. (Charles University in Prague)*
No 63: High and Central Asia - Pleistocene Glaciations and related geomorphological phenomena
Jan Kalvoda: *Integration of orogenetic and climate-morphogenetic processes during the landform evolution of the High Asian mountains in the Quaternary. (Charles University in Prague)* ***Jan Kalvoda***, *Jaroslav Klokočník, Jan Kostelecký: Dynamics of Quaternary landform evolution in High and Central Asia recorded by the gravitational signatures of EGM 2008. (Charles University in Prague)*
No 64: Reconciling modern and the Quaternary rates of landscape evolution
Jaroslav Kadlec, *Gary Kocurek, David Mohrig, Ashok Kumar Singhvi, D. P. Shinde, M. K. Murari, Filip Stehlík, Helena Svobodová – Svitavská: Late Glacial lacustrine and fluvial processes in the Lower Moravian Basin, the Czech Republic. (Institute of Geology, Academy of Sciences of the Czech Republic)* *Jiří Bruthans, Michal Filippi, Mohammad Zare,* ***Renata Kadlecová***: *Can an increase in aridity trigger rapid surface erosion of diapir surfaces and intensify the brine flow in a semiarid climate? (The Zagros Mountains, Iran). (Czech Geological Survey in Prague)*
No 71: Reconstructing historical climate variability using documentary sources
Rudolf Brázdil: *Recent progress and the future potential of historical climatology in Europe. (Masaryk University in Brno)*
No 81: Chronologies and the Quaternary Record
Dana Homolová, *Johanna Lomax, Kurt Decker, Ivan Prachař, Petr Špaček: Building a stratigraphy of fluvial sediments in the Budějovice Basin (the Czech Republic) based on absolute ages – the first OSL-ages of the Vltava river terraces. (University of Vienna)*
No 90: Palaeofloods in the Earth's history
Libor Elleder, *Anja Nießen, Thomas Roggenkamp: Historic floods in the city of Prague – a reconstruction of peak discharges. (Czech Hydrometeorological Institute in Prague)* ***Martin Margold***, *Krister Jansson: Pleistocene Glacial Lake Vitim outburst flood, central Transbaikalia, Siberia. (Stockholm University)*
No 103: pan-European correlations in Quaternary stratigraphy
Břetislav Balatka, Philip Gibbard, ***Jan Kalvoda***: *Morphostratigraphy of accumulation terraces of the Sázava and Vltava Rivers in the Bohemian Massif and its correlation with the North European stratigraphical classification of the Quaternary. (Charles University in Prague)* ***Petr Kuneš***: *Testing the correlation of fragmented pollen records of the middle and late Pleistocene temperate stages. (Charles University in Prague)*

The review paper presents research patterns of these selected sessions. The submitted report is mainly based on a set of sessions résumé (compare http://www.inqua2011.ch/), abstracts of contributions and the authors' experiences gained during the congress. A set of papers presented by Czech specialists during the XVIIIth INQUA Congress in Bern was, unfortunately, very modest in comparison with the large-scale research activities conducted in the Czech Republic (compare http://www2 gli.cas.cz/kvarter/ and http://www.geomorfologie.eu/).

However, these contributions were accepted (in detail see chapter 3) within the scope of selected sessions of the meeting which were characterised by progressive topics briefly described in the following paragraphs.

2. Topics of specialized sessions with contributions from the Czech participants

The session *"Chronologies and the Quaternary Record"* was focused on a large amount of results obtained by high-resolution dating techniques and many regional chronologies. The main topics were (http://www.inqua2011.ch/): a) how chronometric data obtained using different dating techniques can best be combined, b) what additional analysis and combination of chronometric data can be used to improve the resolution and precision of age models, and c) what progress in the understanding of Quaternary palaeoenvironmental changes has been made using variable dating techniques and datasets. Contributions of the session *"pan-European correlations in Quaternary stratigraphy"* aimed to present multidisciplinary approaches to interpretation and comparison of sedimentary sequences and ages of rocks at local and regional scales. Development of European Quaternary stratigraphy is related to extensive mapping of Quaternary deposits. It provided a basic knowledge of geological processes and climate changes during the Quaternary. Comparisons are also possible based on *"Reconciling modern and Quaternary rates of landscape evolution"*. This session was mainly focused on the interaction of geomorphic and tectonic processes at various spatio-temporal scales relevant to the Quaternary. Denudation rate variations reflect strong fluctuations of climate or tectonic activity. The emphasis in this session was to understand a) feedback between climate variability, glacial and non-glacial denudation rates, and neotectonics in mountain systems, and b) how contemporary denudation rates reflect landscape evolution in the past. In the regional session *"High and Central Asia – Pleistocene Glaciations and related geomorphological phenomena"*, selected results were presented from the Himalaya, Karakoram and their neighbouring regions. Geomorphological data of the maximum glacier extent during the Late Glacial Maximum were summarised and traces of older glaciations were discussed. Contributions regarding the glacio-isostatic crustal movement, the snowline reconstruction of the Asian mountains and the palaeo-climatological consequences of the glaciation of High Asia were also included.

The session *"Palaeohydrological archives, fluvial environments and surface-groundwater flow processes"* was concerned with short and long-term fluvial dynamics in response to tectonic, climate and environmental changes (http://www.inqua2011.ch/). These cause and effect relationships are especially relevant to understanding the future response of water cycle components (rainfall, runoff, discharge, groundwater recharge) and fluvial regime indicators (mean discharge, floods, droughts) to expected climate and environmental changes. In this session contributions were presented on a) regional palaeohydrological interpretations of fluvial Quaternary evolution from sedimentary records and landforms, b) interrelations among basin components and processes, c) interpretation of hydrostratigraphic units, distribution of groundwater reservoirs and low-temperature geothermal energy resources, d) advances in applied techniques. *"Palaeofloods in the Earth's history"* session was focused on the understanding of the origin, mechanisms and dynamics of past high magnitude floods which significantly changed the landscape during the Quaternary. It helps to estimate the potential of current and future high magnitude floods within regional or global environmental changes. Similar aspects of rapid natural processes were presented in the session *"The Palaeorecords of fire in the Earth's System: Climate or Humans?"*. Palaeofire and vegetation-change observations can be used as records of interplay between climate, vegetation, ignition and people. Fire records in sedimentary archives have been assembled for the last 21 ka, as well as the last glacial period and the past two millennia. Palaeoenvironmental datasets characterize fire regimes across space and time and provide baseline estimates of the historical range of variability in fire for comparison with contemporary fire regimes. They also serve as benchmarks for assessing palaeomodel simulations of fire and vegetation change. The influence of humans, climate and fuel has been investigated on regional and global scales. In this session the weight of fire under different climates was also discussed as well as the nature of fire feedback to the climate system via changes in vegetation and fuels.

The session *"Ecological Responses to Climatic Change at Decadal to Millennial Timescales: From Genes to Biomes"* presented amassed records of palaeoecological studies which are often based on pollen and macrofossils. It is essential for reconstructing past species distributions, developing ecological theories, evaluating human impacts, and testing model predictions of climatic and biotic changes from the past to the future (http://www.inqua2011.ch/). Selected issues of global change were studied, e.g. spatial patterns of genetic diversity in relation to past climatic and ice-sheet dynamics, vegetation shifts in response to novel climatic conditions, biogeochemical processes associated with abrupt climatic events, and biospheric feedback to the global climate system. These topics were close to the main tasks of the session *"Reconstructing historical climate variability using documentary sources"* which emphasized research at the forefront of climate reconstruction and impact studies, new methods and sources used in historical climatology and improvements in the analysis of historical texts. These sources incorporate pre- and early- instrumental data and include references to frost dates, droughts, famines, the duration of snow and sea-ice cover, and other phenomena valuable to reconstructions of the past climate.

They are used as an extension of instrumental records, corroboration of evidence from natural archives (e.g. tree rings, ice cores and coral reefs), and exploration of essential impacts of historical climate variability and extreme climatic events on society. The session *"Geoarchaeology: Paleoenvironments and Human Interactions"* was focused on the application of geoarchaeological knowledge to the investigation of environmental processes in the Quaternary. Recent geoarchaeological surveys and related modern methods were presented, providing evidence of changes in historical environments, ecosystems, and geomorphology that affected regional archaeology. The geoarchaeological session highlighted multidisciplinary reconstructions of past landscapes, palaeoenvironments, and various human footprints on natural systems.

3. The main results of research presented by Czech participants

(*Note: Names of presenters are printed in bold and numbers indicate interdisciplinary sessions with topics specified in Table 1. Abstracts of all papers are available at* http://www.inqua2011.ch/).

Soil charcoal distribution in sandstone landscape (**Přemysl Bobek**, No. 11)

Distribution of soil charcoal in places with low erosion activity reflects the frequency of wildfires during the Holocene. Concentration of soil charcoal was measured in the highly variable relief of the sandstone area in Northern Bohemia providing an opportunity to observe diverse environmental conditions, ranging from deep moisture gorges to dry rock plateaus. A semiquantitative chemical method, based on nitric acid digestion and loss on ignition technique, was used to differentiate between soil organic carbon, mineral matter and charred plant particles in soil samples. It was found that considerable heterogenity in the concentration of charcoal in soils ranges from 0.0006 g kg^{-1} to 21.0234 g kg^{-1}. The highest concentrations are distributed particularly on exposed rock plateaus.

The natural environment of human societies in Poprad Basin (NE Slovakia) from the Late Palaeolithic to the Mediaeval Period: landscape character and vegetation changes (**Eva Jamrichová**, Vlasta Janovská, No. 34)

This study is based on results from pollen analyses, which have been confronted with archaeobotanical information obtained from the archaeological material of the studied area. These results were used for palaeoecological reconstruction of the natural environment of Poprad Basin from the Late Palaeolithic to the Mediaeval Period. Vegetation of this area had the character of coniferous taiga, forest-tundra and mountain tundra at its highest elevations during the Late Glacial (Weichselian) Period. Larix together with Pinus cembra were the dominant trees in the taiga and forest-tundra stands. Anthracological analysis of the material from the Palaeolithic Period proved the presence of coniferous stands and undemanding deciduous tree species. During the Early Holocene, there was an expansion of Picea, a decrease of Larix and Pinus cembra, and the first occurrence of species of Quercetum mixtum. During the Atlantic Period, there was an expansion of spruce stands and a spreading of Quercetum mixtum in climatically and edaphically favourable biotopes. Primary anthropogenic indicators started to appear in the Subboreal Period as a reaction to occupation in the Poprad Basin at the end of the Aeneolith, but mostly during the Bronze Age. Poprad Basin was largely inhabited during the Subatlantic Period. Human impact on the vegetation was reflected by a decrease of deciduous and a complete dominance of coniferous trees in the pollen spectra. It is possible to assume that this is a reaction to the exploitation of the deciduous wood, because of metal mining in the Poprad Basin.

Central European vegetation of the Early and Middle Holocene as seen from the Southern Urals (**Lydie Dudová**, Barbora Pelánková, No. 42)

Modern vegetation and the environments of the Southern Urals are very similar to those of Early and Middle Holocene Central Europe. This area lies outside the distribution range of beech and hornbeam, whose invasion of Central Europe in the Late Holocene significantly changed the species composition of forest vegetation. It contains tree species that were found in Early to Middle Holocene Central Europe, such as oak, elm, lime, maple, birch, pine and larch, combined with steppe vegetation. The paper reports the analysis of 50 surface pollen samples obtained from six main vegetation types of the Southern Urals: dry steppe, mesic steppe, hemiboreal coniferous pine-larch forest, small-leaved birch-aspen forest, broad-leaved oak forest and broad-leaved maple-lime-elm forest. In turn, these types represent the main vegetation units as they had replaced one another from the Late Glacial/Holocene transition to the Middle Holocene.

The Jizera River terraces – a vulnerable source of water for Prague (Czech Republic) (**Renata Kadlecová**, František Buzek, Jiří Bruthans, No. 53)

One of the strategic sources of water used for supplying Prague is located in river terraces developed at the Labe and Jizera river confluence about 30 km northeast from the capital. The fluvial sands and sandy gravels overlaying Cretaceous marine marlstones and sandstones were deposited by the Jizera R. during the middle and late Pleistocene and formed several terrace levels. The average thickness of terraces is 15 m with a water saturated zone 4–6 m thick. The riverbank filtration system (RBF) pumps groundwater infiltrating into these sediments from the underlying sandstones (40%) and from the modern Jizera R. channel (60%). The RBF supplies the capital with

15,000 m^3 of water a day. The CFC concentrations measured in groundwater flowing from the Cretaceous aquifer show a residence time of several decades. The groundwater reveals nitrate concentrations (up to 40 mg l^{-1}) due to longer exposure to anthropogenic pollution sources. This water is diluted by an artificial recharge network when water from the Jizera R. channel with low nitrate content (1–15 mg l^{-1}) is conducted by conduits to the terrace sediments. The quality of water infiltrating into the fluvial sediments from the unsaturated zone is affected by local agriculture management – mainly fertilizing – in the yield area. Based on model scenarios, the simulated impact of present warming on the total runoff of the fluvial sediment aquifer will be more affected. Increased temperatures will cause a groundwater level decrease due to higher evapotranspiration. The resulting decrease of discharge of groundwater in surface streams during summer seasons increases the contribution of infiltrated precipitation from the unsaturated zone to discharge.

Analysis of vegetation and environmental changes since 11.5 ky BP from an extinct oxbow lake of the flood plain of the Elbe River, the Czech Republic (**Pavla Žáčková**, Libor Petr, Lenka Lisá, Jan Novák, No. 53)

The Late Glacial palaeomeander Chrast is situated in the area of the middle Elbe river floodplain, where a huge number of paleomeanders with a unique complex of relict wetlands and fen meadows of Holocene age are preserved. The investigated profile (total depth 285 cm) was obtained from an oxbow lake. Plant macro- and micro-fossils were studied with supportive evidence from geochemical and sedimentological data. Based on the results, the profile was divided into 5 zones (A1–A5). The last 110 cm (A1–A3) contains a unique record of Allerød vegetation. Sediment of the base of the palaeomeander (11,450 ± 60 years BP) contains a record of macrophyte vegetation (Nuphar lutea, Batrachium, Potamogeton ssp). The local pollen spectra give evidence of the occurrence of aquatic species (Myriophyllum spicatum-type, Pediastrum, Sparganium/Typha angustifolia). Subsequently, organic production increased rapidly during 11 523 ± 120 years BP (A2) and the shallow lake was filled in. This is supported by the presence of macroremains of Carex vesiraria/rostrata, C. riparia and Menyanthes trifoliata. Salix, Betula and Pinus wood fragments were also recorded indicating the presence of birch-pine forest intermingled with spruce. Fires, which were frequent during the end of the Last Glacial, are documented by the record of a large number of burnt seeds and charcoal. Calcium carbonate accumulations of the lake marl originated at the beginning of the Younger Dryas (11,010 ± 60 years BP). Increased sand deposits (A4) indicate a change from a meandering type of river to a braided one. The end of the sand deposition might be linked with the Glacial/Holocene transition phase. Local human impact (A5) is documented in the middle of the Holocene (6510 ± 40 years BP).

Integration of orogenetic and climate-morphogenetic processes during the landform evolution of the High Asian mountains in the Quaternary (**Jan Kalvoda**, No. 63)

The High Asian mountain ranges were presented as a particularly suitable region for research on the topical aspects of landform evolution under the very variable orogenetic and palaeoclimatic conditions which occurred during the late Cenozoic. Geomorphological observations in the Himalaya, Karakoram, Pamirs and Thian-Shan suggest significant feedback between the rate of orogenetic processes and the intensity of climate-morphogenetic processes during the Quaternary. The extreme exhumation of deep crystalline rocks in the Himalaya and Karakoram during the late Cenozoic was the result of morphotectonic processes as well as the effective tuning of paleogeographical changes in the extension of the main climate-morphogenetic zones. Moreover, the observed landform changes on a decadal scale indicate the high intensity of recent climate-driven morphogenetic processes. The latter are especially very effective in the erosion and transport of weathered material by a combination of diverse exogenetic factors, integrated with active morphotectonic processes.

The dynamics of Quaternary landform evolution in High and Central Asia as recorded by gravitational signatures of EGM 2008 (**Jan Kalvoda,** Jaroslav Klokočník, Jan Kostelecký, No. 63)

Landform patterns in High and Central Asia provide evidence of the nature of the very dynamic landscape evolution through the late Cenozoic, including intense morphotectonic processes, high rates of denudation and sediment transfer and deposition. The resulting landforms are also controlled by litho-structural features within uplifting ranges. Gravity data are therefore very valuable for establishing a better understanding of the processes driving uplift and erosion in these active orogenic regions. The results of the correlation of regional features of the Earth Gravitational Model 2008 (EGM 2008) with morphogenetic and orographical patterns in High and Central Asia were presented. Strong coincidences between large-scale morphogenetic styles of these regions and the extension of areas with very high positive values of the radial second derivative of the disturbing gravitational potential T_{zz}, and the most likely in combination with conspicuous areas of high negative values of T_{zz} in their close neighbourhood have been identified. The variable values of T_{zz}, computed from EGM 2008, display significant gravitational signatures of extensive differences and changes in mass density and/or rock massif and regolith distributions. It is suggested that areas discovered in High and Central Asia where very conspicuous combinations of significantly high positive or negative values of radial second derivatives of the disturbing gravitational potential T_{zz}, computed from EGM 2008, are under the strong influence of present-day active geodynamic and geomorphic processes.

Late Glacial lacustrine and fluvial processes in the Lower Moravian Basin (the Czech Republic) (**Jaroslav Kadlec**, Gary Kocurek, David Mohrig, Ashok Kumar Singhvi, D. P. Shinde, M. K. Murari, Filip Stehlík, Helena Svobodová-Svitavská, No. 64)

The Lower Moravian Basin extends along the lower Morava River, close to the Czech, Slovak and Austrian borders. Its Miocene base is overlain with Pleistocene and Holocene terrestrial deposits. A key for deciphering the late Pleistocene history of the basin is in the sediments exposed in the Bzenec sand quarry and in a cut bank of the meandering Morava R., both located about 4 km northwest of Straznice in the Hodonin District, the Czech Republic. The exposed sandy deposits reveal a 9.5 m thick section dominated by cyclic horizontal beds. Capping the horizontal beds is an interval of trough cross-stratified beds which are in turn overlain with well-sorted laminated fine sand. The following interpretation for this sedimentary succession is proposed: (1) the cyclic beds were deposited by turbidity currents in a lacustrine environment; (2) the uppermost section of the lake turbidites was reworked by running water; and (3) wind-blown sand dunes were formed after draining of the lake. OSL dating of the lake sediments indicate deposition between 20 and 13 ka. Elevation of the sedimentary sequence documents that the lake level was 15–17 m higher than the Morava R. level today. The dam required to produce this lake could have been formed by aeolian sand dunes sourced from the late Pleistocene terraces at the Morava and Dyje river confluence. After collapse of the dam that formed the lake, the Morava R. constructed large meander bends across the newly developed floodplain. Radiocarbon ages together with pollen data from organic fill drilled in a paleomeander located at the floodplain edge document that the Morava R. channel was incised 18–20 m below the former top of the lake sediments during the Alleröd Interstadial.

Can an increase in aridity trigger rapid surface erosion of diapir surfaces and intensify the brine flow in a semiarid climate? (Zagros Mountains, Iran) (Jiří Bruthans, Michal Filippi, Mohammad Zare, **Renata Kadlecová**, No. 64)

Zagros Mts. host numerous salt diapirs, which differ in uplift rate and relief. Some diapirs are exposed to arid conditions; some are situated at higher altitude in less arid climate. A few diapirs are formed by vast surfaces built predominately by halite, at others, the rock salt is covered by an up-to-30 m thick surficial residuum, which even enables the planting of crops thanks to recharge concentration at sinkhole bottoms. Erosion rates were measured for a period of up to 10 years by plastic pegs as benchmarks. Salt exposures are eroded at a rate of 30–120 mm $year^{-1}$, while thick surficial deposits covered by vegetation show negligible erosion. Salt exposures produce huge amounts of dissolved and clastic load, thus affecting the land use in the vast surroundings of the diapirs. Based on field observation, most of the rainwater will infiltrate, while overland flow predominates on rock salt exposures. As most of the water evaporates from vegetated surfaces the amount of water generated by percolation in the underlying rock salt is very low. This enable the distinguishing (based on aerial imaginary) of the alluvial fans in diapir surroundings, which will likely be heavily polluted by brine from those potentially interested in groundwater abstraction. Radiocarbon and U-series dating of calcretes capping some diapir surfaces indicates that diapirs reached their largest extent during the Last Glacial. Since then, the original thick surficial deposits have been undergoing erosion on many diapirs. During less arid periods, vegetation cover protected the diapir surfaces. After the onset of an arid climate, the erosion rapidly accelerated thanks to vegetation degradation and consequent changes in the surficial deposit types and thicknesses.

Recent progress in and the future potential of historical climatology in Europe (**Rudolf Brázdil**, No. 71)

Several groups of documentary evidence (narrative written records, visual daily weather records, personal correspondence, special prints, official economic records, newspapers, pictorial documentation, epigraphic data, early instrumental observations, early scientific papers and communications) and their use for the creation of a series of weighted monthly temperature and precipitation indices were presented. Alternatively, a series of (bio) physically based documentary proxies usually reflecting any systematic economic activity (e.g. from agriculture or transport) were also discussed. Methodology of climate reconstruction from data based on application of the standard paleoclimatological method (calibration and verification procedures) working with the overlap of documentary-based series and instrumental measurements was described. The study also demonstrates examples of the analysis of droughts, floods, windstorms, tornadoes and hailstorms in Central Europe based on documentary evidence from the viewpoint of their occurrence, severity, seasonality, meteorological causes, perception and human impacts during the past millennium.

Building a stratigraphy of fluvial sediments in the Budějovice Basin (the Czech Republic) based on absolute ages – first OSL-ages of the Vltava river terraces (**Dana Homolová**, Johanna Lomax, Kurt Decker, Ivan Prachař, Petr Špaček, No. 81)

The Budějovice Basin, situated in Southern Bohemia is a fault-bounded sedimentary basin with a multiple subsidence history overlying the Variscan crystalline base of the Bohemian Massif. The Vltava River, crossing the basin from the south to the north, accumulated terrace bodies of different extent during the Pleistocene and probably further back in the past. The presented study is focused on the mapping and dating of Pleistocene river terraces in the vicinity of Hluboká nad Vltavou in order to establish a chronology of terrace development. Currently available data were derived from about 100 outcrops and hand drillings and 17 shallow boreholes. Stratigraphic correlations are based on 19 OSL ages. Pilot results show five terrace levels in the crystalline base and at least four levels in the Budějovice Basin. The uppermost terrace levels are out of the dating range of the method, but for the lower river terraces, it was possible to create a consistent stratigraphy with ages ranging from about 80 ka to the Holocene.

Historic floods in the city of Prague – a reconstruction of peak discharges (**Libor Elleder**, Anja Nießen, Thomas Roggenkamp, No. 90)

The oldest reliable record of flooding in Prague is related to the disastrous 1118 flood. About 150 floods are mentioned in documentary sources. About half of these are described in a qualitative way, i.e. regarding the damage and impact. The level of the important cases is recorded more exactly, mostly as flooding of different buildings in the Old town area of Prague. Approximately 20–30 maximum water levels since 1481 are denoted by flood marks, or marked at the Bearded Man, a gothic relief on a wall near Charles Bridge, or by early instrumental measurements. The main challenge of this reconstruction is the consideration of man-made floodplain modifications influencing the cross-section area and the hydraulic roughness significantly. The presentation of this approach includes the procedure of reconstructing the hydraulic parameters of the river channel and the inundated floodplain as well as a final verification of the reliability of estimated peak discharges. Due to the different hydraulic background, all winter-flood events are excluded to avoid calculating floods with a possible ice jam effect. 14 reconstructed discharge maximums were found. The validation of the technique by comparison with the recent gauged flood of 2002 reveals results of adequate accuracy. The comparison also shows that the flood event of 2002 was conspicuously greater than all calculated flood events between the years 1481 and 1825.

The Pleistocene Glacial Lake Vitim outburst flood, central Transbaikalia, Siberia (**Martin Margold**, Krister Jansson, No. 90)

The prominent Glacial Lake Vitim in Transbaikalia, Siberia, was formed when glaciers descending from the Kodar Range dammed the Vitim River. Evidence for the existence of the lake, such as fossil shorelines and deltas, infers that the lake filled the Muya-Kuanda intermontane depression and branched into many tributary valleys in the upper catchment of the Vitim River. The total area of the lake at its maximum extent was 23,500 km^2 and the water volume was ca 3000 km^3, which makes it one of the largest documented glacial lakes dammed by mountain glaciers. A large canyon incised in the bedrock (300 m deep, 2 km wide and 6 km long) cuts through the slope of the Vitim valley in the vicinity of the postulated ice-dam. The canyon was formed during an outburst flood from the lake. The flood path followed the Vitim River and the water was subsequently drained into the Arctic Ocean through the Lena River.

Morphostratigraphy of accumulation terraces of the Sázava and Vltava Rivers in the Bohemian Massif and its correlation with the North European stratigraphical classification of the Quaternary (Břetislav Balatka, Philip Gibbard, **Jan Kalvoda**, No. 103)

The results of geomorphological research in the Sázava and Vltava basins in the Bohemian Massif were presented with regard to identifying the main remains of river terrace sedimentary sequences. The construction of the long profiles through the river terraces and of a series of transverse-valley profiles, has enabled the differentiation of 7 main terraces with several subsidiary levels and 2 levels of Neogene fluvial to fluvio-lacustrine sediments. The typically developed incised meanders and bends were mostly formed during the Middle Pleistocene. Their comparison with the terrace system of the Labe River, as well as correlation with the North European stratigraphical classification of the Quaternary was presented. The surfaces of pre-Quaternary deposits occur at up to 135 m higher than the present river levels. The Quaternary incision of the Sázava and Vltava valleys reaching to an average depth of more than 100 m was induced by neotectonic uplift of the Bohemian Massif. Based on the current Quaternary stratigraphical scheme, the entire Sázava and Vltava terrace system was mostly formed during the Middle and Upper Pleistocene Subseries, that is to the period from the Cromerian Complex to the Weichselian stages. Erosional events, before the accumulation of terrace I, fall at the end of the Early Pleistocene.

Testing the correlation of fragmented pollen records of the middle and late Pleistocene temperate stages (**Petr Kuneš**, No. 103)

Existing continuous chronosequences from Southern Europe provide good chronologies and thus enable a biostratigraphic definition of at least younger MIS. However, in Northern Europe, the fragmentary character of the records and the weaknesses of absolute dating prevent good age estimates. Age-determination of the majority of fragmentary records depends on site-to-site correlations. In the presented study, a correlation of well and poorly known pollen records of the middle- and late-Pleistocene temperate stages from Northern-Central Europe, as well as evaluations of the usefulness of several numerical techniques, was performed. TWINSPAN analysis identifies groups of temperate stages based on the presence/absence of their indicative taxa and may be useful for distinguishing between older and younger interglacials. Site-to-site sequence slotting allows the determination of the most similar pairs of records, based on sample dissimilarity following their stratigraphic constraints. Sequence slotting performs well when correlating the Holsteinian interglacial and Cromerian stage II, and also provides tentative correlation of some problematic records. Ordination compares the main trends in pollen stratigraphies of all pollen sequences. It finds very similar patterns between Eemian records and Cromerian stage II. The implications for progress suggest focusing on better sampling resolution, multi-proxy approaches to climatic reconstruction and obtaining better independent dating.

4. Discussion

Quaternary research involves a broad range of specialists because the study of environmental changes during the last 2.5 million years of the Earth's history has a strongly interdisciplinary character. The complex environmental changes in glacial and interglacial ages of the Quaternary are studied in order to understand the causes, timing and dynamics of the Earth's surface events during the period of human evolution. An evaluation of significant Quaternary environmental changes, which are stimulated by an integration of endogenic and climatic processes, also contributes to endeavours to calculate realistic prognoses of the future existence of mankind. The main subject of the presented report consists of an evaluation of interdisciplinary research patterns of the XVIIIth INQUA Congress.

The integrated endeavour for understanding the evolution of Quaternary environments can be summarized by topical clusters of complex subjects: a) stratigraphy and chronology of Quaternary marine and terrestrial deposits, processes and events, b) Quaternary climate changes and their palaeoenvironmental consequences, c) human history in the Quaternary, d) key regions of the Earth for Quaternary research.

Research results related to the stratigraphy and chronology of Quaternary processes and events were part of concerned almost all sessions of the congress. However, the main progress has been made in chronostratigraphy and methods of dating. Advances in Quaternary stratigraphy and correlation of regional records about glaciations (e.g. Antarctic, Europe) have contributed to substantial improvements of knowledge about palaeoclimate evolution. Development in Quaternary chronologies in "classical" areas is strongly supported by relevant studies in orogenetically active settings including high-mountain regions. Global and regional correlations of climate events using marine ^{14}C reservoir ages, atmospheric pCO_2 and $\delta^{18}O$ records were systematically performed. Rapid advances in dating methods were reported in determination of $^{40}Ar/^{39}Ar$ and ^{14}C ages of Quaternary events and processes, dating of landforms by cosmogenic nuclides, radiometric dating of speleotherms, applications of tephrochronology and magnetostratigraphy in archaeological and palaeoenvironmental studies, amino-acid geochronology and DNA datasets.

The presentations of research results concerning Quaternary marine and terrestrial processes and deposits made a substantial contribution to the better understanding of present-day (and future) natural processes and events. Corresponding sessions highlighted several fundamental and applied themes such as a) integration of ice core, marine and terrestrial global records during the period 60,000 to 8000 years ago, b) sea-level changes during the Quaternary and records about coastal evolution including rapid coastal changes such as co-seismic uplift or subsidence, tsunamis and storm impacts, c) assessing the spatio-temporal resolution of fossil proxies and large extinction events, d) long-term and rapid slope processes including landslides in historic and prehistoric times, e) reconciling modern and Quaternary rates of landscape evolution. The traditional cluster of research topics was connected with Quaternary continental and mountaineous glaciations. Extraordinary attention was given to the Antarctic, Greenland and British Ice Sheets and/or to High- and Central Asian, South- American and Alpine mountaineous glaciations. Papers about Quaternary glacier variability from the tropics to the poles include enormous amount of field and interpretation data about palaeo-ice stream dynamics, glacial processes, sediments, landforms and ecosystems including their dating.

The most investigated and discussed subjects at the INQUA Congress were Quaternary palaeoclimate and palaeoenvironments. A multidiciplinary research approach in these topics is conspicuous from Antarctic, South American, African and North Atlantic studies, e.g. comparison of multiproxy records and past circulation patterns, polar ocean efficiency in CO_2 storage, Late Quaternary history of humans and regional climate changes during the last 2000 years. Special attention was also given to Late-glacial and Holocene climate change in continental Asia, catastrophic palaeoenvironmental processes and events in large water bodies of SW Asia and sea-level changes related to climate during the last 140 ka in the Mediterranean. Of fundamental significance are the complex studies of drowned landscapes and continental shelves of the last glacial cycles, past dryland and deserts dynamics as well as palaeohydrological archives concerning palaeogroundwaters, fluvial environments, surface- and groundwater flow processes and palaeofloods in the Quaternary.

A cluster of studies related to a) reconstruction of environmental impacts of climate changes from MIS 5 to present and especially over the last millennium (based mainly on terrestrial and lacustrine archives), b) ecological responses to climatic change at decadal to millennial timescales, c) inter-hemispheric climate perspectives from high-precision glacier records and d) reconstruction of historical climate variability using documentary sources provide great potential for predictions and/or prognoses of future environmental changes.

A topical cluster of subjects in Quaternary Science is concerned with human history. It was demonstrated how lifelike present-day critical problems of a society can be defined through many topics of the INQUA Congress sessions with relation to the history of humans in the Quaternary. Main attention was given to Mio-Pliocene hominid evolution and its environmental context, geoarcheological studies of human interactions with Quaternary paleoenvironments and understanding of the last glacial cycle ice sheets and meltwater impact through data and modelling interactions among fauna, vegetation, and humans. Similarly, studies of water ecosystems as a component of the geographical mantle and the anthropogenic influence over them as well as high-resolution records of climate and human impact in mountain regions were presented. Humans history during the Late Quaternary was represented by various clusters of subjects: a) quantifying and modelling human and climatic impacts on hillslope and fluvial sediment dynamics during the Holocene; b) the palaeorecords of fire in the Earth System (climate or humans?); c) mechanisms and impacts of agricultural transitions. Recent and present-day practical aspects of Quaternary research were also emphasized by palaeoseismological contributions related to megacities and critical social infrastructures. A plenary lecture about living with the uncertainty about climate change and insurance was remarkable.

The general and practical subjects mentioned above were complemented by studies in selected key regions of the Earth for Quaternary research. Evolutionary, behavioral and cultural ecology of Plio-Pleistocene hominin populations in Africa and Asia was emphasized. Quaternary human, climate and ecosystem interactions in Africa were studied as well as East and Southeast Asian palaeoanthropological multidisciplinary records. Special attention was also given to a) palaeoenvironmental change and human response during the last 30,000 years in a corridor from the Western Mediterranean to the Caspian Sea, b) environmental and cultural dynamics in Western and Central Europe during the Upper Pleistocene, and c) climate, environment and economy in the North and Central European Neolithic. The Magdalenian period was highlighted from the point of view of human adaptations to the Late Last Glacial in Western and Central Europe. A lecture about the impacts of Quaternary sciences on the philosophy of radioactive waste disposal in Switzerland was also very topical.

5. Conclusions

Attention to both basic and applied aspects of Quaternary research is a very conspicuous methodological attribute of the presented results of the Czech participants at the XVIIIth INQUA Congress in Bern. It is strongly disirable to present central European Quaternary research in larger regional and/or global contexts. The presented papers contribute to regional and/or global correlations, which are very effective tools for progress in Quaternary science. Unfortunately, a comparison of a large spectrum of long-term Czech activities in Quaternary research with the modest Czech participation at the XVIIIth INQUA Congress gives evidence of economic limits to the participation of Czech scientists at important international meetings. On the other hand, the dominance of young specialists from the Czech palynological community, who successfully presented their results, incited very promising experience. The range and multidisciplinary spectrum of Quaternary research performed by the Czech specialists are undoubtedly significantly larger than could be exposed during the XVIIIth INQUA Congress in Bern. However, it is a sad reality that apart from Dr. Vlasta Jankovská no other representative of the INQUA Czech National Committee joined the meeting. Will this still unfavourable situation be improved in 2015, when the XIXth INQUA Congress will be held in Nagoya, Japan?

In Central Europe, including the Czech Republic, essential dating of palaeoenviromental records is a problem. Erosion has been dominating in most of the Czech Republic territory during the Quaternary. Major thicknesses of Quaternary deposits are preserved mainly in the Moravian basins developed along a large zone of the morphotectonic contact between the eastern margin of the Bohemian Massif and the Western Carpathians. Large bodies of fluvial deposits and loess/palaeosol sequences represent traditional subjects of regional palaeoenvironmental studies.

Recent glacial, fluvial and geomorphological studies in the Central European region have also improved knowledge of natural processes driven by Pleistocene cold oscillations. At present, palynology is the most advanced research topic focused on Late Quaternary natural archives represented mostly by peat and ox-bow lake deposits. However, traditional stratigraphical divisions based on mammal or mollusc palaeontology should be verified and advanced using modern dating techniques. Unfortunately, with the exception of magnetostratigraphical studies, only one radiocarbon laboratory using the conventional dating method is available in the Czech Republic. Development of OSL and U-series dating laboratories would be very helpful for progress in Quaternary palaeoenvironmental studies.

What is encouraging is the long-term international cooperation of Czech specialists in the framework of Quaternary research projects not only in the territory of Central Europe, but also in various environments of the Earth such as Antarctic and other polar regions, mountainous ranges of High Asia and the Andes or semi-arid and/or humid landscapes in Africa.

Acknowledgements

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RÉSUMÉ

Příspěvky českých účastníků na XVIII. kongresu INQUA v Bernu

Referativní práce se zabývá odborným podílem českých účastníků na XVIII. kongresu INQUA, který se konal ve dnech 20. 7. až 29. 7. 2011 v Bernu. Jsou uvedeny výsledky českých výzkumů předložené v 10 vybraných víceoborových sekcích, které byly zaměřeny na chronologii a kvartérní záznamy, pan-evropskou korelaci kvartérní stratigrafie, vývoj krajiny v kvartéru, pleistocénní zalednění Asie, paleohydrologické archivy ve fluviálních prostředích, příčiny a význam povodní a požárů v přírodním systému a historii Země, ekologické odezvy klimatických změn v měřítku desítek až tisíců let, rekonstrukce historických změn klimatu podle dokumentárních záznamů a na geoarcheologické aspekty vztahů mezi přírodním prostředím a člověkem. V diskuzi jsou komentovány hlavní tématické okruhy oborově integrovaných výzkumů kvartérního období: a) stratigrafie a chronologie kvartérních mořských a suchozemských sedimentů, procesů a událostí, b) klimatické změny v kvartéru a jejich paleoenvironmentální důsledky, c) historie člověka v kvartéru, d) identifikace klíčových oblastí Země pro výzkum kvartéru.

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COLOUR APPENDIX

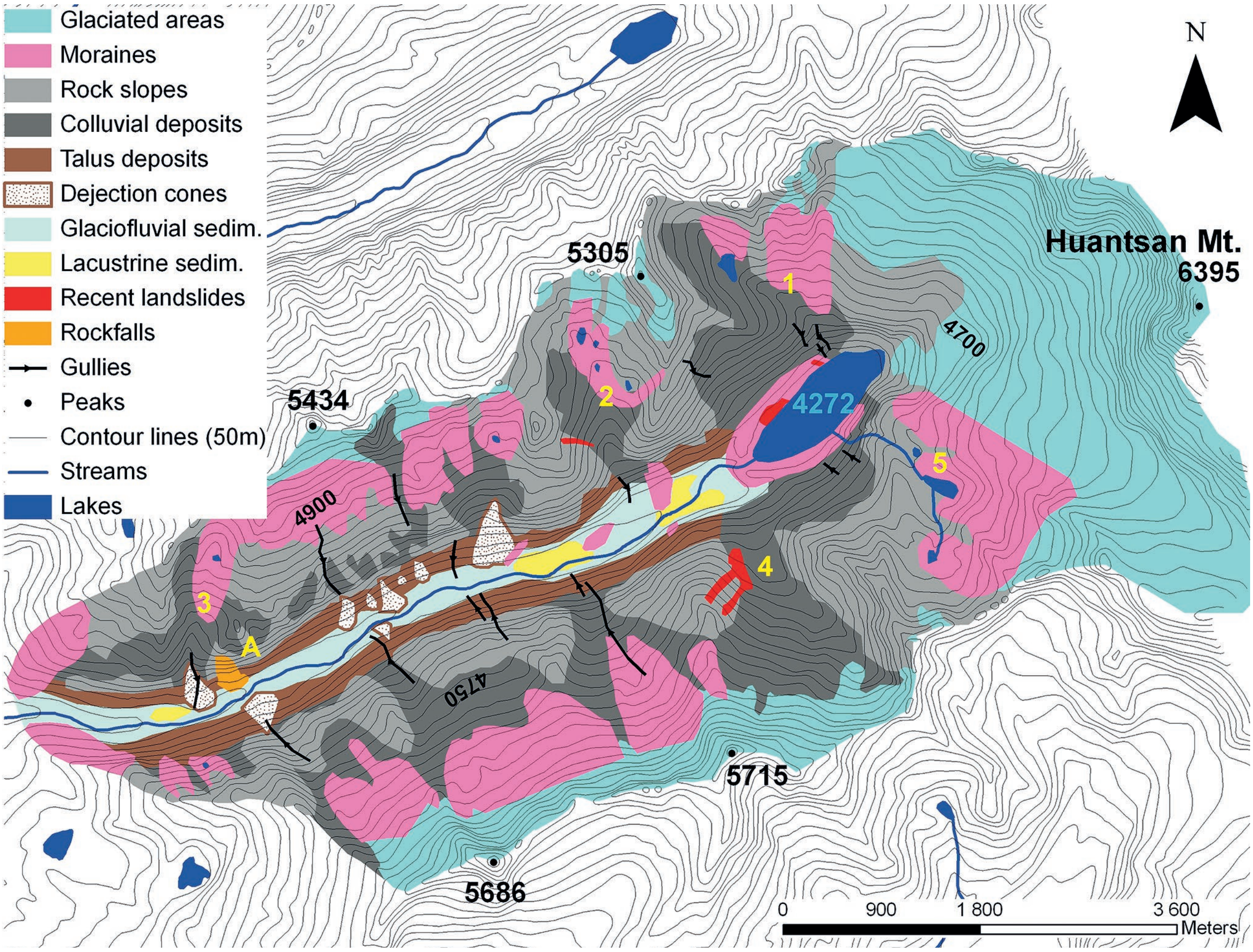

Fig. I Geomorphological map of the Rajucolta Valley. Yellow numbers indicate hanging valleys, light blue number shows water level of the lake, A – rockfall referred in the text

Fig. II Photo of the Uruashraju Lake taken from the moraine to the west. On the right site of the photo are visible debris flows source areas with accumulations

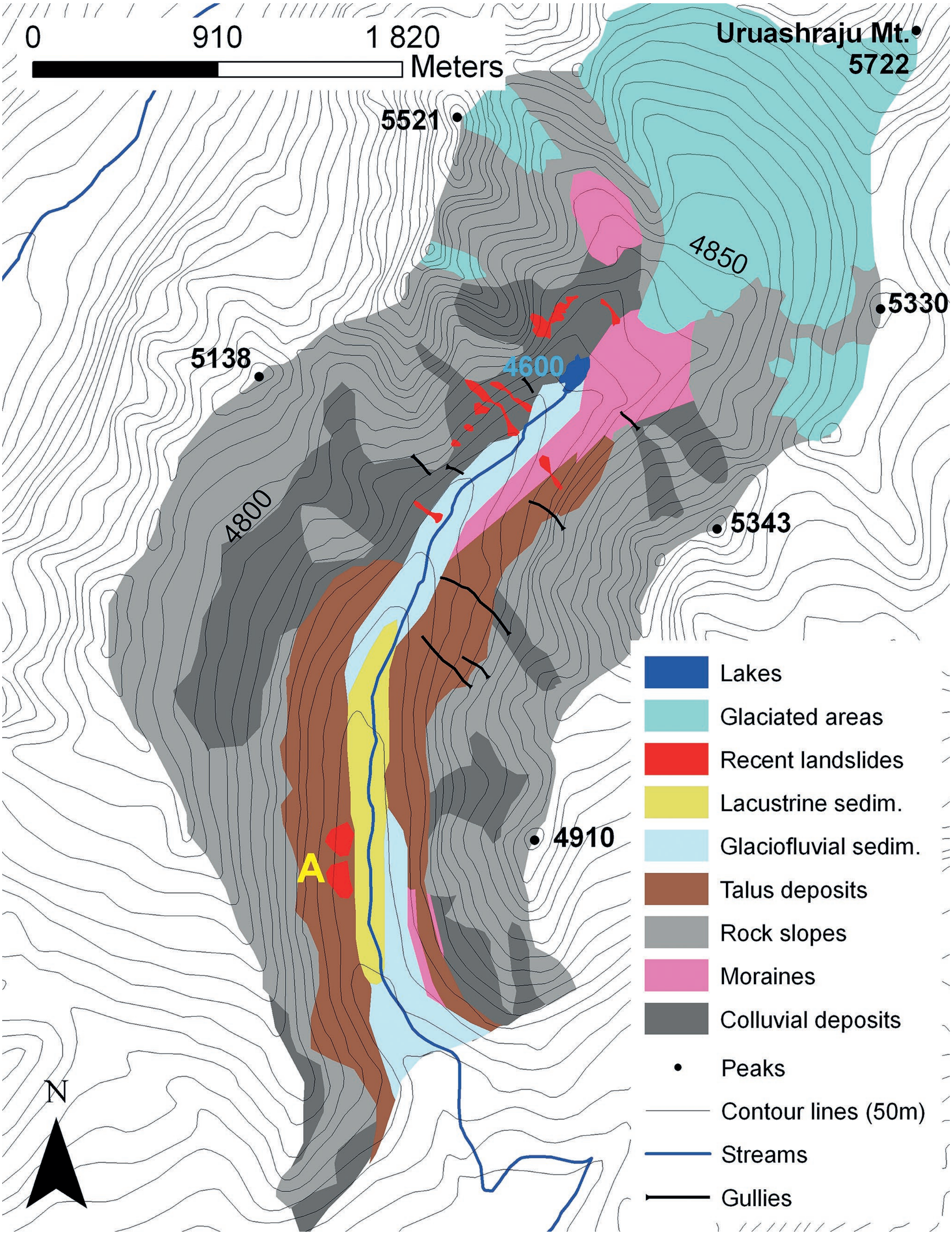

Fig III Geomorphological map of the Pumahuaganga Valley. Light blue number shows water level of the lake, A – rock slide accumulations

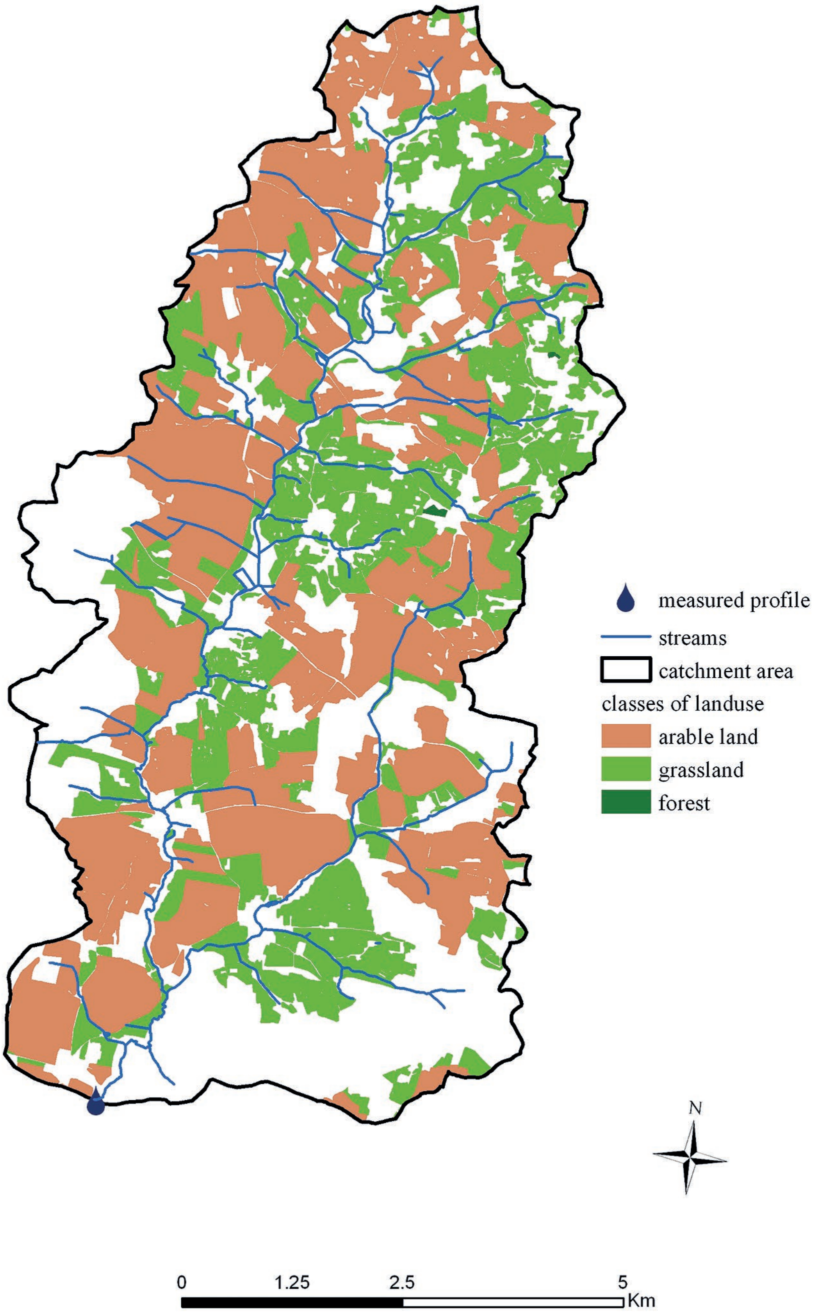

Fig. IV Representation of landuse in the catchment area – LPIS (Hrejkovický brook)

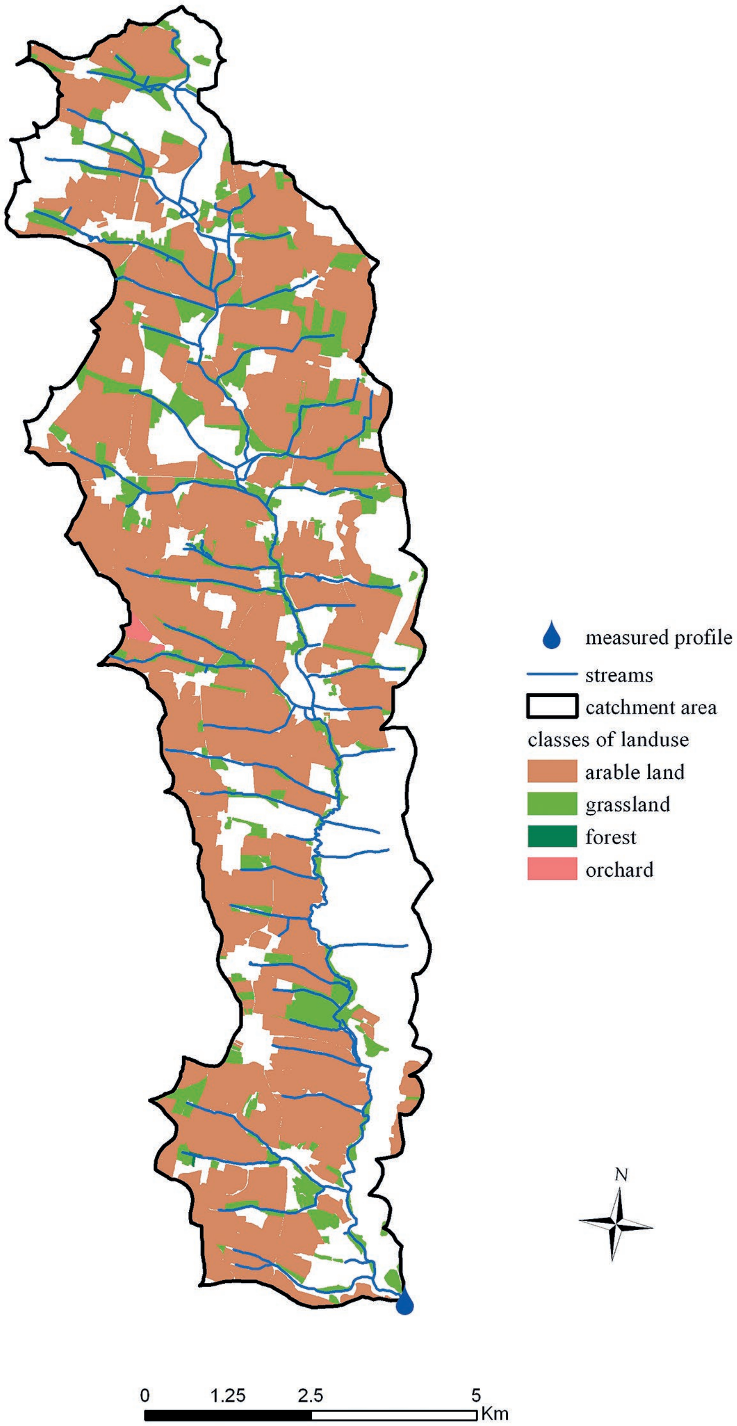

Fig. V Representation of landuse in the catchment area – LPIS (Bilinský brook)

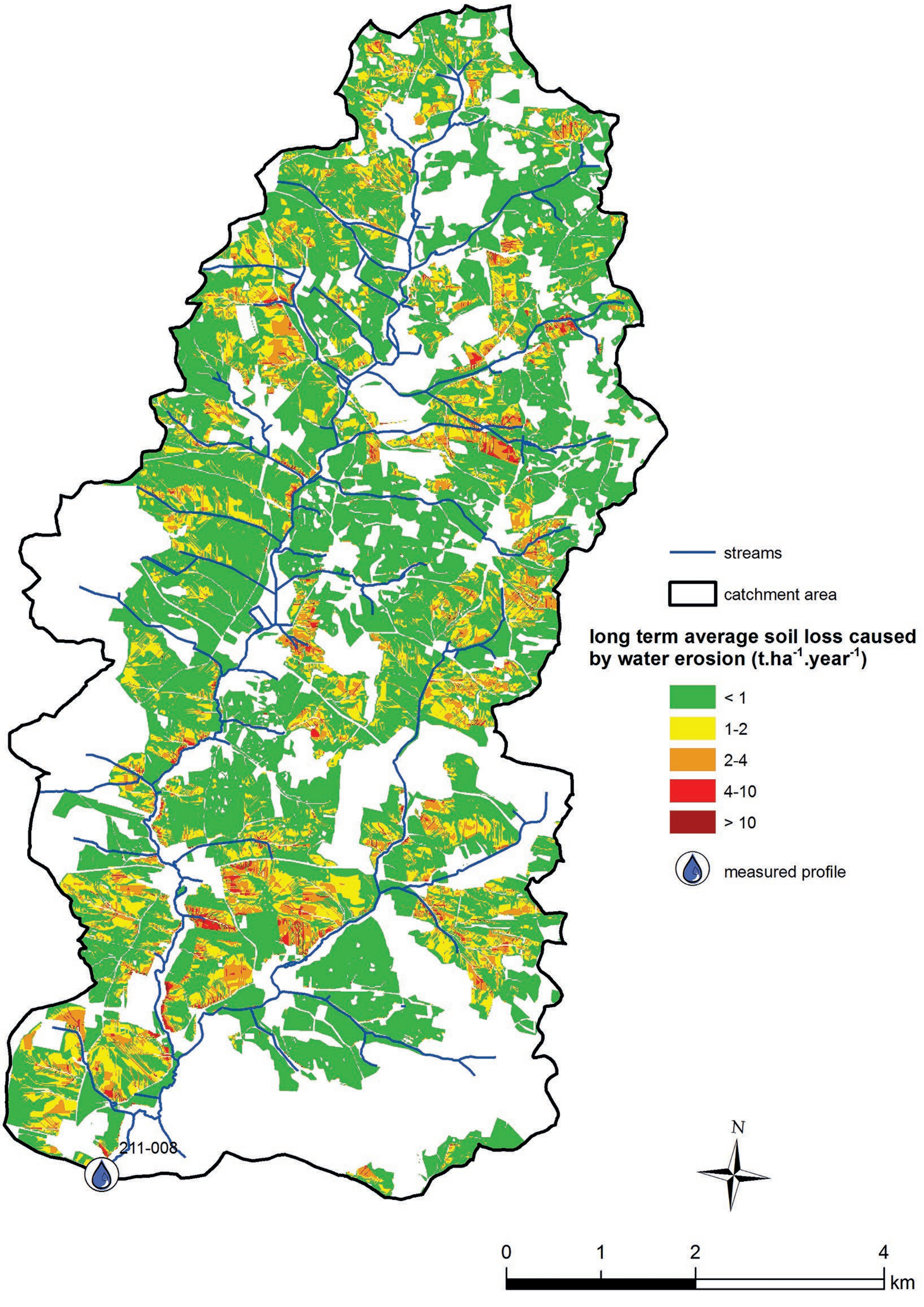

Fig. VI Long term average soil loss caused by water erosion (Hrejkovický brook)

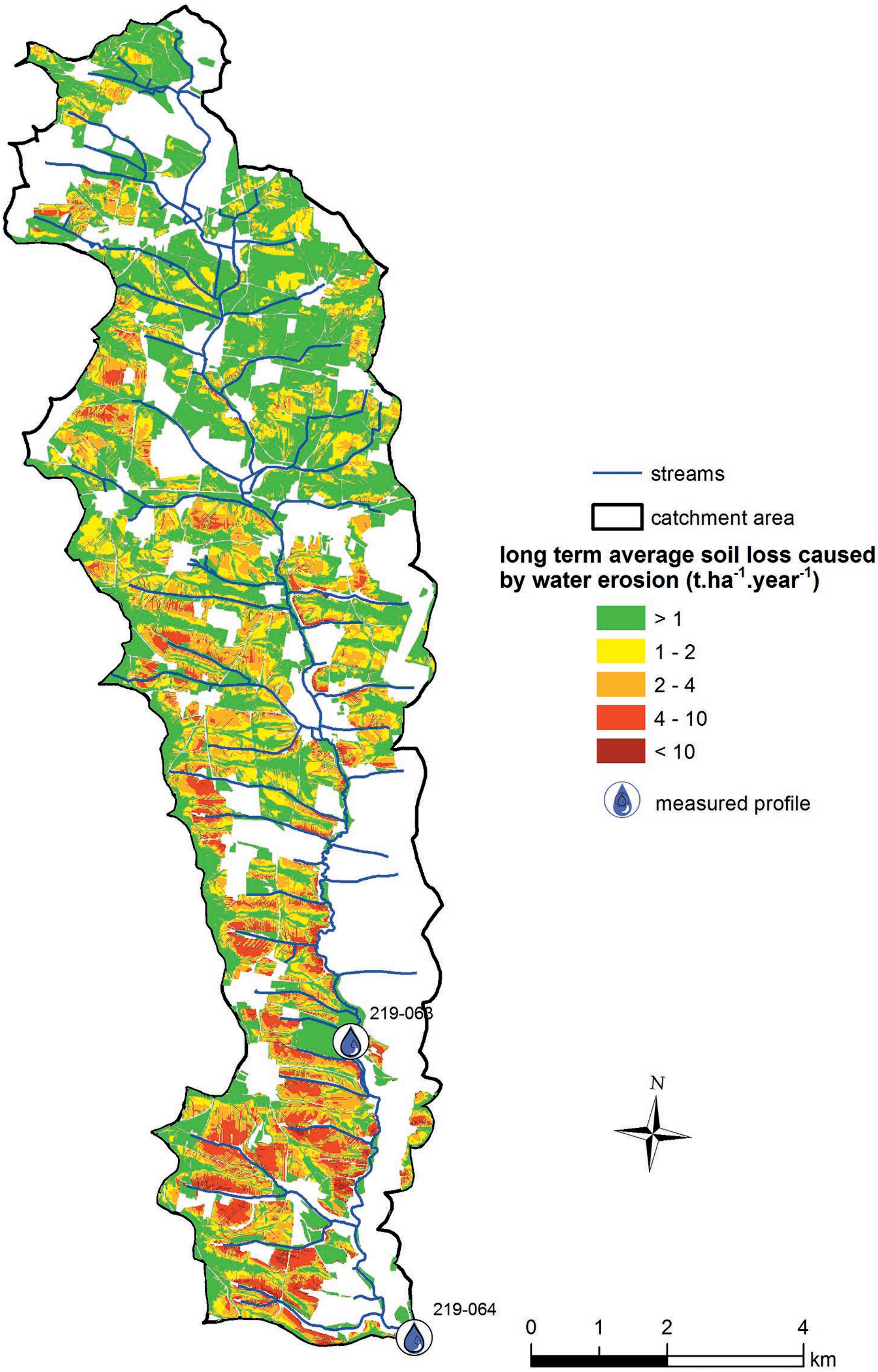

Fig. VII Long term average soil loss caused by water erosion (Bilinský brook)