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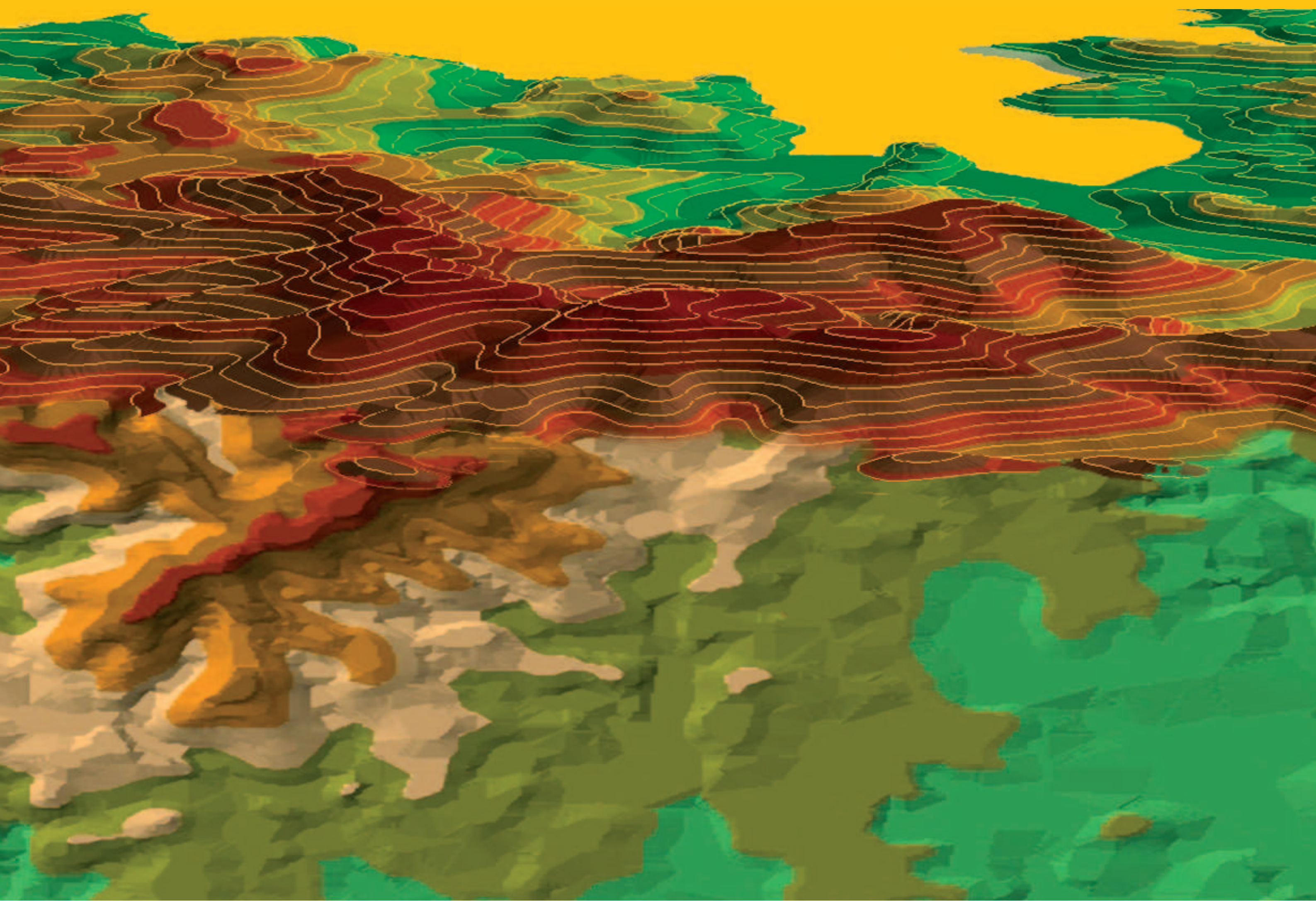

Fig. 2: Oblique aerial view of the meandering Morava River in the Protected Landscape Area Litovelské Pomoraví northeast from Olomouc (Photo: P. Holub)

Fig. 4: Natural fluvial development of the Morava riverbed in the National Nature Reserve Vrapač northwest from Litovel (Protected Landscape Area Litovelské Pomoraví) (Photo K. Poprach, http://naturephoto.tyto.cz/)

Illustrations related to the paper by. I. Machar et al.

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Articles:

Religion and gender inequality: The status of women in the societies of world religions

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Abstract

The status of women in society is very diverse worldwide. Among many important traits associated with the differentiation of gender inequality is religion, which itself must be regarded as a fluid concept with interpretations and practices 'embedded' and thus varying with respect to cultural and historical relations. Admitting the complexity of the issues, some religious norms and traditions can contribute to the formation of gender inequalities and to subordinate the role of women in society. Using an exploratory quantitative analysis, the influence of religiosity on gender inequality in social, economic and political spheres is examined. Three categories of states have emerged from the analysis: (a) states where the majority of inhabitants are without religious affiliation, which display the lowest levels of gender inequality; (b) Christian and Buddhist societies, with average levels of gender inequality; and (c) states with the highest levels of gender inequality across the observed variables, whose inhabitants adhere to Islam and Hinduism.

Keywords: *gender inequality, geography of religion, status of women, world religions*

1. Introduction

Gender inequality[1] belongs among the most prevalent forms of social inequality and exists all over the world, with different effects in different regions. These differences are primarily due to cultural legacies, historical development, geographic location, and, last but not least, the religious norms which predominate in society (Inglehart and Norris, 2003). Religion[2] plays a vital role in the cultural life of different spaces. It is deeply rooted in peoples' experiences and influences the socioeconomic and political direction of societies (Stump, 2008). On a similar note, Peach (2006) asserts that for social geographic investigation, religion may now be a more important variable than race or ethnicity.

The status of women in society is an outcome of the interpretation of religious texts and of the cultural and institutional set-up of religious communities (Klingorová, 2015). The role of religion is, obviously, complex and it varies across time and space. We accept the premise that everyone benefits from gender equality (Verveer, 2011). Throughout this research project, we approach the topic of gender equality from a "post-Christian" standpoint, a predominantly secular perspective. We consider gender equality and the emancipation of women as important factors for the economic, social, and democratic progress of the world's regions and for the development of human society. This process is influenced by institutional norms, as well as culture and tradition, which are both largely determined by religion. As the relationship between religion and culture is reciprocal, religious systems are locked in a circle of mutual influence with social norms and patterns of social organisation (Sinclair, 1986). It is apparent that the study of the status of women in religion also reflects the status of women in society as a whole (King, 1995), while considering the cultural, political and geographic factors.

Of course, at least two key questions remain to be asked: (1) *How significant is the influence of world religions on gender inequality and the social status of women?* Unlike previous studies, which predominantly focused on explanation using social surveys (e.g. Seguino, 2011), this research attempts to find answers through a statistical analysis of data reflecting the status of women in groups of selected states, organized by the predominance of world religions in their territory.

Every religion promotes somewhat different norms, creates different institutions, and builds on different cultural and historical foundations. The influence the individual world religions have on the status of women is very differentiated (Klingorová, 2013, 2015), and we should then ask: (2) *To what extent do religions determine the status of women and the level of gender inequality in the four largest religious societies studied at the level of states?*

Through an analysis of diversification of the selected religions, as part of this assumption, we would like to expand on the study by Seguino (2011), which primarily concerned itself with the influence of religiosity on gender inequality within a set of socioeconomic parameters of the selected states. Furthermore, we accept the statement that the level of gender inequality is also influenced by a state's level of economic development (Dollar and Gatti, 1999; Seguino, 2011), and this will be taken into account in the analyses.

This study attempts to contribute to the multidisciplinary debate on the influence of the four key world religions (and secularity) on gender inequality in 50 selected states. We

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[1] Gender inequalities can be defined as culturally and socially created differences between men and women when both sexes do not have the same share in the decision making and wealth of a society (Ridgeway, 2004).

[2] We understand religion as an ideology which affects the socio-political practices of a society and as a complex cultural system of meanings, symbols and behaviours in communities (Stump, 2008).

consider quantitative analysis to be a suitable method for analysing the influence of religiosity on the status of women at the level of national states, even if this method is not frequently used in feminist geographies (England, 2006). Furthermore, it seeks to contribute to the field of the new geography of religion (Kong, 2001), whose study of the world religions and gender equality is still in its early stages.

2. World religions, women and their social status

This article reflects the increasingly more lively debates on the relationship between religion (religiosity) and gender (Hopkins, 2009; Seguino, 2011; Moghadam, 1991; Chaudhuri, 2013). It builds primarily on theoretical concepts provided by feminist geographies and the geography of religion, both of which have recently increased their presence in the academic sphere (Massey, 1994; Rose, 1993; Havlíček and Hupková, 2008, 2013; Kong, 2001, 2010; Sharp, 2009; Del Casino, 2009). Furthermore, questions of gender continue to make their way into religious studies. A significant part of such recent research is based on the assumption that gender roles are primarily constructed through religion, culture, lifestyle and upbringing (King, 1995). The status of women within individual religions, most significantly in Islam, has become a research topic for a number of geographers (see Hopkins, 2009; Falah and Nagel 2005; Moghadam, 1991; Inglehart and Norris, 2003; Aitchison, 2007). Feminist geographies of religion (Hopkins, 2009) mostly focus on gender identities and gender relations in the context of religion. It is even possible to speak of the existence of a new paradigm in religious studies, which is tied to the entry of women researchers into the study of religions (Kong, 2010).

All world religions today maintain male social dominance within societal structures (Young, 1987). On the other hand, women are more inclined to participate in religious life (Hamplová, 2013, 2011; Renzetti and Curran, 1999). Empirical research on developments in the individual religions, especially in the case of Islam, indicate a negative shift in society towards a decreased status of women with the emergence of the so-called advanced religions (Holm, 1994; Krejčí, 2009). Also, religious norms and prejudices may reflect patriarchal values (Nešpor, 2008), which are characteristic of all societies of the world religions (Seguino, 2011). The role of God, or a creator of a religion, is always taken by a male and the woman is primarily valued as a mother, especially as a mother to a son. Her place is in the household, less so at religious ceremonies or in public positions. The real status of a woman in a religion is more complicated, however, as in some religions certain women have acquired significant posts (Holm, 1994).

In the histories of religions, the voice of women is rarely heard, due to the patriarchal dispositions of societies in which these religions emerged, and which eventually stifled some of the changes in the status of women triggered by these new religions. The world religions all agree on the respect for women and their crucial role in family life, especially with emphasis on women as mothers and wives. They do not, however, advocate emancipation in the sense of total equality with men. According to Holm (1994), the most severe restrictions apply to women during their periods of menstruation and pregnancy, when, for example, they cannot enter the temple or touch the Quran.

Male and female roles are therefore much differentiated and also unbalanced in the world religions. The influence of women on the formation of religious norms and traditions is small, even though in certain doctrines, we can find women who succeeded in having their normative views accepted, or men who advocated equal integration of women into religious ceremonies. It needs to be stated that there exists a certain discrepancy between normative conditionality, which refers to what the given religion proclaims (equality of men and women before God) and practical conditionality, which involves the role of women in religious communities and state societies in terms of everyday life (Holm, 1994). In addition, the heterogeneity of the global categories ('Islam', 'Hindu', etc.) must be emphasized, such that general conclusions must be tempered by admitting such variability in religious affiliation – otherwise we would tend to stereotype religious affilitation, which is certainly not intended here.

3. Methodology and data

3.1 Data used in the analysis

The quantitative analysis aims to explore the extent of the influence of selected world religions on the indicators of gender inequality and the social status of women. States with a majority share of inhabitants without religious affiliation[3] have also been included for comparison.

Overall, 50 'states' have been chosen as the cases for this analysis. The selection criterion was religiosity. States with the highest share of religious (self-identified) people in the world were selected, as well as states with the highest share of people "without religious affiliation" (Zuckerman, 2007, who takes into account so-called 'lived religiosity'). These include 30 states in which one of three the most common religions (Christianity, Buddhism, Islam – ten of each) are dominant. Note that differences between Christian denominations have not been given attention in this analysis. Furthermore, the dataset includes ten federal states of India with the highest share of adherents to Hinduism, since no nation states (aside from India, Nepal, and Mauritius) have a high enough percentage of adherents to Hinduism to lend themselves to meaningful analysis. Therefore, the article uses the ten federal states of India which fulfil this requirement. All federal states of India have their own government, yet remain part of the State of India and defer to its legislature. They cannot be considered as fully independent in all areas, which must be kept in mind when interpreting the results.

States from each religious group (Christian, Buddhist, Muslim and Hindu states) have the first to the tenth highest share of the religion's believers in the world. This method allows the possibility of finding a relationship between religiosity and indicators of gender inequality at the state level. Of course, the results cannot be generalized to the entire societies of selected states. Similarly, ten states with the highest share of inhabitants who declare themselves as without religious affiliation were selected (Zuckerman, 2007). Vietnam was excluded from the analysis and replaced with Belgium since Vietnam is not a democratic country, which may affect official statistics. This method of selecting the units of analysis allows for a

[3] This term applies to persons indifferent to organised religion or even rejecting religion in general, who can subscribe to some other philosophical attitude (e.g. agnosticism, atheism, laicism, etc.): see Zuckerman (2007).

comparison of predominantly religious and non-religious states. Furthermore, the analysis has been limited to states exceeding 100,000 inhabitants, in order to secure a possibly higher informative value of the results.

The statistical analysis uses a set of variables reflecting the state of gender inequality in social (sex ratio, literacy, and tertiary education), political (share of women in parliament) and economic (women in the labour force) spheres, as well as a complementary variable expressing the share of inhabitants adhering to the specified religion and the Gender Inequality Index. The following factors are used in the analysis:

- *'Adherents'* (adherents) signifies the share of the inhabitants following the dominant religion, or the share of inhabitants without religious affiliation;
- *'Sex ratio'* (sex ratio): On average, men slightly outnumber women in the world (World Factbook, 2013). One of the principal reasons for this occurrence can be traced back to culturally determined social norms in predominantly Muslim and Hindu areas, where the life of male offspring is considered more valuable. On the opposite side of the spectrum, women outnumber men in secular and Western Christian states (Huntington, 1996), because no gender is preferred by social norms or state policy. For this reason, we consider a higher share of women in society to be a sign of greater gender equality;
- *'Difference in male and female literacy'* (literacy): The ability to read and write improves women's lives and allows them to more actively participate in the economic sphere. Better-educated women are also more likely to take part in public life and the economic development of their state. Women have a better status in societies which grant them equal access to education with men. Literacy makes women overall less dependent on men and gives them enhanced freedom;
- *'The share of women enrolled in universities'* (university): The chance to pursue higher education helps women to achieve economic independence and is indicative of an equal access to education in general. Women educated at universities are more than able to fulfil leadership roles, be they managerial, educational or governmental. In the developed countries, more women tend to attend university programs than men (United Nations Statistics Division, 2011);
- *'The share of women in parliament'* (parliament): Women parliamentarians can have a direct influence of political decision making within a state. A higher share of women in parliament is indicative of a society that is mature and in favour of gender parity, and has dealt with the kinds of prejudice which would see only men as capable of holding political office (and other positions of leadership);
- *'Percentage of women in the adult labour force'* (labour force): The higher the percentage of women in the adult labour force, the more independence women have to conduct their economic affairs and to contribute to the development of their countries;
- *'Gender Inequality Index'* (GII) directly provides a measure of the given state's level of gender equality. This index has been selected because it is one of the most commonly-used indicators of the status of women and addresses gender inequality in the economic, the political, and also the social sphere (Chaudhuri, 2013). It values range from 1 and 0, where 0 represents the ideal type of absolute equality, whereas close proximity to 1 indicates severe inequality. The index is composed from three key factors: fertility, women's share of power, and women's share of the labour market. The index represents the extent to which a state's progress, in terms of human development, is disrupted by gender inequality (United Nations Development Programme, 2013). We are aware of the criticism of this measure on conceptual grounds, however; and
- *'Gross Domestic Product per capita'* (GDP) expresses the economic power of a state's economy, which needs to be considered throughout the analysis of gender inequality. The level of economic development is at least as important in determining gender inequality in society as levels of religiosity (Seguino, 2011); however, this paper is focused on religiosity as a factor determining gender relations in selected states. The influence of economic development is included in the analysis.

The factors used in the analysis are summarised in Table 1.

3.2 Methodology

The method chosen for this analysis is simple correlation (Pearson's r), to examine whether religiosity affects the status of women in society and gender inequality, as reflected in the relations between the chosen variables. A correlation analysis was carried out for religiosity in a state, regardless of the specific religions, and the variables of gender inequality in selected social spheres. For the Pearson's correlation coefficient, values of r are tested at a significance level of $p < 0.01$. All calculations were carried out using SPSS.

In the evaluation of the results, it is necessary to keep in mind some of the limitations of Pearson's correlation coefficient, such as its susceptibility to distortion by outlying values. A certain degree of autocorrelation must be expected in the data, since it includes 50 geographically unevenly distributed states.

4. Outputs of the statistical analysis and their discussion

4.1 Correlation analysis

As outlined above, some authors (e.g. King, 1995; Krejčí, 2009; Seguino, 2011) associate religiosity with gender inequality in most aspects of social, political, and even religious life. "Religious people are more intolerant and have more conservative views of the role of women in society" according to Guiso, Sapienzad and Zingales (2003, p. 280). Religiously-minded people also tend to patriarchy. Of course, this statement does not apply to all religions to the same extent (Klingorová, 2013), nor does it uniformly apply to all believers. Generally speaking, however, it can be asserted that adherents to the world religions display more conservative and more patriarchal attitudes towards women and their role in society (Seguino, 2011; Guiso, Sapienzad and Zingales, 2003; Dollar and Gatti, 1999). The aforementioned studies indicate that religious women are less publically and economically active. This study endeavours to test this assertion by correlation analysis of empirical data.

The analysis correlated the variables representing gender equality with religiosity, which represents the intensity of the country's religious life, while controlling for GDP per capita. The influence of economic development on gender inequality was therefore controlled statistically and the results indicate the relation between religiosity and gender inequality factors given such adjustments. The greatest emphasis needs to be put on the relationship

Variable	Description	Mean	S.D.	Min.	Max.	Period	Source
Adherents	Percentage of adherents/non religious people	83	19	42	100	2001–2013	World Factbook, 2013; Zuckerman, 2007; Census of India, 2001
Sex ratio	Share of men and women	1.001	0.060	0.840	1.210	2011–2013	World Factbook, 2013; Census of India, 2011
Literacy	Difference between literacy of men and women	8	10	− 26	31	2011–2013	World Factbook, 2013; Census of India, 2011
University	Percentage of women at university	48	10	18	65	2011	UN Statistics Division, 2011
Parliament	Share of women in parliament	0.237	0.200	0.000	0.808	2012	Inter-Parliamentary Union, 2012; Women in Indian Parliaments, 2013
Labour force	Percentage of women in adult labour force	37	10	15	50	2001–2011	International Labour Office, 2011; Census of India, 2011
GII	Gender Inequality Index	0.401	0.212	0.049	0.707	2013	UN Development Programme, 2013
GDP	Gross Domestic Product per capita in USD	31,529	16,499	1,000	60,900	2011–2013	World Factbook, 2013; UN Development Programme, 2013

Tab. 1: Summary of the variables used in the statistical analyses. Source: authors
Note: the values of the variables adherents, literacy, labour force are measured in %. GII values range from 1 and 0, where 0 represents the ideal type of absolute equality. The index comprises three key factors: fertility, women's share of power, and women's share of the labour market. From the variable adherents is calculated the variable religiosity, used for correlation analysis. The GII and university values of the federal states of India are represented by an average value for all of India

		Correlations					
		Sex ratio	Literacy	University	Parliament	Labour force	GII
Religiosity	*Pearson Correlation*	.251**	.465**	− .315**	− .634**	− .678**	.794**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	759,706	759,706	721,206	718,532	721,206	702,806
Sex ratio	*Pearson Correlation*		.380**	− .330**	− .295**	− .638**	.477**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
	N		759,706	721,206	718,532	721,206	702,806
Literacy	*Pearson Correlation*			− .415**	-.250**	− .585**	.540**
	Sig. (2-tailed)			0.000	0.000	0.000	0.000
	N			721,206	718,532	721,206	702,806
University	*Pearson Correlation*				.444**	.301**	− .337**
	Sig. (2-tailed)				0.000	0.000	0.000
	N				718,532	721,206	702,806
Parliament	*Pearson Correlation*					.527**	− .669**
	Sig. (2-tailed)					0.000	0.000
	N					718,532	700,132
Labour force	*Pearson Correlation*						− .729**
	Sig. (2-tailed)						0.000
	N						702,806

Tab. 2: Correlation analysis weighted by GDP per capita.
Sources: Adherents, 2013; Zuckerman, 2007; Census of India, 2011, 2001, 1991; World Factbook, 2013; Inter-Parliamentary Union, 2012; International Labour Office, 2011; United Nations Development Programme, 2013; United Nations Statistics Division, 2011; Women in Indian Parliaments, 2013. Processed by the SPSS software.
*Note: N represents the amount of values. A correlation coefficient (r) of 0–0.3 is considered weak correlation, a value of 0.3–0.6 represents an average correlation and strong correlation is attributed to the values of 0.6–1. The analysis is weighted by the GDP per capita; ** Correlation is significant at the level $P < 0.01$.*

between religiosity and the Gender Inequality Index. The table of correlations (Tab. 2) indicates that the religiosity variable has an average correlation with all of the included variables, with the exception of sex ratio (with which it correlates weakly), and it is strongly correlated with the GII (r = 0.794), parliament (r = 0.634) and labour force (r = 0.678) variables. All r-values are significant at $p < 0.01$.

It can be asserted that the religiosity of a state is statistically significantly related to the selected variables of gender inequality (with Sig. values lower than 0.01; the selected level of probability). The strong correlation between religiosity and GII (r = 0.794) can be generally stated as follows: the level of gender equality has an overlap of 79% with the trend in religiosity, almost the same as with the share of women in parliament and with the share of women in the labour force. It is a positive correlation, so that gender inequality is higher in the selected states with higher religiosity. The argument, that religiosity increases gender inequality in society (Seguino, 2011), can be therefore confirmed. The intensity of religious life within selected states thus seems to have a significant impact on the level of gender inequality in their society in social and, most significantly, in political and economic ways. Nevertheless, this correlation could be largely fuelled the very high values of religiosity in many Muslim states and their corresponding high levels of gender inequality.

4.2 Comparison of the status of women in the selected religions

Through the statistical analysis, we have confirmed that religion has a significant impact on the status of women in society (Tab. 2). The analysis does not, however, allow us to identify in which religious groups the levels of gender inequality are the highest or lowest, or what the situation is in the individual selected states.

On the basis of an Analysis of Variance between the groups of states by religion (Klingorová, 2013: testing for mean differences) and the different norms and traditions in selected religions (Klingorová, 2015), it can be stated that the influence of selected religions on gender inequality in society is quite differentiated. This proposition is examined further here by an analysis of variables expressing different aspects of gender

State	Adherents	Sex ratio	Literacy	University	Parliament	Labour force	GII	
Non-religious								
Czechia	58%	0.950	0.00	56	0.282	43	0.136	
Belgium	43%	0.960	0.00	55	0.653	45	0.068	
Denmark	62%	0.970	0.00	58	0.642	47	0.060	
Estonia	49%	0.840	0.00	62	0.263	50	0.194	
Finland	44%	0.960	0.00	54	0.739	48	0.075	
France	49%	0.960	0.00	55	0.367	47	0.106	
South Korea	46%	1.000	2.40	39	0.186	41	0.111	
Germany	45%	0.970	0.00	50	0.490	46	0.085	
Norway	52%	0.980	0.00	61	0.657	47	0.075	
Sweden	66%	0.980	0.00	59	0.808	47	0.049	
Mean		*0.957*	*0.24*	*55*	*0.509*	*46*	*0.096*	
Order		*1*	*1*	*1*	*1*	*1*	*1*	*1.00*
Christianity								
Armenia	98%	0.890	0.30	56	0.120	46	0.343	
Honduras	97%	1.010	– 0.40	60	0.243	34	0.511	
Malta	98%	0.990	– 2.20	56	0.095	35	0.272	
Moldova	98%	0.940	0.90	56	0.247	49	0.298	
Papua New Guinea	96%	1.050	12.50	35	0.028	48	0.674	
Romania	99%	0.950	1.20	56	0.154	45	0.333	
Greece	98%	0.960	3.60	50	0.266	42	0.162	
Samoa	84%	1.050	– 0.10	44	0.043	34	-	
Venezuela	98%	0.980	0.60	62	0.204	40	0.447	
East Timor	98%	1.030	16.00	40	0.625	33	-	
Mean		*0.985*	*3.24*	*52*	*0.202*	*41*	*0.380*	
Order		*2*	*3*	*2*	*3*	*3*	*3*	*2.67*

Tab. 3: Analysis of the differences in the status of women between groups of states organised by religion
Sources: Adherents, 2013; Zuckerman, 2007; Census of India, 2011, 2001, 1991; World Factbook, 2013; Inter-Parliamentary Union, 2012; International Labour Office, 2011; United Nations Development Programme, 2013; United Nations Statistics Division, 2011; Women in Indian Parliaments, 2013
Note: States are organised into groups according to their predominant religion. The analysed variables are averaged for each group and subsequently compared. The average rank in all variables (at the right side of the table) serves as the output of this process; "-" Data not available

State	Adherents	Sex ratio	Literacy	University	Parliament	Labour force	GII	
Buddhism								
Myanmar	89%	0.990	– 7.50	58	0.064	49	-	
Bhutan	75%	1.100	– 26.00	40	0.093	42	0.495	
Japan	71%	0.940	0.00	46	0.086	42	0.123	
Cambodia	96%	0.940	20.60	34	0.255	50	0.500	
Laos	67%	0.980	20.00	43	0.333	50	0.513	
Mongolia	50%	1.000	– 1.00	60	0.175	46	0.410	
Singapore	42%	1.070	8.00	50	0.320	42	0.086	
Sri Lanka	69%	0.960	2.60	65	0.061	32	0.419	
Tchaj-wan	93%	1.010	4.40	-	-	-	-	
Thailand	94%	0.980	2.80	56	0.188	46	0.382	
Mean		*0.997*	*2.39*	*50*	*0.175*	*44*	*0.366*	
Order		*3*	*2*	*3*	*4*	*2*	*2*	*2.67*
Hinduism								
Andhra Pradesh	89%	1.008	15.82	40	0.122	38	0.617	
Chhattisgarh	94%	1.009	20.86	40	0.122	43	0.617	
Gujarat	89%	1.082	16.50	40	0.088	32	0.617	
Haryana	88%	1.123	18.61	40	0.111	32	0.617	
Himachal Pradesh	95%	1.026	14.23	40	0.044	44	0.617	
Madhya Pradesh	91%	1.070	20.51	40	-	37	0.617	
Rajasthan	88%	1.074	27.85	40	0.145	38	0.617	
Tamil Nadu	88%	1.010	12.95	40	0.060	35	0.617	
Tripura	85%	1.040	9.00	40	0.050	28	0.617	
Odisha	94%	1.022	18.04	40	0.034	31	0.617	
Mean		*1.046*	*17.44*	*40*	*0.086*	*36*	*0.617*	
Order		*5*	*5*	*5*	*5*	*4*	*5*	*4.83*
Islam								
Afghanistan	99%	1.030	30.50	18	0.383	15	0.707	
Algeria	99%	1.010	19.50	58	0.462	17	0.412	
Iraq	97%	1.030	15.40	36	0.337	18	0.579	
Iran	98%	1.030	13.10	49	0.032	18	0.485	
Comoros	98%	0.940	10.50	42	0.031	30	-	
Morocco	99%	0.970	25.00	47	0.204	27	0.543	
Mauritania	100%	0.930	13.70	28	0.284	27	0.605	
Saudi Arabia	100%	1.210	9.10	52	0.000	15	0.646	
Tunisia	98%	0.990	18.10	60	0.365	27	0.293	
Turkey	99%	1.020	15.70	44	0.165	29	0.443	
Mean		*1.016*	*17.06*	*43*	*0.226*	*22*	*0.524*	
Order		*4*	*4*	*4*	*2*	*5*	*4*	*3.83*

Tab. 3 continuing

inequality in selected states. We compared states belonging to the five groups organised by predominant religious affiliations: see Table 3. A state that is 'ideal' in terms of gender equality should have: a higher ratio of women to men; women enjoy equal levels of literacy; a high share of women attends universities; a high share of women participates in parliament; and a high share engages in economic activity. Such a state is also expected to score favourably in the GII.

The religious groups of states were classified according to the average rank of their mean values across all variables (in Table 3). The final ranking is as follows: without religious affiliation (mean value of 1), Christianity and Buddhism (each 2.67), Islam (3.83), Hinduism (4.83). Three distinct categories emerge from this comparison: (a) a group of states without religious affiliation, with the first ranked value in all of the studied variables; (b) a second group comprising Christian and Buddhist states with average values; and (c) the third group which includes Muslim and Hindu states with very high measures of gender inequality in the observed social parameters.

There is a clear distinction between the states with the majority of inhabitants without religious affiliation (mean = 1) and the states dominated by Christianity (2.67) and Buddhism (2.67). These states have the most favourable means of all of the studied variables with respect to gender equality. One only needs to take into account their average GII value of 0.096 (when compared to the world average of 0.492, United Nations Development Program, 2013) to recognise that the society in these states is the most equal. This is largely due to the presence of some states which have some of the world's lowest values of the GII: Sweden, the world's lowest value (GII = 0.049), and Denmark, which ranks third (GII = 0.060) (United Nations Development Programme, 2013). The level of economic development was not included in this secondary analysis, which may influence the results, in particular within this first group of states.

The world's Buddhist states occupy the second position together with the group of Christian states. They had the largest share of economically active women (50% in Cambodia and Laos), and the second lowest discrepancy betwen male and female literacy (2.39%). Since they reach second position in the GII variable (0.366), which is considered as most significant for the study of gender inequality in society, we place them at the second place overall. The possible explanation is that Buddhist tradition seems to afford equality to women (Cabezón, 1992), traditionally. On the other hand, they have only the fourth highest share of women in parliament (0.175). It appears that political participation of women is not very significant in this group of Buddhist states (lowest in Sri Lanka at 0.061 and Burma at 0.064). Economic participation and membership in parliament are two important components comprising the GII (United Nations Development Program, 2013). In this case, one of these indicators improves the GII score of the Buddhist states, while the other does the opposite. The GII of the Buddhist states therefore probably supersedes the result of the Christian states because of significantly higher female labour participation.

The Christian states scored second in the sex ratio and university indicators. They register as third in literacy, parliament, labour force and GII. The Christian group of states has a slightly higher value of the index of gender inequality, but this difference is very marginal (0.014). With emphasis placed on this important indicator, which most comprehensively evaluates the state of gender inequality, we place the group of Christian states in the third place behind Buddhist states (their statistics are adversely affected by the presence of the states of Papua New Guinea, GII = 0.674 and Honduras, GII = 0.511). In the Christian states, in contrast to their Buddhist counterparts, women are less likely to work (as part of the labour force) but more likely to participate in political decisions. Generally, Christianity does not tend to be profoundly discriminating against women. The Christian view of women is based on varying interpretations of Biblical sources (see Drury, 1994; Bilezikian, 2006); nevertheless, it is not uncommon within Christianity to find stereotypical expectations of gender roles.

The Muslim states have a high share of women in their respective parliaments (0.226), which bring them to second place on this characteristic, even though their differences in rank compared to the Christian and the Buddhist states are small. Considering the generally complicated public presence of women in many Muslim states (Nasir, 2009; Knotková-Čapková, 2008), it was expected their participation in politics would reflect that. Levels of discrimination vary across the Muslim countries (Moghadam, 1991), however, and the selected Muslim states are relatively modernised in this respect, so women can often effectively participate in public life (especially in Algeria and Tunisia). It is also necessary to evaluate the real political power of these women. In this group of states, women have the worst status attributed to them in the area of labour participation. The smallest share of women economically active is found in Afghanistan (15% of women), Saudi Arabia (15%), and Algeria (17%), therefore geographic differentiation is obvious in Muslim states in the role of women in society.

According to the available data for the selected states, the status of women seems to be problematic in the world of Hinduism (see more in Sugirtharajah, 1994; Chaudhuri, 2013). Yet, their engagement in the labour market is better than in the case of the Muslim states (women take up 36% of the labour force, compared to 22% in the group of selected Muslim states). Hinduism prohibits a woman's economic independence (Sugirtharajah, 1994), which is probably the cause of the highest levels of inequality between genders. These data may be determined by the fact that all of the analysed Hindu federal states are affected by the policies of one federal government. They have similar cultural, political and economic points of departure, and the data for GII and university do not offer information pertinent to the individual federal states. These statistics are also considerably affected by the low level of overall economic development of the Indian states.

On the basis of this analysis, we can assert that there is the highest level of gender equality based on GII and other selected variables in selected states without a dominant religious affiliation, followed by Buddhist and Christian, and finally Muslim and Hindu states. In order to validate these findings, further research is necessary. Such research would more thoroughly differentiate the state of gender inequality within and across the world religions, and would likely be more qualitative in nature.

5. Conclusions

Religious studies tends to be a rather androcentric discipline and in both geography and the sociology of religion, women as researchers and subjects of research had long been in the minority up until the last couple of decades (King, 1995), even though Hopkins (2009) tried to open up the discussion about feminist geographies of religion. Yet, it represents a creative and stimulating research approach in the social sciences, and its neglect is tied with the status of women in religious norms and traditions as much as in society in general.

Within this selected sample of 50 world states, the study tried to confirm that religion significantly affects the status of women and the state of gender inequality, since it seeks to regulate the role of women in certain aspects of social and political life in a given society. The analysis confirmed the relation between religiosity and gender inequality factors, while the strong influence of economic development on gender inequality was controlled statistically. We have tested this proposition through the use of a correlation analysis of variables representing gender inequality in selected states: the results indicate that gender inequality is higher in those selected states with a higher religiosity. A strong correlation exists between religiosity and the Gender Inequality Index (r = 0.794) for the 50 selected states. We are aware of possible errors in this analysis, as the influence of education, age, income, etc. have not been included; however, the influence of economic development (Seguino, 2011) was incorporated into the analysis.

The relation between religion and gender equality can be explained by the assertion that societies with higher religiosity accept the authority of religious teachers, who advocate a patriarchal organisation of society (Norris and Inglehart, 2004). We assume that those women who adhere to the dominant religions, might also not be inclined to take part in their society's public life, due to their upbringing and the social traditions surrounding them. Nevertheless, many religious institutions are always helpful for women in economic and social distress.

Higher levels of religiosity in these selected states tend to magnify gender inequality; however, every religious doctrine has a slightly different attitude towards the public participation of women, which we have, contrary to Seguino's polemics (2011) and in accordance with Dollar and Gatti (1999), discussed the selected world religions by an analytical application. In terms of the individual religious traditions and their contribution to gender inequality, three categories of states have emerged from the analysis: (a) states where the majority of inhabitants is without religious affiliation, which display the lowest levels of gender inequality across the observed variables; (b) Christian and Buddhist states with average levels of gender inequality; and (c) states with the highest levels of gender inequality across the observed variables, whose inhabitants adhere to Islam and Hinduism, respectively.

Simultaneously, we have confirmed that the most visible women's public presence can be found in the selected states where the majority of inhabitants are the most secular. In these societies, patriarchal religious traditions, which predominate within the states with higher religiosity, do not seem to be well engrained. Buddhist states selected for the analysis exhibit a higher involvement of women in economic life, with small differences between men and women in literacy and education. The Buddhist society seems to be more equal in terms of gender than the Christian, Muslim, and Hindu societies (Cabezón, 1992; Gross, 1994). Christian structures betray a traditional patriarchal system, which has not been sufficiently disrupted even by feminist critique, and women participate in public life tangibly less than men (Drury, 1994). Fewer gender inequalities have been identified within the Muslim states than those adhering to Hinduism. The selected Muslim states have higher shares of women in parliament and provide women with better access to education. Hinduism's traditional disavowal of women's economic independence (Sugirtharajah, 1994) might be a significant factor affecting their status in society. In contemporary democratic India, as in most of other selected states, the equality of men and women has been normatively included in the country's legislation. Traditions and customs, however, are still powerfully entrenched in society and may represent obstacles to practical implementation of these norms.

Following these analytical procedures, we believe that we have answered the two key questions raised at the outset in the Introduction, in an affirmative manner. Even so, we do acknowledge that the situation we have examined is extremely complex, such that these conclusions should be taken in the exploratory manner in which they have been presented.

If we take into consideration the strengthening modernisation and liberalisation of the world as part of the processes of globalisation and their associated "westernisation" (Gunewardene, Huon and Zheng, 2001), it can be expected that religious societies will eventually become more accommodating to gender equality, because traditional patriarchal structures will start to wane. Despite this, women should take more interest in religious doctrines and participate in the formulation of new interpretations. Under such influences, religious institutions might undergo reforms more favourable to gender equality (Gross, 1994). Muslim and Hindu societies are expected to undergo the most significant changes in order to achieve this. But changes can occur in the opposite direction as well, due to the rise of religious fundamentalism and post-secularism (Sturm, 2013). Even in the more liberal Christian and Buddhist societies, progress towards absolute gender equality has not reached its final destination. Civil societies and governments should support gender equality and economic emancipation, provide equal access to education, and strive for an increased participation of women in politics. This might strengthen democratic principles in relation to gender equality, to the benefit of society as a whole.

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Merging diaries and GPS records: The method of data collection for spatio-temporal research

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Abstract

The results of a 'proof-of-concept' study that examined a new opportunity for using GPS technology in activity surveys are presented in this article. The aim is to demonstrate the method of collection and processing of individual time-space data via the dual records of a time-space diary and the GPS locator. The GPS technology here is not treated as a substitute for the traditional method of diaries; rather, the paper concentrates on the potential existing in a combination of these two techniques. The time-geographical approach and the corresponding methodology are used in order to assess the complexities of an individual's everyday life, and to capture the spectrum of human activities in a data frame applicable to different analyses in behavioural, social and transportation research. This method not only improves the quality and robustness of spatio-temporal data, but also reduces under-reporting and the burdens on the respondents.

Key words: *time geography, GPS, time-space diary, survey method development*

1. Introduction

The necessity to capture an individual's behaviour in time and in space is a natural and inherent effort of geographical studies. The recording and analysis of varied human activities and their interactions in an integrated time-space environment is limited, however, by the actual capacities of the traditional tools for the collection and processing of individual records. One of the approaches facilitating tracking of an individual's activities in the complex of social and spatial interaction is time geography. This sub-discipline of Geography with a distinct multidisciplinary character, established itself in the field of geographical research in the 1960s and since then it has produced some successful approaches, providing a systematic theoretical and methodological frame for the analysis of human activities (Carlstein et al., 1978; Hägerstrand, 1970; Lenntorp, 1976; Pred, 1981). Time geography enabled a better comprehension of an individual's spatial and temporal behavioural patterns and the limitations that restrict them (place of work, transport options, administrative barriers, etc.).

In spite of offering such a conceptual apparatus, time geography did not avoid criticism for its unrealistic assumptions or scarce interest in people's individual motivations and social conditions (Hallin, 1991). The response to this criticism has drawn attention to everyday life, where the richness and variety of life styles and the formation of adaptation strategies prevailed over the exact description of spatial mobility (for example, Pratt, 1996; Jarvis, 2005; Novák and Temelová, 2012). On the other hand, researchers who refused to abandon the effort to gather an exact spatial record of individual behaviours, turned to Geographical Information Systems (GIS). At the outset, however, an individual's behaviour modelling in time-space was limited. Researchers worked exclusively with physical space and various simplifying assumptions were adopted. For instance, regular distributions of opportunities in space and a uniform speed were considered. Although the theory concentrated on individuals, the applied part was often based on aggregated territories (Kwan, 2000). But GIS has compensated for many of the limitations of traditional time-space research methods, enabling the capture of activities and an individual's interactions as "processes", anchored in time and space, as the results of interactions of a number of factors.

At the beginning of the 1990s, Miller (1991) had already implemented the concept of a space-time prism into GIS. He tried to mitigate the assumption of a regular speed in the physical environment by the approach of a discrete net representation of time-space. This method was later used by several authors to derive the potential path area of individuals in the research on individual accessibility under the effect of time-spatial constraints (Kwan and Hong, 1998; Miller and Bridwell, 2009; Miller and Wu, 2000; Weber and Kwan, 2002). While some authors dwelled on the analysis of an individual's everyday activities via simple time- and space- queries (Ritsema et al., 2005; Shaw and Wang, 2000), an effort emerged to include the elements of individual cognitive maps associated with spatial behaviours into GIS models, which may contribute to a more realistic dimension of the individual's subjective environment to the theoretical and analytical bases of spatial analysis (Golledge et al., 1994; Kwan, 1998). The results of these analyses, however, were limited by insufficient analytical tools for realistic representations of the environment (Kwan, 2004; Spek et al., 2009), and the lack of detailed individual spatio-temporal data, as well as limited analytical processing due to a 'missing' computing algorithm (Miller, 2005).

The last two decades have brought about a distinct quality improvement in the field of computer technology and software applicable for the collection, processing, analysis and visualisation of large volumes of data. Post-modern society, globalisation, the onset and continuous progress of informatisation, the development of communication technologies (ICT) and adoption of these technologies by the public at large, also changed the relationships between space and time, and contributed to new incentives for human lives. Phenomena, such as 'virtual mobility' and

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the 'fragmentation of daily activities', require approaches which concentrate on individuals and are able to analyse their varied activities and interactions in one integrated time-space environment. GIS is an appropriate tool for the processing and interpretation of such comprehensive data. Applications of GIS were considerably enriched by the development of ICT, and their position in spatio-temporal research has been strengthened by new techniques, which make it possible to track individual movements.

Location-aware technologies, such as the global positioning system (GPS) and radio-location methods based on wireless communication systems, allow measurement of basic time- geographic entities and relations at spatio-temporal resolutions hardly imaginable during time geography's genesis in the mid-20th century (Miller, 2005, p. 18). A key role in such an innovation is played by GPS technology, which has become an indispensable part of peoples' daily lives and a fundamental tool for spatial studies. Time geography has acquired powerful hardware and software tools to process large amounts of data with high resolution of spatial records. Attempts to develop new GIS tools and additional modules are emerging (Buliung, Kanaroglou, 2006; Chen et al., 2011; Shaw et al., 2008; Yu and Shaw, 2008). Current post-modern society brings to the fore fundamental questions for further development of time geography (Hallin, 1991; Kwan and Lee, 2003; Lenntorp, 1999), as well as the need for a transformation of its conceptual and methodological framework (Madajová and Šveda, 2013).

The objective of this paper is to present a particular framework for spatio-temporal research of human behaviours by improving traditional data collection methods in time geography – diary surveys – to include GPS-data collection. Previous research comparing diary-reported to GPS-recorded surveys have generally considered the GPS data to be a powerful tool for time-space research (see Bricka et al., 2012, for discussion). GPS units themselves, however, are not fail-proof and they cannot provide all the necessary data for behavioural research. By merging survey-reported and GPS-reported data collection records into one framework, we aim to provide "true" spatial trajectories, and to reduce trip and activity under-reporting. Individual spatial data have a high scientific potential and have acquired considerable importance, especially in diverse social and transport studies, but their utilization in human (behavioural) geography is rare. Although both data sources are relatively frequently used in time-space studies, we can find only a few examples of their combined use.

Ohmori et al. (2006) presented the development of a GPS-equipped PDA-based activity diary survey system. By comparing the activity data collected by the PDA/GPS instrument with data from a conventional time-space diary survey, it was found that the former method was useful in reducing the time lag in data entry. As well, it was shown that both the number of activities and total activity time recorded were longer in the paper-based survey, particularly for in-home activities (Asakura and Hato, 2009).

Millward and Spinney (2011) combined diary records and precise GPS tracking in the Halifax STAR (Space–Time Activity Research) survey. Respondents kept track of all the places they visited by carrying a GPS-logger and writing travel activity in a log throughout a 48-hour period. This innovative survey of both time use and travel activity merits the designation of one of the largest GPS samples, within the context of a household travel survey project, undertaken to date. Unfortunately, it is not clear how the data from diary and GPS data were processed, and what challenges and difficulties were encountered in the development of the methodology.

Since there has been a methodological gap in the context of dual diary-GPS surveys, by casting light on this method we can evaluate its usefulness in behavioural research. Using recently collected GPS data from a medium-scale survey (n = 60 individuals), this article attempts to verify the applicability of the method based on a dual record using the time-space diaries and a GPS-logger. The first part the article briefly presents both data sources. Subsequently, a detailed workflow of data synchronization is presented. The article concludes by comparing this method with two alternative ways of time-space tracking.

2. Merging time-space diaries and GPS records

Time-space diaries (budgets) represent the traditional method of individual data collection about the everyday activities of a population, and appear with modifications not only in geographical research but also in sociology, psychology and anthropology. Spatial location by GPS is a comparatively frequent form of records in transportation studies, but its application in behavioural or sociological research is rather rare. These tools will be briefly presented in order to introduce the methodological procedures used here.

2.1 Time-space diaries

The time-space diary is the traditional tool used in order to identify human activities in space and time. It is a systematic record of an individual's time use and a fundamental tool for the study of the character, duration, sequence, frequency, and the location of human activities (Ira, 2001). This (originally) sociological method is used for tracking phenomena in an individual's life in certain intervals over a certain period, normally over one day or a week. The time-space forms are, as a rule, filled in by the individuals themselves and at certain intervals (after minutes or hours) from the beginning of the particular period, putting down the kind of activity carried out at a given moment and place (geographical feature); whether they carried out the activity alone or in the company/interaction with someone else (sociological feature). The way they got to the place of the given activity reflects the transportation aspect, which, apart from the identification of means of transport, also contains questions about any means of communication used by the individual during the day (telephone, e-mail, chat, etc.).

Time geography research concentrates first of all on the activities and the time they required, such that the location of activities is often generalised. On the contrary, transportation studies focus on paths in space and the activities themselves, which leads to the use of the paths, such that activities are given less attention (see Bose and Sharp, 2005; Harvey, 2003). These two different views are related to two basic types of time-space diaries: i) activity diaries; and ii) trip diaries. Travelling is one of the activities in the first type, while in the second type activities are partially included as a purpose of the given trip (trip to work, shop or school). Harvey (2003) studies the construction of the two types of diary in detail and discusses their pros and cons. He points out the deficient spatiality of the two approaches and the need to connect the types of diaries in order to obtain the most detailed data possible. Although the time-space diaries bring unique individual records, the spatial dimension is limited and its verifiability (reliability) is problematic. In other words, this procedure is posited on the respondent's active collaboration – a requirement that undoubtedly affects the quality of the data gathered (Shoval and Isaacson, 2006). As a matter of fact, respondents may report incorrect time and spatial coordinates of activities or they may leave out some activities. The traditional record does not explicitly show the character of trajectories and does not allow for anchoring the stations in particular spatial coordinates.

The traditional form of time-space diary is also applied in behavioural research in Slovakia and the Czech Republic, both in rural (Ira, 1986) and urban settings (Drgoňa et al., 1994; Ira, 2000; Klapka and Roubalíková, 2010; Pospíšilová and Ouředníček, 2011). Additionally, Osman (2010), who dealt with the specific features of time-spatial behaviour of immobile persons, Mulíček et al. (2010), who researched the transformation of the post-industrial town in terms of its time organisation, and Novák and Sýkora (2007), who analysed time-spatial behavioural patterns of suburban migrants, based their studies on time-geographical concepts. As well, Temelová and Novák (2011) investigated the everyday manifestation of increasing cultural and social diversity and the variability of lifestyles in the transforming centre of Prague, and Temelová et al. (2011) made use of time-geographical tools in the analysis of adaptation strategies of populations living in the periphery.

2.2 The Global Positioning System (GPS) in spatio-temporal research

Applications of GPS in research on a population's time-spatial behaviour are ever more frequent because of new technologies which make possible the tracking of individual movements in space. The Global Positioning System is the satellite system, formerly used only for military purposes, which establishes position and time on the Earth's surface. When the ban on use in the civil sphere was rescinded in 2000, this technology experienced a dramatic development although the actual boom has occurred only in the last decade with the increasing accessibility of GPS receivers. They have become the everyday companions of people – navigation in cars, devices for sport and leisure, or as a part of mobile telephones and personal computers (PDAs), where they assess a position regarding the particular requests of a user. At the beginning, GPS devices were used mainly in transportation surveys (Murakami and Wagner, 1999; Wolf et al., 2000) to capture ways of transport (via in-vehicle GPS systems). Understanding the regularity and the variability of individual travel behaviours over time has been one of the key issues in travel behaviour research for more than two decades (Draijer et al., 2000; Jong and Mensonides, 2003; Giaimo et al., 2009; Krygsman and Nel, 2009). Recently, such positioning technologies offer a real opportunity for innovative research approaches. The feasibility of integrating GPS technologies and behaviour surveys has already been demonstrated in numerous experiments, including a real-time interactive activity diary (e.g. Ohmori et al., 2006), or passive monitoring and automatic trip data processing, as well as hybrid approaches combining passive monitoring and prompted recall interviews (e.g. Auld et al., 2009).

The current technologies of GPS route recording possess characteristics which make time-space research more efficient. They are:

- a high spatial and temporal accuracy;
- a capacity to capture movement in actual time;
- a capacity to record great volumes of data;
- an option to acquire automatically some data concerning an individual's activity and movement without the need for additional enquiry (beginning and aim of the trip, choice of trajectory, distance travelled, speed, etc.);
- an option to check the data – for instance, capturing unreported activities; and
- an option of simple connection with other digital databases (public transport network, address points, etc.).

The extent to which the GPS is able to provide more accurate information about an individual's movement in space, and whether there is the option for the total replacement of the classic data collection method by such a technology, is examined in this article. As mentioned by Bricka et al. (2012), the role of GPS has been primarily designed for the purpose of evaluating the accuracy of trip reporting – identifying trips recorded in the GPS data streams that were not reported by the respondents in the diaries. Analyses of these non-reported trips have provided critical insights that have led to improvements in the survey materials and data collection methods, resulting in improved capture of trips via diaries. The following method of time-space recording not only uses the GPS device as a supplement for the trip corrections, but also as an integral part of research. The key role is played by the synchronization of diary data with the GPS record.

2.3 The synchronization of time-space diary and GPS records

The basic methodological procedure for synchronization of the GPS records with time-space diaries is presented. Synchronization of the two records at first glance appears to be a simple process – individual activities should be assigned to particular spatial data points, based on time consistency between the diary and route record from the GPS logger. But the GPS device records continuously the position and therefore contains an enormous amount of data, which must be adjusted. Respondents, too, do not always complete the diaries correctly. This may lead to an erroneous interpretation or an over-generalisation of the route record. The following steps must be carried out for the synchronization of time-space diaries and GPS records. Fig. 1 represents the workflow scheme.

Stages are reported in order here. The GPS Data cleaning stage: location-positioning errors are inevitable in the data obtained by the GPS device. The first step in data processing, then, is termed: cleaning. The tracklog contains redundant records, which need to be deleted.

The episode of GPS track, during which the individual stays at one place (station), can be due to an inaccurate satellite signal recorded as a movement. This can lead to the formation of a "bundle" of unrealistic movements. For instance, GPS units will show dislocation in space even when an individual is moving within the same building or shopping complex, resulting in activity-bundling within a confined space. Bricka et al. (2012) consider the threshold of acceptable dislocation to be a challenging issue in trip detection algorithms. Therefore the method presented here relies on manual identification of stations, using information from diaries (stations of home, work...) and map sources (e.g. the centre of building where the activity is carried out). By identifying an activity and its specific spatial anchoring, we are able to clean the GPS recorded track from unrealistic

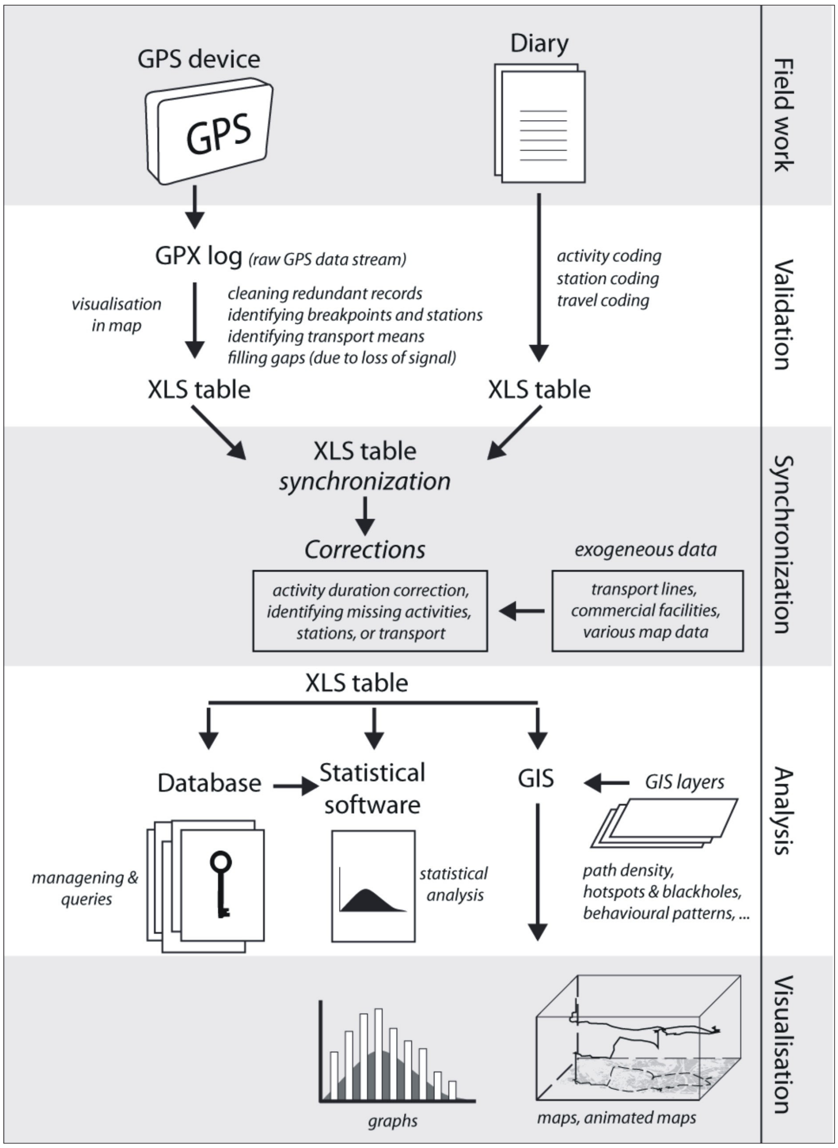

Fig. 1: Merging the time-space diary data and GPS tracklog: the workflow scheme. Source: authors

movements, and simplify the path to two points with the same spatial coordinates for input and output time of an individual at the station (Fig. 2).

To increase the accuracy of the record, it is appropriate to integrate and align spatial data with the road and settlement network. The record may slightly deflect from the road network if the GPS signal is shaded (e.g. in transport means). Especially in highly urbanized areas with a dense urban structure, the position accuracy of GPS decreases. The radio signals sent by the GPS satellites are too weak to penetrate through narrow urban canyons. This is known as the Urban Canyon Effect phenomenon. Mostly, we can correct the inaccuracies in GPS records by adjusting points for the transport network and settlement structure (Fig. 2). Using a web mapping service application (e.g. Google Maps), we are able to get an amount of additional information such as public transportation and various points of interest.

For the identification of breakpoints, a key step is the identification of breakpoints in the route record as, for instance, distinct spatial or temporal leaps or an abrupt change in speed or direction of movement (Mountain and Raper, 2001). Such breakpoints can be used for the delimitation of episodes in a respondent's trajectory (Fig. 2). One episode should contain a relatively homogeneous time-spatial record (for instance a trip by car).

The principal indicators of breakpoints are:

- any changes in frequency of the time route record. Sudden prolongation or shortening of interval follows after a relatively regular time route record;
- an abrupt change of speed or direction of movement. For instance, change of transport means (car – walking) or a 180-degree turn (trip of a parent from home to school and back);
- leaving the spatial frame (envelope) represented by the polygon delimiting a certain scope of a spatial record of the position when staying in a station. The merging of route points under certain spatial/temporal delimitations enables the simplification of the route record.

The indicator of the speed of movement is suitable not only for the separation of individual route segments (episodes), but it can be also used for determination of the way of transport in the case when the information on transport usage is missing in the diary. As is obvious from Tab. 1, each basic type of transport is characterised by certain mean speed. All points of the route segment which have a speed recorded in a certain interval identify the particular ways of transport. For example, certain route segments with a speed under 7 $km.h^{-1}$ represent walking. For a method for dividing trajectories into activity (single-mode segments) and their classification according to the transportation mode used, see Biljecki et al. (2012). An aid for the identification of the particular type of transport can also be an observation of the used infrastructure (road, rail) and the beginning (end) of the route segment, in certain particular places (e.g. a stop in the public transport system). The combination of GPS and diary data does not require setting tolerances for breakpoints and the automatic determination of transport means, as mentioned in diary data. The speed data, however, make the delimitation of episodes (trips, rides) easier.

For the activity duration and coding, the following is noted: as respondents do not put down accomplished activities immediately after they end but some time afterwards, their actual duration is often biased. While respondents can precisely estimate duration of some types of (routine) activities (trip to work, trip to language school, etc.), in the case of less frequent activities the duration may be rounded (e.g. stroll in the park). If such activities do not take place in one station only (e.g. in the case of working from home) but are distributed among several stations, the duration of the activity linked to the given station (e.g. shopping in the market) or transport (change of direction and speed of movement in the place of the stop, etc.) can be established

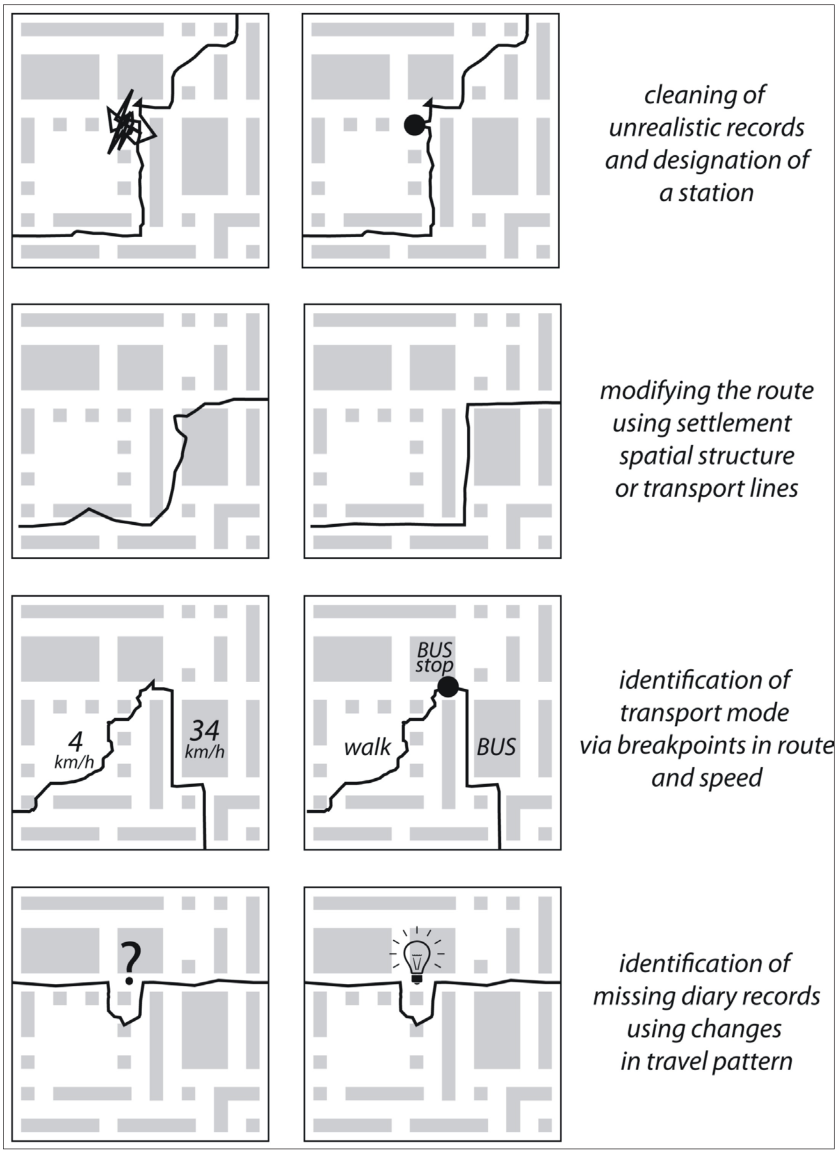

Fig. 2: Correction of route using multilevel data from tracklog, time-space diary and exogenous data (maps, transport lines, various points of interest e.g.). Source: authors

Transport mode	Fixed route	Fixed stops	Average speed [$km.h^{-1}$]	Max. speed [$km.h^{-1}$]
Walk	No	No	4	7
Tram	Yes	Yes	20	60
Bus	Yes	Yes	30	90
Car	No	No	40–50	130

Tab. 1: Characteristics of transport means regarding route record via GPS. Source:authors

more precisely by means of input and output times. For example, if a respondent notes that s/he spent 15 minutes at a grocery store, but from the input and output times of the GPS tracklog, we find out that the shopping took only 9 minutes. Such traceability is crucial in estimating activity duration.

Simultaneously with specifying activity duration, we define activities by a coding scheme. Gathering and coding activity data requires an understanding of what activities should be captured and how they should be structured. There are many activity coding schemes (see for example, Harvey, 2003) suitable for different research perspectives (social, travel, economic, etc.).

As far as synchronization is concerned, the results of the adjustments mentioned above are merging the diary records (Tab. 2) with those of the GPS logger (Tab. 3), into a single table (Tab. 4), which contains the duration of individual activities along with their spatial location, as well as the spatial trajectories of the individual's movement. As each activity has not only duration but also spatial coordinates, it is recorded in the table in two lines (for the beginning and the end points). In the case of activities bound to one station, coordinates of its beginning and end will be the same and it will be represented in time-spatial visualisation (3D) by a vertical line segment.

After these steps, we are able to import the data into the GIS system, which provides comprehensive data on many aspects of the environment and transportation systems. These contextual data allow the activity-travel data to be related to the geographical environment of a region during the visualization (see Kwan, 2004). Fig. 3 shows the visualization of the time-space paths of two families from the survey.

3. Assessment of accuracy and reliability of the combined record

The reliability and precision of the route record were tested on a sample of 60 respondents, who obtained a small briefcase with the diary and a GPS device. We used the GPS logger Holux M-1000C, which has the size of a match-box, weighs only 60 g and is able to record the position with a precision of ± 3 metres (66 channels, sensitivity − 162 dBm). Participants were instructed in how to carry the GPS logger (e.g. attached to purse, keys, or bag) and how to regularly update the diary during the 24-hour period (the battery of the device holds the charge for around 30 hours). Respondent selection was based on the following criteria: testing the survey method in varied conditions (town, rural area, shopping mall, transport means, etc.), with the aim to optimise the setting of record frequency and processing.

The following (recommendations) were identified:

- the wearable GPS device should be small in size and lightweight, so that it does not bother the respondent during the survey. The device may be easily clipped to keys, backpack or purse, so that the risks, such as not carrying the GPS device correctly or forgetting to carry it at all, are minimized;
- it is appropriate to optimize the trip detection algorithms by finding a balance between a too sensitive record (over-identifying trips) or not sensitive enough (under-identifying trips). The recording interval should be in accordance with the objectives and scale of research,

Time	Activity	Where?	With who?	Travel	Parallel activity
0:00–6:30	sleeping	at home			
6:30–6:45	personal care	at home			
6:45–6:50	meal preparing	at home	husband		watching TV
6:50–7:05	braekfast	at home	husband		watching TV
7:05–7:15	hosework	at home			
7:15–7:30	dressing	at home			
7:30–8:00	travel to work		husband	car	
...	...	...	...	...	...

Tab. 2: The record from 24-hour activity diary. Source: authors

ID-GPS	Local time	Latitude [°]	Longitude [°]	Altitude*	Speed [$km.h^{-1}$]
1	6:24:33	48.27319	17.016890	179	0.2
2	6:24:38	48.27319	17.016890	179	0.1
3	6:25:11	48.27319	17.016890	179	0.3
...	...	...	...	...	...
125	7:23:15	48.27319	17.016890	179	0.1
126	7:24:11	48.27319	17.016890	179	1.1
127	7:24:54	48.27319	17.016966	162	12.1
128	7:24:57	48.27321	17.016756	162	20.0
...	...	...	...	...	...

Tab. 3: The record from the GPS logger. Source: authors.
** Height above ellipsoid WGS84*

Index	Accumulative time	Latitude	Longitude	Speed	Activity	Station	Social	Travel	Parallel activity	Distance	Duration
0	0.0	48.27319	17.01689	0	S1	S1					384.0
1	384.0	48.27319	17.01689	0	S1	S1					0.0
2	384.0	48.27319	17.01689	0	S2	S1					21.0
3	405.0	48.27319	17.01689	0	S2	S1					0.0
4	405.0	48.27319	17.01689	0	S3	S1	P1		V8		5.0
5	410.0	48.27319	17.01689	0	S3	S1	P1		V8		0.0
6	410.0	48.27319	17.01689	0	S3	S1	P1		V8		15.0
7	425.0	48.27319	17.01689	0	S3	S1	P1		V8		0.0
8	425.0	48.27319	17.01689	0	S4	S1					10.0
9	435.0	48.27319	17.01689	0	S4	S1					0.0
10	435.0	48.27319	17.01689	0	S2	S1					9.9
11	444.9	48.27319	17.01689	0	S2	S1					0.0
12	444.9	48.27319	17.01696	12.1	D			D8		8.7	0.1
13	445.0	48.27321	17.01675	20.0	D			D8		9.5	0.1
14	445.1	48.27322	17.01660	20.4	D			D8		9.3	0.1

Tab. 4: Route record with assigned diary and GPS data. Source:authors

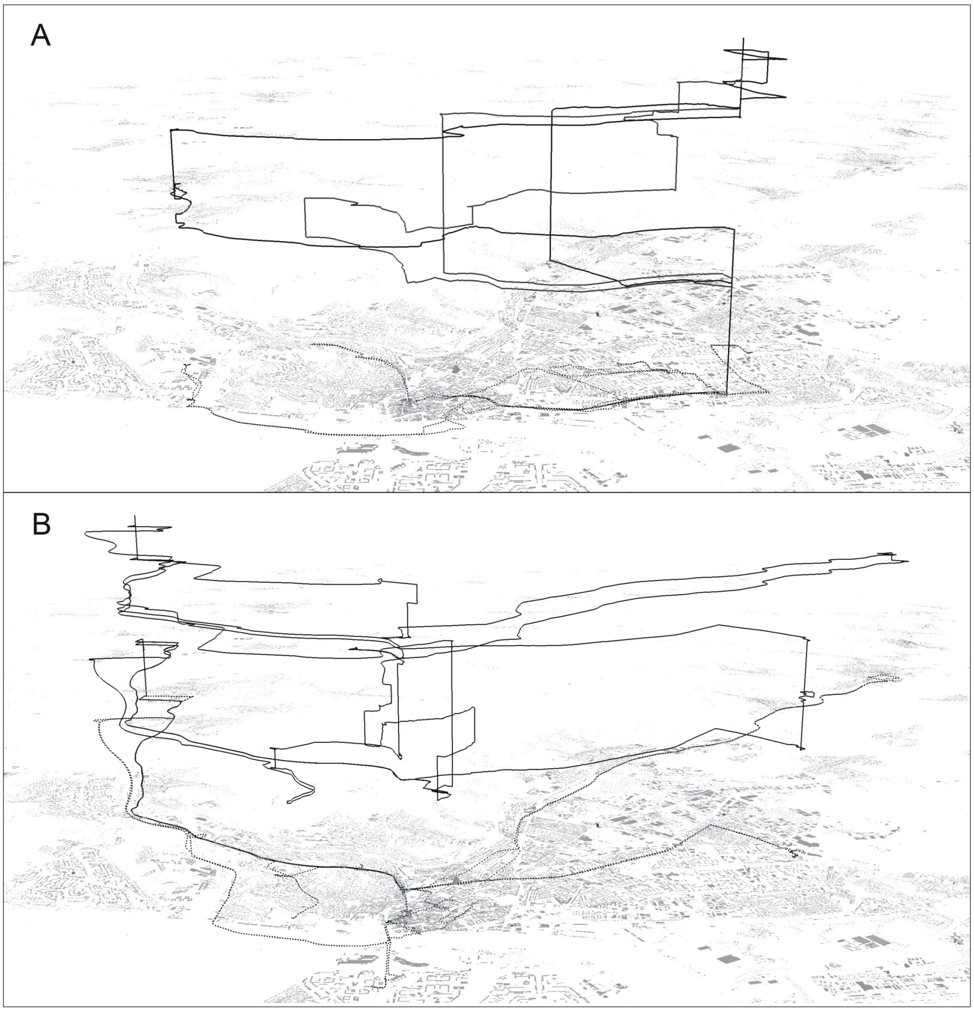

Fig. 3: The visualization of time-space paths of two families (eight individuals) in Bratislava (Slovakia). Family "A" lives in the city centre, family "B" in the suburban zone. The different spatio-temporal pattern is obvious. Source: authors

we suggest an interval no longer than 10 seconds, respectively 20 meters;

- it is also necessary to consider the effect of a "cold start", which can take several minutes to download data from the satellites that describe the position and timing of all of the satellites in the system. We can avoid this effect by updating the navigation message[1] just before the beginning of a survey.

The two most probable reasons for trips not being identified in the GPS unit-based streams, but being reported in the survey data, were (i) forgetfulness on the part of the respondent to take the device during one or more trips, and (ii) GPS device problems (Stopher and Shen, 2011). There is not much the researcher can do to counteract the unreliability of human memory, but we should consider the mis-reporting due to loss of GPS signal (see section 2.3).

Many prior GPS studies have focused on under-reporting of trips in household travel studies (see Bricka et al., 2012). The potential of combined diary-GPS survey is to identify under-reporting of trips and activities in self-reported surveys. The under-reporting can be caused by the memory decay of respondent, failure to follow survey instructions, respondents considering the activities or trips unimportant, or unwillingness to report full details (Wolf et al., 2003). Oft-forgotten or omitted activities in our pilot survey were activities (or trips) that occur as part of a trip chain (e.g. waiting at a bus stop, making coffee at work) or activities of short duration (under 10 minutes) that were missed due to forgetfulness of the respondent, or the lack of importance given by the respondent to the activity (mainly activities of self-care and communication).

Activities are the crucial element supporting the logical structure of a diary, and are the reason why the first column of the diary represents the activity record and not that of time (Fig. 4). It is more natural and more intuitive to quote: "What I am doing", and specify the time limit of the activity later. Open time intervals were used in the diary. Fixed intervals (for example 5 minutes) provide a clearer time structure (and simplify orientation in the diary), but regarding the option to synchronize diary and GPS records their use was not necessary, because in many cases it was possible to specify time limits of activities to the level of seconds.

There is the option to enclose a table of categories with pre-defined activity types for the time-space diary (Fig. 4). A respondent then chooses some of the offered activities (a comparatively large choice) and puts their codes into the diary. On the one hand, this makes the processing of data easier, but it also implies the risk of discouraging the respondents from participation because it is rather demanding. As reported by Kenyon (2006), the use of activity codes contributes to perceptions of time-space diary data as 'safe', in terms of privacy protection. On the other hand, freedom in activity recording, here preferred, brings the risk that the diary will not be kept with sufficient detail. The natural effort of a researcher is to obtain the most detailed data possible, but it has to be borne in mind that a detailed record is not only more demanding on data collection but also on processing. Any attempt to reach a high spatio-temporal resolution may produce a counterproductive result. As Kenyon (2006) reports, there is a danger that, in the effort to capture everything, at the end very little is detected. It is then appropriate to have the time-space diary adapted to the specific features of the given research parameters (transport, social, economic, etc.). Enclosure of examples of different activities to the diary proved to be helpful (Fig. 4). From this process, a more accurate record was obtained because the respondents were aware of the degree of specificity of the activity records that was expected. The records reveal that respondents often found inspiration in an enclosed activity list, and quoted such activities which they would have previously considered unworthy of recording (personal hygiene, surfing on the web, etc.).

4. Alternative ways of time-space tracking

The method of dual GPS-diary records presented here is obviously not the only way to track space-time movement. The potential use of mobile communication devices in travel and behaviour research has been discussed within the field for many years. Among many approaches, two general techniques are emphasised here with a brief discussion of their pros and cons.

The first method is based on tracking mobile telephones using the precision of network cells of mobile operators. There are different locational methods used by operators to determine the position of a mobile phone within their network. These locational methods have been an inherent component of the mobile phone service since the 1980s in order to be able to find where a mobile phone is and where a call has to be routed to, as well as to facilitate a seamless transfer of a telephone call between base stations, whilst the mobile phone is moving through space (Mateos, 2005). In general, mobile positioning data are similar to movement data gathered using GPS. The mobile positioning data have location coordinates and a time coordinate (Ahas et al., 2010). The major difference is in the spatial accuracy, which depends on the architecture of the GSM network and the density of the transmitter stations (Novák, 2010). In general the accuracy varies from 100 m (city centres) to 5,000 m (rural areas).

The most important research activity in this field in Europe is perhaps that carried out by the University of Tartu. The experiments in Estonia have used active and passive mobile positioning data. Active mobile positioning (active tracking) data are collected after a special query/request to determine the location of a mobile telephone (Ahas and Mark, 2005; Ahas et al., 2010). Passive mobile positioning data (passive tracking) is collected from secondary sources such as the memory or log files of mobile operators (Ahas et al., 2007b, 2008). A detailed insight into the use of mobile telephones as part of the study of individual behaviours was presented by Asakura and Hato (2004), though they used the mobile phones "only" as a tool suitable for tracking the movement of individuals without taking into account the owners' (tracked objects) characteristics. On the contrary, Ahas and Mark (2005) developed a method describing spatial behavioural patterns of individuals based on a combination of position coordinates of their mobile phones and personal characteristics. They denoted this approach as the social positioning method. Using mobile phones as a data collection technique became a frequent topic in transport and

[1] The navigation message is a continuous 50 bits/second data stream modulated onto the carrier signal of every satellite. It includes information on precise satellite position (ephemeris), satellite clock correction and other parameters. It takes 12.5 minutes to transmit all of the information.

GPS unit number: [ ]

24-hour diary

Age: [ ]

Gender: M | F

Education: ZŠ | SŠ | VŠ

Municipality: [ ]

Marital status: *single* | *married*

Occupation: *employee* | *entrepreneur* | *SZČO* | *unemployed* | *student* | *childcare*

Profession: [ ]

Number of vehicles in household: [ ]

How many people live in your household: *total* [ ] *kids* [ ] *retired* [ ]

How to complete the diary

Please try to record all of your activites for the whole day (working day). We understand that there might be gaps in the table when you are not traveling, using communicatioin technologies, or doing simultaneous activities. A number of activites are listied below for your inspiration.

Type of acitivities (examples)

Comunication
Personal comunication
Handling e-mails
Chat (Facebook, ICQ, etc.)
Phone call
...

Leisure activites
Relaxing
Stroll
Reading
Hobby
Sport (active)
Cinema, theater, sport event
Hanging out with friends
Watching TV
Listening to music, radio
Web surfing
Social media (Facebook, MySpace, Twitter...)
Playing computer games
Volunteering
...

Shopping

Formálne činnosti
Work (paid)
Education
Spiritual acitvities (praying, visit the church)
Civic (bank, post office)
...

Personal care and home acitvites
Sleeping
Personal care (hygiene, dressing, make-up)
Eating, food preparing
Housework
Caring for others (kids, elderly)
Caring for pets (dog walking)
Healthcare (doctor)
...

Transport
Walk
Car
BUS
Tram
Train
Bike

24-hour diary

Please, fill all your acitvities during 24 hour (including routine activities such as sleeping, personal care etc.)

	Acitvity (what did you do?)	Time start	Time end	Place (where?)	Social context (with whom?)	Transport and communication mode (how did you get there?)	Parallel acti-vity (what else were you doing?)
example	having breakfast	7:15	7:30	at home	wife		watching TV
example	travel to work	7:30	8:00		wife	car	

Fig. 4: The form of the 24-hour time-space diary (Note: the diary contains not only space for activity recording but also a short guide and examples of activities that explain what character of information is expected from respondent). Source: authors

behavioural research (Ratti et al., 2005; Raubal et al., 2007; Yuan et al., 2012.). Novák and Temelová (2012) have examined the possibilities of mobile telephone location data combined with deep interpretative interviews.

According to Ahas et al. (2007a), localisation via mobile telephones while tracking an individual's movements is more suitable than GPS instruments. Mobile phones are widely accessible and technologies facilitating their location rapidly advance. It is possible to track a number of people simultaneously in real time and to obtain digital location data (Ahas et al., 2010). On the contrary, Novák and Temelová (2012) point out a possible inadequacy in usage of the mobile telephone location data (passive tracking) for the analysis of an individual's behaviour in terms of time geography, because the amount depends on the intensity of mobile telephone use. Naturally, there is also the question of potential privacy abuses of this technology (see Novák and Temelová, 2012). Particular attention should be paid to the handling of non-anonymous and disaggregated data. Some limited spatial accuracy of this method is suitable for regional-scale analyses of migration, commuting, traffic monitoring, tourism, etc.

The second approach is based on the new generation of telephones with the Assisted GPS function (A-GPS). It uses a combination of a GPS and a land-based antenna network to assist in obtaining a location. This technology was designed to supply a solution for locating mobile telephones in a cellular network at a resolution greater than the resolution possible using cellular triangulation (Shoval and Isaacson, 2006). The utilization of smart-phones with A-GPS creates new opportunities for time-space research, as it combines the high spatial accuracy of GPS and the accessibility of mobile phones (for a review, see Wolf et al., 2014). Undoubtedly, this method opens up new options for large-scale research, in the broadest sense of the word. But, at this time the massive utilization of A-GPS in time-space research is limited by the distribution of smartphones among the population, and by the development of an application to be used for data collection in which respondents' activities will be detected (real-time questions). Although the distribution of smartphones among the population is rapidly growing (with technology penetration), there are still mobile device users (e.g. elderly respondents) who do not use smartphones, potentially due to difficulty or plain dislike of the product. According to Wolf et al. (2014), there are still a few technological and methodological challenges to overcome before smartphone solutions can become dominant in activity and travel surveys. As these authors assert, such challenges include:

a. market fragmentation – it is difficult and costly to develop apps for multiple platforms and operating system versions to support the majority of participants with smartphones;
b. power management – continuously logging GPS data will rapidly deplete a smartphone battery; and
c. data plans and associated costs – participants may have limitations on their data plans.

Both approaches of using devices owned by participants (mobile telephones) can address common implementation challenges in GPS-based surveys by: (a) eliminating the need to ship out and retrieve GPS loggers; (b) shortening the time between travel date collection and data review; and (c) reducing costs (Bricka and Murakami, 2012). Localization via mobile telephones undoubtedly brings new opportunities for time-space research. While the GPS instruments are highly accurate and provide a strictly individualised record, tracking via mobile phones offers the possibility of (regular) collection of a great volume of spatial data. The approach of mobile-phone-based tracking has proven its applicability in large-scale research (e.g. Ahas et al., 2007b, 2010), but the potential arising from the use of A-GPS technology is waiting for breakthroughs in the methodology. Tab. 5 summarizes and compares selected properties of mobile-phone-based localization and localization by GPS (conventional tracking by GPS-logger). The purpose of this comparison is to show the range of current data requirements in time-space surveys to be considered when evaluating various data sources to replace conventional surveys.

5. Conclusions

GPS technology seems to be a suitable tool for the collection of individually-coded and spatially-located data. It not only represents a more sophisticated tool for the collection of spatial data but it is also a phenomenon, which helps to achieve a more correct analysis of peoples' spatial behaviour. The data obtained by the combined GPS device and conventional data collection methods via time-space diaries, supplement and specify each other. Taking into account certain constraints of the GPS technology, researchers are able to acquire very accurate and detailed individual spatial trajectories.

	GPS localization	Mobile-phone-based localization via transmitter stations	Mobile-phone-based localization via A-GPS
Principle of operation	Positioning data is collected from the memory of GPS device. Passive record, with the possibility of setting variable parameters (time frequency, distance frequency, speed limitation.	The principle of operation is based on localization of mobile phone via transmitter stations. We can distinguish two approaches: Active mobile positioning data is collected after a query/request to determine the location of a mobile phone. Passive mobile positioning data is collected from secondary sources such as the memory or log files of mobile operators	The principle of operation is based on the mobile phones with the Assisted GPS function (A-GPS). It uses a combination of a GPS and a land-based antenna network to assist in obtaining a location. Active use – respondents use the phone application to respond to survey questions during the day (activities, type of stations, transport means). Passive use - all recordings take place automatically in the background, with the application transmitting the captured data for processing

Tab. 5: Comparison of basic characteristics of location by GPS and by mobile phone
Source: authors, characteristics of active mobile positioning data have been processed according to work Novák (2010) and Novák, Temelová (2012).

	GPS localization	Mobile-phone-based localization via transmitter stations	Mobile-phone-based localization via A-GPS
Spatial accuracy	3–20 meters, accuracy is reduces in areas with limited open-sky view (e.g. in dense forest)	Depends on the architecture of GSM network and density of transmitter stations. Accuracy varies from 100 to 5000 meters	Depends on the device and network specifications, in case of combination of GPS, GSM and Wi-fi it can be up to a few meters. Localization is supported also in areas with limited open-sky view and confined spaces.
Impediment to accuracy	Urban canyon effect, start up time to first fix, unreal records while staying in buildings.	Variable connection of non-movement mobile phone to different base transceiver station („hand over noise“)	Depends on the device and network specifications
Frequency of record	Seconds	Minutes	Seconds
Survey size	Sample group	Sample group or all mobile phone users	Sample group
Requirements	Open-sky environment (view of three or more GPS satellites)	GSM signal coverage	Specialized application transmitting the captured data, connection to an internet servis provider. Data access (which can cost money) depends on the data plan with the mobile operator.
Battery preservation	Depends on battery life, usually 18-30 hours.	The need to have charged mobile phone allows practically unlimited endurance.	The need to have charged mobile phone allows practically unlimited endurance; however, using GPS reduces battery life.
Cooperation needed	Demands a higher level of cooperation from the subject, especially during a multi-day record (forgetfulness to take the device, switch off the device, battery discharge)	The need to have a mobile phone during whole day contributes to the reliability of data collection	The need to have a mobile phone during whole day contributes to the reliability of data collection.
Type of data obtained	Geographic coordinates, speed, distance, altitude, time	Geographic coordinates, time	Geographic coordinates, speed, distance, altitude and time. Activities, transport means and other survey questions can be asked via special application.
Privacy	User controlled. Personal contact with the respondent allows obtaining informed consent.	Passive localization: the need to apply an anonymisation algorithm to the raw data before processing. Active localization: personal contact with the respondent allows obtaining informed consent.	Location using the system is user controlled. Personal contact with the respondent allows obtaining informed consent.
Processing	The need of cleaning the record of unrealistic trajectories (mostly during the stay at confined area)	The need for "cleaning" algorithms to eliminate unrealistic records, which are caused by variable connection of non-movement mobile-phone to different base transceiver station	Depends on survey application architecture
Overall characteristic	Position and time accuracy allow to record not only time-space path, but also identify vehicle used, or time and space collocation (e.g. members of household). Higher demands on the cooperation are in the necessity to recharge the batteries if the survey exceeds 24 hours. Carrying GPS device can sometimes be annoying even when the size of the device is compact and wearable. The costs of data collection (hardware and labour costs of data collectors) is acceptable and is compensated by the quality of data.	High penetration rate of mobile phones in population enables large-scale tracking surveys, possibility of continuous recording over longer periods of time, less expensive in terms of hardware and communication costs. Unresolved legal and ethical issues. Dependence on cooperation with mobile operators.	High penetration rate of mobile phones in population enables large-scale tracking surveys. Automated collection of real-time data is possible. However, it is neccessery to develop an application for data collection in which respondents'activities will be detected. Few technological and methodological challenges to overcome. Some population groups (elderly people) may not be represented in the data sample.

Tab. 5: continuing

Synchronization and linking with the diaries yields a powerful tool for spatio-temporal research, facilitating an insight into the complexity of everyday spatial and social interactions of individuals. The principal positive features of the methods presented here include their high levels of spatio-temporal accuracy, the option to reveal unrecorded activities and the record of speed, or the option to interlink the route record with different digital databases (public transport network, shops, address points, etc.).

Future time-space surveys will undoubtedly rest on automated data collection, using mobile telephones with in-built GPS modules and communications with the user via specialised applications. Providing respondents with the option to use their own device for data collection can reduce costs, as well as increase the likelihood that the respondent will remember to carry the device. Research in the field of location-based technologies using the advanced architecture of various software applications (Raper et al., 2007; Lathia et al., 2013; Wolf et al., 2014), which are able to capture individual behaviours in real time, also seem to be very promising. Some population sub-groups, such as the elderly or low income residents, has been slower to use consumer products such as smartphones and, therefore, may not be represented in the data samples (how many people use smartphones?, and is the user group demographically biased?). Therefore, to provide a representative sample, it is necessary to design a universal survey system that requires a minimum operation of data collection devices. From this point of view, the method of a combined GPS-diary records system, as presented here, can be considered a formally simple, practically very reliable, and an affordable way of recording individual spatio-temporal data.

Time geography does not answer a lot of why and how questions, but that is due to its general nature. What it does is to form a basis for asking these types of indispensable questions (Lenntorp, 2003). In a similar view, we should consider methods of space-time research as general methodological bases rather than as precisely calibrated tools. The method presented in this article allows a deeper understanding of the organization of everyday activities and the spatial trajectories of individuals, and there are many areas in social science research where this method can be fruitfully applied. In particular applications, it is necessary to adapt the parameters and scale of the method for local circumstances.

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Socio-economic changes in the borderlands of the Visegrad Group (V4) countries

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Abstract

Under the influence of globalization and state integration processes, the importance of a border as a barrier is gradually decreasing. Borderlands are still perceived as specific phenomena, however, not only in terms of historical development but especially in the context of their changing impact on the daily lives of their inhabitants. Along with EU enlargement, the de-bordering process has also become significant in many countries where the borderland played an important role in the past. These include the V4 countries, whose borderlands are the object of this research. In this article we analyze these areas on the basis of selected socio-economic indicators, with a focus on change in the period 2001–2011. As indicated by the Analysis of Variance, the results show the significantly differentiated development of the borderlands, in terms of the individual values of indicators both within the borderland of the EU member states, as well as along the external border of the EU.

Keywords: *Border, borderland, periphery, indicators, the Visegrad Group (V4 countries: Czech Republic, Slovakia, Poland and Hungary), Analysis of Variance (ANOVA)*

1. Introduction

Under the influence of globalization and multi-state integration processes, the importance of a border as a barrier is gradually decreasing, which can in many respects evoke a world without limits, without borders (even if we think about national boundaries only). Although the idea of a borderless world is tempting, research on borders and borderlands has emphasized that the boundaries still exist, the significance of borders persists (Best, 2007), but their meaning has become more complex (Paasi, 2012). This phenomenon occurs in the social and cultural sphere as well as along the national borders, as in the case of the EU, where the introduction of the common market for goods, capital, and services often resulted in narrowing their importance only to the delimitation of the geographical territory of independent states. As a result, the status of many borders has changed significantly and is now being reflected in the research literature. This indicates a declining significance of bounded areas, in terms of the rise of the 'space of flows' of capital, information and people (Newman and Paasi, 1988; Anderson and O´Dowd, 1999), and increased cross-border cooperation (Best, 2007; Bufon and Markelj, 2010; Johnson et al., 2011).

EU policies and activities aimed at the mitigation of borders as barriers can generally be described as processes of de-bordering and political restructuring (Nelles and Durand, 2012). Although globalization has challenged us in a positive way and enabled the opening of boundaries which had previously separated us, its impact affects only some cross-border flows, and as Newman (2006) points out, we need to realize the real existence of a hierarchical world with existing borders (whether spatial or aspatial) that are part of our daily lives. At the same time, we need to accept that these borders do not necessarily correspond with national borders; moreover, they often fail to coincide with them (Anderson and O´Dowd, 1999). Such research connotes the interactions and dichotomies between different types of boundaries (e.g. physical, symbolic, political or socio-economic), as well as an understanding of boundaries as such (Jackson and Molokotos-Liederman, 2015).

Even today, however, we can find places where borders still represent some form of a barrier (e.g. a military, transportation or communication barrier), especially for the territory on both sides of the border – the borderland. Thus, from the perspective of economists, historians and even geographers, the borderland is, due to various negative barrier effects, often considered to be a periphery. And it is not only from a geographical standpoint but also from the perspective of national policies, as a supplement to the already degraded socio-economic status of these areas (Nelles and Durand, 2012), or as a result of the concentration of economic activities in core regions instead (Paasi, 1999; Xheneti et al., 2012). Moreover, in the borderland one finds mostly rural areas which are already very often perceived as peripheral. As many scholars point out, although geographic location is still an important factor, with the decreasing importance of the border as a barrier on the one hand and increasing cross-border cooperation on the other, the perception of any geometric aspects is shifting from looking through the distance of an area to its accessibility. Thus, in the borderland we can identify peripheral as well as core areas (Jeřábek et al., 2004). An example of this is the existence of the area across the Polish (PL), Czech (CZ) and German (DE) borderland zone described by Johnson (2009) as the region of prosperity. Similarly, the area between Bratislava, Vienna and Győr (in a broader sense, Budapest) is known as the 'golden triangle' (Rajčáková, 2005).

The analysis of changes in the meaning of borders and their impact on the borderland is interesting to study, especially in those countries whose borders have changed significantly in the past; for example, as represented by an important line in the formerly politically divided Europe (the so-called 'Iron

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Curtain'), and now part of the EU's internal borders. This includes, among others, the V4 countries (Slovakia (SK), The Czech Republic (CZ), Poland (PL) and Hungary(HU) whose borderlands are the object of this research. In fact, we agree with Anderson and O´Dowd's (1999) reflection on the relevance of borderland research – in terms of its comparison and relations with other adjacent regions of the neighbouring state(s).

First, a theoretical framework addresses the issue of the border and borderland and its re-positioning within European re-territorialization and restructuring processes, as well as how the new regional geography[1] adds emphasis to work on borderlands, while focusing on the Central European countries. This is followed by a section which discusses the methodology for the delimitation of the border, and the relevance of the indicators used in our analysis. Building on this theoretical and methodological background, attention is then given to the analysis of the borderland of V4 countries, with emphasis on understanding the ongoing socio-economic changes. In the last section we summarize the most important aspects of borderland research, in terms of the Central European space, and the key findings of this research are presented.

2. Theoretical framework

This section looks more deeply into the theoretical issues related to the merits of research on borderlands and transboundary space and its position within the new regional geography, in the context of Central European countries. As pointed out by Johnson (2009), Europe is an interesting example of how border regions create a new space for the government, cultural interaction and economic development and, at the same time, it is the transboundary space which helps to address many of the spatial queries prompted by on-going globalization trends. Reflecting on the importance and status of the borderland in theoretical considerations, we must first think about its position within the regional structure of national states. In particular, since the borderland has become the spotlight of many studies due to the spatial changes related to EU enlargement (e.g. revision or changing the status of borders) (Xheneti et al., 2012), border areas are put into a rather new situation, as they are both marginal within the territorial structure of individual states, while also central in consideration of the EU integration processes (Bufon and Markelj, 2010). We can therefore speak of the so-called conflict of territorial logics, where borders are of vital importance for nation states while at the same time undermine the unity and integration promoted by the EU (Popescu, 2008).

On the other hand, former transition and transformation processes and the current influences of globalization and internationalization are redefining the European space, through locational impact (recreating places from the sub-continental to the local level), and thus articulating a new regional geography (Dingsdale, 1999). Existing links over the national borders have created corridors of co-operation (ibid.), which according to Johnson (2009) play an increasingly important role in the changing territorial structure of the EU. In this context, O´Dowd (2001) even speaks of 'trans-frontier' regions (or cross-border regions, Euroregions) as central to European integration, as an alternative to a Europe of sovereign states. Pikner (2008) adds that the implementation of cross-border structures, such as Euroregions, is a partial aspect of the institutional innovation and shifting territorial configurations within the EU.

It should also be emphasized, that these borders, once perceived as physical barriers, the dividing line between states and geographic space, have been recently considered not only as a geographical space but rather conceptualized as "transformative and evolving processes that are politically, economically and socially embedded" (Xheneti et al., 2012: 317). It is the impact of the border on the territory, i.e bordering and de-bordering processes, which should be in the spotlight of current academic, social, and political discourses (Newman, 2006).

These aspects are just some of the many issues which highlight the apparently strong position of border and borderland issues in the discussions within the new regional geography. Many scholars, however, suggest that there is still enough space for the study of borders and, in particular, cross-border areas, within discussions of the territorial restructuring of Europe (Perkmann, 2003). Supporting the idea that boundaries are in fact parts of rescaling processes, Paasi (2002) justifies the lack of attention paid to the border and borderlands resulting from researchers whose field adopted simplified visions of a borderless world and where the importance of spatiality is underestimated.

Moreover, we can agree with Johnson's (2009) critisism of the emerging studies on restructuring and political rescaling (based on the work of scholars such as Brenner, 2000, 2003 and Gualini, 2004), where the borders and the borderland issues are not sufficiently addressed and often even neglected. Even so, Brenner, highlighting the importance of ongoing rescaling and restructuring processes within Europe, focuses more on the fact that it is the centre or in fact "city-regions that have become key geographical sites in which various trends and counter-trends of state reorganization are being articulated" (Brenner, 2003: 319). On the other hand, Gualini (2004) argues that the omission of cross-border areas in his research is made in order to simplify the interpretation of results. Thus, Johnson's (2009) criticism is justified since, as he argues, transboundary regionalism is closely linked to territorial restructuring processes across Europe, and there are still many questions to be answered in this respect. For instance, as emphasised by Varró (2014), criticisms of state-centrism in studies on cross-border regions have already pointed out deficiencies in terms of a largely one-dimensional perspective, focusing in particular on the territorial and scalar aspects of cross-border regionalism.

We believe that Central European countries (V4 countries in this case), in particular, since they have undergone not only economic transformation but territorial transformation as well (Buffon, 2007), represent an interesting 'experimental' field for the study of how former transition and current globalization processes, transform the status of their borderlands. Even more is this the case when we consider that the fall of the Iron Curtain and EU enlargement resulted, in fact, in some borders disappearing while others were created (Häkli, 2008). As a result of the above-mentioned processes, some parts of their borderlands

[1] The 'new regional geography' is a term used by some geographers, mainly in the 1980s and 1990s, who were engaged in solving the problem of the region by reframing the terms of the study itself. In this regard, region was seen as a medium and outcome of social practices and power relations operating at multiple spatial scales, while serving as a kind of fix. Its critique focuses on insufficiently spatialized social theory and political economy (see Gregory et al. [eds.], 2009).

have been transformed from peripheral areas to areas of interest and economic growth (Stryjakiewicz, 1998), while at the same time the peripheral position of other border areas could have even been exacerbated. As already highlighted, the EU enlargement process itself tended to prioritize the development of central regions, leaving a number of borderlands in vulnerable positions (Xheneti et al., 2012). Moreover, the current spatial structure of these countries (which is now being shaped by Europeanization through the influence of the EU (Dingsdale, 1999)), often does not correspond with the historical form of territorial organization, while persistent cross-border regions (relations and ties) tend to copy the former spatial framework and often do not fit into the current spatial regionalization (Buffon, 2007; Buffon and Markelj, 2010).

Thus, it seems that V4 countries might be a convenient laboratory for analysis of the borderland, cross-border linkages and the diversity/similarity of adjacent areas on both sides of the border. Therefore, in this article we analyze such areas on the basis of selected socio-economic indicators, with an emphasis on the population characteristics of those who live in the borderland. We attempt to somehow connect conventional, traditional approaches accentuating mostly the territorial aspects of peripherality (in terms of geographical isolation, peripheral location – i.e. the borderland), with unconventional perspectives emphasizing aspatial peripherality (peripherality connected not only with a physical space, but with the multiplicity of social spaces which overlap the same geographical area (McDonagh, 2002)).

Our work is based on the assumption that despite the geographical proximity of the analyzed borderlands (Central European countries, neighbouring countries), historical circumstances (transformation processes) and their position in relation to EU (accession to the EU in 2004), differences in changes in indicator variables and also in the level of development and current status between certain areas along and across the border, can be observed. Thus, some parts of the borderland can be considered as peripheral and others as central; as barriers on the one hand and as gateways of interaction on the other (Anderson and O´Dowd, 1999; O´Dowd, 2001).

Based on this general hypothesis, we attempt to answer questions related to the intensity and extent of changes in the selected socio-economic indicators. In particular, we focus on both changes along the border (within the country) and changes between neighbouring areas on both sides of the border (cross-border relations). Since border areas are often at the interface of different economies, environments and cultures, borders can act as barriers resulting in different development paths on both sides of the border (Krätke, 1999; Johnson, 2009). Bearing this in mind, despite the dual functions of the borders, and a frequent weakening status of the border as a physical barrier, there is a kind of imaginary barrier that exists between these countries, which causes differences, and in some areas still represents a dividing line.

3. Methodology

The borderland represents an interesting research space not only from the geographical perspective, but also from the perspective of historians and economists. Although 'borderland' is a common research subject in these disciplines, its delimitation is far from being uniform. In academic research we can find a variety of views, procedures and criteria used to define the borderland. As Jeřábek et al. (2004) point out, an exact definition or universal delimitation of the borderland does not exist, since every single discipline studies this phenomenom from a different perspective and the final delimitation of a borderland is adjusted to reach different research objectives. But, in general, we can identify the most commonly-used types of borderland definition, based on prevailing criteria (see Tab. 1).

Type of delimitation		Criterion and characteristics
Objective	Administrative	Delimitation based on administrative subdivision (municipalities, districts along the border, Euroregions in EU). Practical delimitation due to data availability.
	Geometric / distances perspective	Delimitation based on the distance from the border area, often using the administrative criterion. – 15 km – definition of the borderland for the purpose of questionnaire surveys (Jeřábek et al., 2004) – 20 km – zone defined on the basis of national legislation (Arnold-Palussiére (1983) in Jeřábek et al., 2004) – 25 km – definiton in various international acts upon adoption of bilateral agreements on the regulation of cross-border movement of goods and people (Bufon, 2007).
	Historical	Delimitation based on common historical development features (e.g. relict boundaries – now non-existent).
	Cultural / ethnic dimension	Delimitation of the borderland as a culturally or ethnically homogeneous area (usually according to share of ethnic minorities).
	Political and economic	For example delimitation based on EU requirements on the possibility of drawing support for the borderland (borderland as territory with population of 1 million and more).
	Physical-geographical aspect	Definition based on delimitation by natural barriers (e.g. mountains). This aspect is currently receding into the background due to technical progress.
Subjective	Perceptual dimension	Delimitation based on a subjective identification of people with the borderland. This approach emphasizes 'bottom-up' delimitation (useful especially in identifying and building the identity of the borderland).

Tab. 1: Types of borderland delimitation. Sources: Jeřábek et al., 2004; Bufon, 2007; edited by authors

Some authors focus on issues of border and borderland without its explicit delimitation, emphasizing its dependence on the definition of the type and nature of the border, especially in terms of the openness and permeability of the border (Džupinová et al., 2008; Jeřábek et al., 2004), or from the perspective of those from one side of the border (Xheneti et al., 2012). Other scholars highlight the problem of spatial scales of boundary construction, which not only plays an important role in the delimitation of the borderland (Johnson, 2009) but also represents one of the major themes in border studies (Newman and Paasi, 1998). Such studies are mostly dedicated to the processes of deterritorialization and re-bordering, generally recognized as rescaling examples (Häkli, 2008), although, as highlighted in the previous section by Johnson´s (2009) criticism, there is still a call for a greater implementation of scale within the border issues.

Based on the empirical findings of a case study in the Czech Republic, Vaishar et al. (2011) and Vaishar et al. (2013) point out quite interesting results, that the influence of a state (national) border is the most significant in the first village (municipality) at the border and at the first town (centre) which provides services of a higher rank. For these authors, such territory can be classified as borderland. We may argue that this statement, although it applies to a certain area in the Czech Republic, can not be generalized. At the same time we need to acknowledge that such understanding of the borderland is limiting to a certain extent and with current globalization influence it can hardly be recognized as unambiguous. As mentioned in the previous section, attention is now shifting from the distance of a certain place to its accessibility (Jeřábek et al., 2004). Thus, a distant area with better accessibility (e.g. transport connectivity) to the border may be more affected by the presence of the border itself.

In the context of EU enlargement processes as well as the increasing importance of EU policies (devoted among others also to border regions and borderlands), several scholars have paid attention to borderland research in terms of the formation of new structures: Euroregions (Perkmann, 2003; Johnson, 2009; Nelles and Durand, 2012; and with regard to the analyzed area, for example, Dołzbłasz, 2013; Tokes and Lenkey, 2013); areas allocated on the basis of different levels of NUTS (Wieckowski et al., 2012); and even administrative units of the countries (Kladivo et al., 2012). In general, we can agree with a borderland being interpreted as "the region or area in relative close proximity to the border within which the dynamics of change and daily life practices are affected by the very presence of the border" (Newman, 2006: 150) or, in other words as, "areas in which both economic and social lives are directly influenced by the proximity of an international border" (Bufon, 2007: 4).

4. Study area

For our analysis we chose Central European countries, expecially the V4 countries (Czech Republic, Slovakia, Poland and Hungary). This study area was not chosen randomly but rather influenced by several factors:

- these neighbouring countries are located in Central Europe, which combines proximity to the socio-economic situation and particularly historical development. Boundaries as well as the borderland of these countries had been changed considerably in the past (e.g. by forming boundaries of a politically-divided Europe, the so-called Iron Curtain). We also bear in mind the different ways in which these particular historical changes impact on the diverse and contradictory dimensions of borders (Anderson and O´Dowd, 1999);
- in 2004, these countries joined the EU (as a part of the EU enlargement process) and their eastern borders have become part of the external border of the EU. Xheneti et al. (2012) argue that the EU enlargement could only have minimal impact on the socio-cultural basis of these border areas since historical, social and cultural dimensions of these boundaries were stable over time. As recognized in another part of their work, however, the nature of the borderland has changed significantly (the eastern boundary is seen as a periphery, the western boundary as a space for cooperation). It is therefore interesting to see whether and how the EU territorial transformation is reflected in the socio-economic status of these borderlands; and
- several authors have carried out their research within the issue of borders and borderlands in the Central European space, highlighting various aspects. The work of Xheneti et al. (2012) examines the impact of EU enlargement on changes in the spatial characteristics of the border regions related to the redirection of the economy and market flow to the west, resulting in peripheralization of eastern boundaries. In comparison, Turnock (2002) and Perkmann (2003) analyze the creation of CBC regions (cross-border cooperation) as a result of the declining importance of borders and increasing regional initiatives, and Wieckowski et al. (2012) focus their attention on the more closely specified area of transport accessibility and tourism development in the PL/SK borderland. The diversity of these studies shows that borders and the borderlands have become important objects of research, and not only in the Central European space.

Given the diversity of borderland interpretations, as well as the various foci of studies, this research requires a variety of methodologies (Bufon, 2007). In our study we used a relatively simple but sufficient zoning method, buffering, based on the definition of direct air distance from the selected object (state border). This delimitation is based on geometric aspects using the administrative criterion as a zone of municipalities located along the borders. With respect to differences within the analyzed countries (area, length, and width), in the first phase of the borderland delimitation we used several distance zones and spatial relations (Fig. 1).

Using 30 and 50 km distances proved to be inadequate, especially because of the small territorial size of Slovakia (the shortest width of the country reaches less than 80 km). When using a given distance 30 and 50 km, the final delimitation of the research would comprise 1,857 or 2,696 municipalities respectively, representing 63% or 90% of all municipalities of the country. Such delimitation of the borderland would significantly affect our interpretation of the results obtained from the research. Moreover, it was also necessary to take into account differences in the size of territorial units (municipalities, districts) or administrative units (NUTS) within the analyzed countries.

After selecting a 20 km distance zone as the most convenient, it was necessary to select the appropriate spatial operation to obtain the final selection of municipalities and so define the borderland. For this purpose we have chosen the position of the centroid of the spatial unit, which appears to be a suitable approximation of its position for its integration into the distance zone. We excluded another spatial operator,

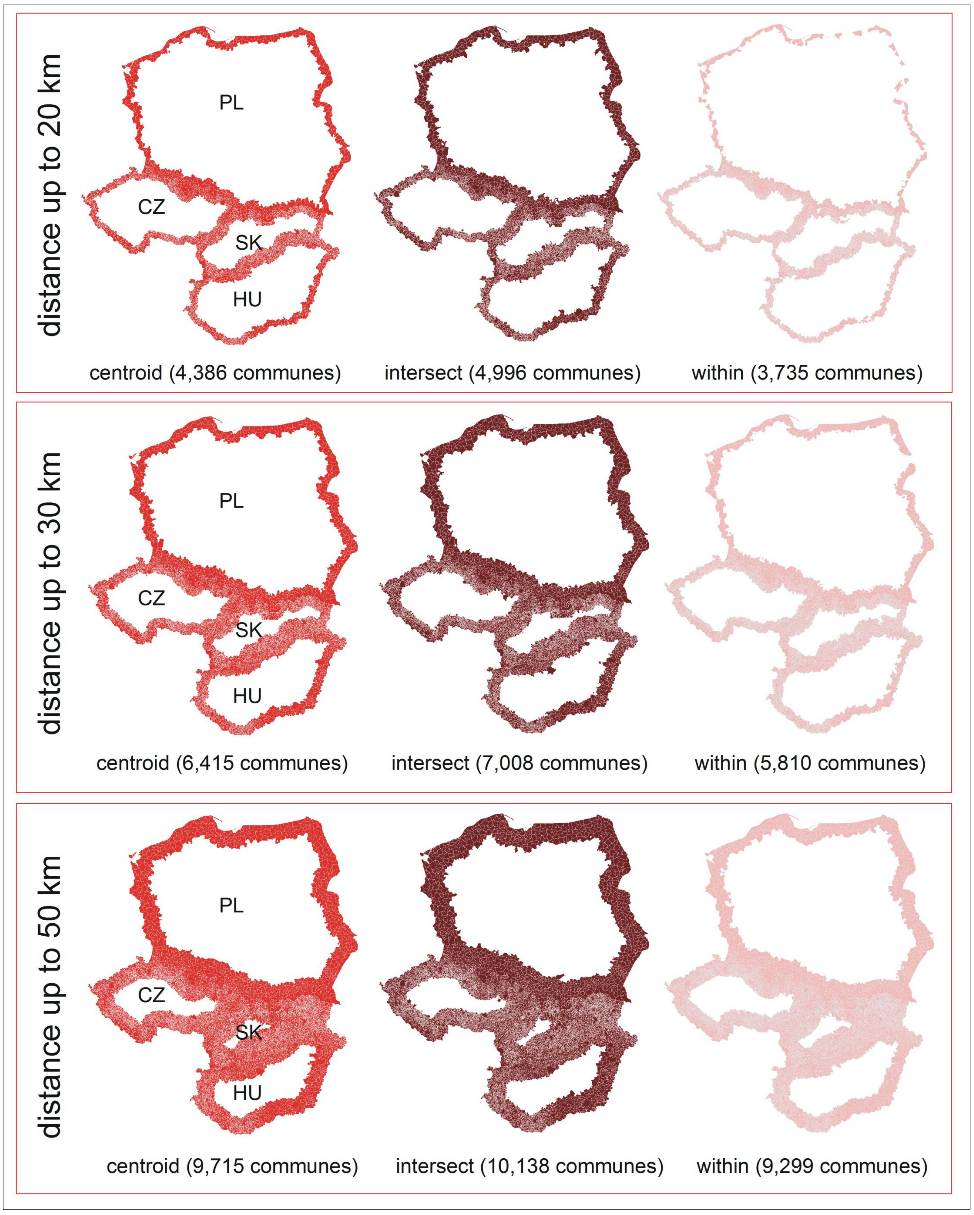

Fig. 1: Distance zones used in making the final selection of analyzed municipalities. Source: authors

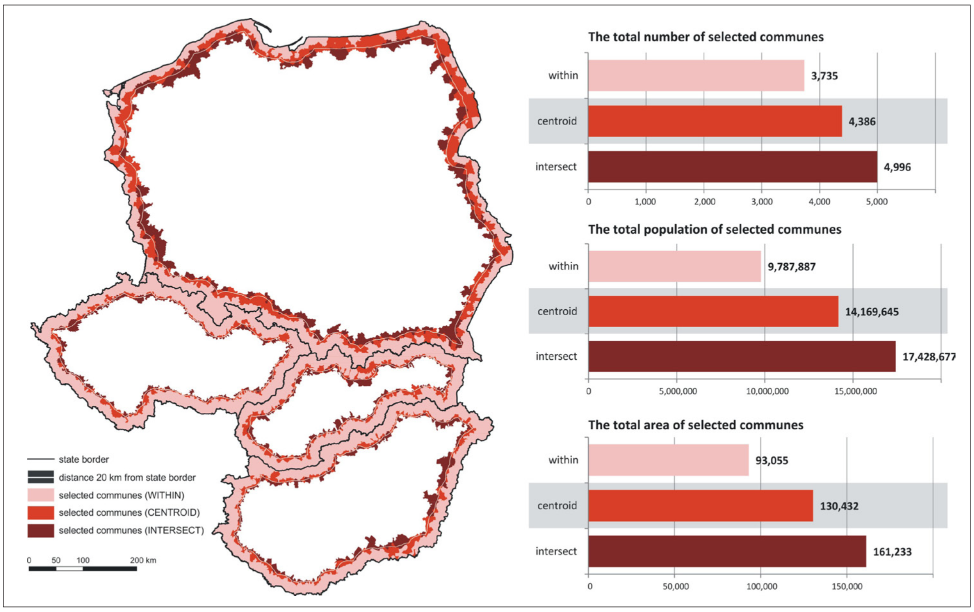

Fig. 2: Basic statistical indicators of the V4 countries borderlands. Source: authors

'intersect', because of the potential inclusion of a large number of municipalities in the final selection. Moreover, in many cases this would be a very small part of the unit without any built-up area and thus, in most cases, uninhabited places. We are aware of the fact that when using the centroid position some possible limitation of the final selection of municipalities must be taken into account. Despite this, it seems to be the most appropriate method in terms of number of municipalities and spatial integrity of the analyzed area.

Figure 2 shows the basic statistical characteristics of the resulting set of municipalities that were analyzed in the empirical part of this paper. The final delimitation covers 24% of the total area of all municipalities in every country and 22% of their total population. Municipalities within the borderland represent 29% of the total number of municipalities in these countries.

5. Data analysis

As the borderland is usually examined at a small scale, such as border areas within a single state (Vaishar et al. 2011, 2013), or the cross-border areas of two or three countries (Kladivo et al., 2012; Wieckowski et al., 2012), or most recently borderland in terms of Euroregions (Turnock, 2002; Pikner, 2008; Popescu, 2008), it is then possible to use a broader scope of indicators for a more detailed analysis. In our case, we looked at the borderland in an unconventional way, and applied a smaller number of indicators, in the relatively large border areas of V4 countries, because of the significance of mutual comparison of these borderlands demonstrated by the Analysis of Variance (ANOVA) (see below). Although the scope of the indicators that we used does not encompass the full complexity of the changes and processes occurring in the borderland, detailed data of different economic and demographic variables reflect the key element of the borderland – population and its characteristics. Moreover, these data are recorded at the lowest hierarchical level, municipalities, which enable us to reveal the changes taking place in specific locations within the borderland and compare these changes with the localities on the opposite side of the border.

In addition to the common spatial level (municipalities) within all four countries, it was necessary to consolidate data for the same time period. Finally, we have chosen the years 2001 and 2011 for our analysis. First of all, a population census in all V4 countries took place in these years which means that data were also available at the lowest local level. At the same time, this period is interesting from the position of these countries with respect to the EU. While in 2001 none of them was a member of the EU, in 2004 all of these countries joined the EU as a part of the EU enlargement processes. Thus, 2011 is the first census year after joining the EU, providing a great possibility for analysis of several socio-economic parameters, as well as the impact of the integration of these countries into the European space.

The main variables that we used to calculate a number of other indicators were data relating to the population, population age structure, unemployment rate and net migration. We focused on the analysis of the changes that have occurred in the individual indicators in the period 2001–2011. The final selection of the variables in the period is shown in Tab. 2.

With the population data, we analyzed: the population growth rate in the period 2001–2011; and data on the age structure were used to calculate the economic dependency ratio of the countries – the young age dependency ratio and old age dependency ratio, as well as the ageing index. Last but not least, the unemployment rate and crude rate of net migration were analyzed. For all indicators, we focused on the change in the period from 2001 to 2011.

Data on three variables (population, age structure and unemployment rate) were available for years 2001 and 2011 in all countries except for Poland, where data on unemployment (local level) were statistically recorded only since 2003. Data on net migration were analyzed for every single year in the period 2001–2011, except for Hungary, where the initial data were available from 2002 only. Table 3 shows the indicators and the corresponding relations used between them.

The data of all indicators have undergone tests of differences in group means (using the Analysis of Variance: ANOVA) in order to determine their statistical significance, using Tukey's HSD Test in a One-Way ANOVA which enables us to determine similarity or difference of changes in individual indicators between each of the V4 countries. The detailed methodology of ANOVA can be found in Rogerson (2001) or Miller and Haden (2006). It should be stressed that we tested the data of indicators for all territorial units (municipalities) in the sample of V4 countries, as well as particularly for selected units (municipalities within the borderland). Our task was to test the following hypotheses:

- The change of a particular indicator in the period 2001–2011 was the same or very similar in the borderland of V4 countries (null hypothesis);
- The change of a particular indicator in the period 2001–2011, with respect to the borderland of V4 countries, varies from state to state (an alternative hypothesis).

Table 4 demonstrates that the analysis (single-factor ANOVA model) shows very low probability values of all indicators (P values < 0.01). Therefore, the general null hypothesis can be rejected and we can accept the alternative hypothesis. Since the V4 countries have different mean values of specific indicators (in terms of change in the period 2001–2011), they are statistically significant and it is therefore appropriate to subject them to a deeper spatial analysis.

6. Results

The most significant results of our borderland analysis with a focus on the changes in the selected indicators in the period 2001–2011 are discussed in this section. For the purposes

Country	Variables			
	Population	Net migration	Age structure	Unemployment rate
Poland	2001, 2011	2001–2011	2001, 2011	2003, 2011
Czech Republic	2001, 2011	2001–2011	2001, 2011	2001, 2011
Slovakia	2001, 2011	2001–2011	2001, 2011	2001, 2011
Hungary	2001, 2011	2002–2011	2001, 2011	2001, 2011

Tab. 2: Variables analyzed at a local level (municipalities) and the available years. Source: authors

Variables	Summary and explanation of the relations		
	Indicator	Relation	Notes
Population	Population growth rate	$\frac{P(t_2)-P(t_1)}{P(t_1)}$	P(t2) – population at the end of the period P(t1) – population at the beginning of the period
Net migration	Crude rate of net migration	$\frac{(P_i - P_e)}{P_m}*1000$	Pi – number of immigrants Pe – number of emigrants Pm – mid-year population
Age structure	Ageing index	$\frac{P_{65+}}{P_{14}}*100$	P14 – population in pre-productive age P65+ – population in post-productive age
	Economic dependency ratio	$\frac{(P_{14}+P_{65+})}{P_{15-64}}*100$	P14 – population in pre-productive age P15–64 – population in productive age P65+ – population in post-productive age
	Young age dependency ratio	$\frac{P_{14}}{P_{15-64}}*100$	P14 – population in pre-productive age P15–64 – population in productive age
	Old age dependency ratio	$\frac{P_{65+}}{P_{15-64}}*100$	P15–64 – population in productive age P65+ – population in post-productive age
Unemployment	Unemployment rate	Data available in the databases of Statistical Offices of Slovakia, Czech Republic, Poland and Hungary*	

*Tab. 3: Indicators and the corresponding relations used in the analysis of borderlands (Note: * Links to the websites of the Statistical Offices are listed in the References)*
Source: Jurčová (2005), edited by authors

Analysis of Variance (ANOVA) – single factor		
Indicator (change between 2001–2011)	All units in V4 countries p-value	The borderland of V4 countries p-value
Population growth rate	1.0265E-297	1.4024E-115
Crude rate of net migration	5.2461E-305	1.68487E-67
Ageing index	3.94077E-18	0.000102459
Economic dependency ratio	1.7662E-138	8.2863E-22
Young age dependency ratio	6.7398E-298	3.38553E-40
Old age dependency ratio	4.01265E-28	6.82028E-11
Unemployment rate	1.58971E-23	0.009808922

Tab. 4: Analysis of Variance (ANOVA) of individual indicators. Source: edited by authors

of our research, we analyzed seven socio-economic indicators (see Tab. 3) which demonstrate dissimilar development of the borderland. One of the key research questions was to determine differences and similarities in the development of geographically differentiated borderlands (along the internal as well as external border of the EU), as well as to answer the questions whether certain changes along the border (within the country) and changes between neighbouring areas on the both sides of the border (cross-border relations), tend to overlap and to what extent. Moreover, we try to examine where the situation has improved and where, on the contrary, the values of indicators have become even worse.

The ANOVA results demonstrated the significance of the selected indicators and their relevance to the study of the borderlands of the V4 countries. Using the Tukey HSD Test in the analysis, we were able to distinguish the differences in the mean values of indicators between each pair of states within the V4 countries. From Table 5 we can clearly see that in all indicators, except the Young age dependency ratio (whether we consider all units or only the borderland of V4 countries), at least one pair of states is characterized by similar mean values of the change in the specific indicator. Moreover, with the exception of Population growth rate, both similarities and differences in the change of specific indicators (whether we consider all units or only the borderland of V4 countries) are subject to change. These results provide sufficient reason to have these borderland areas cartographically analyzed in detail.

The first indicator was the Population growth rate (Fig. 3), referring to the extent to which the population of a certain area (in this case municipality) increases or decreases. The most significant change was along the Hungarian borderland, where there was a decline in population. An exception is the northwestern part of the SK/HU borderland, especially the

Pair-Wise Comparisons via Tukey HSD Test								
Indicator (change between 2001–2011)	All units inV4 countries				The borderland of V4 countries			
Population growth rate		HU	PL	SK		HU	PL	SK
	CZ	P < .01	P < .01	P < .01	CZ	P < .01	P < .01	P < .01
	HU		P < .01	P < .01	HU		P < .01	P < .01
	PL			n/s	PL			n/s
Crude rate of net migration		HU	PL	SR		HU	PL	SR
	CZ	n/s	P < .01	P < .05	CZ	P < .01	P < .01	n/s
	HU		P < .01	n/s	HU		n/s	P < .01
	PL			P < .01	PL			P < .01
Ageing index		HU	PL	SR		HU	PL	SR
	CZ	P < .01	n/s	n/s	CZ	n/s	n/s	n/s
	HU		P < .01	P < .01	HU		n/s	P < .01
	PL			n/s	PL			n/s
Economic dependency ratio		HU	PL	SR		HU	PL	SR
	CZ	P < .01	P < .01	P < .01	CZ	P < .01	P < .01	P < .01
	HU		P < .01	P < .01	HU		n/s	P < .01
	PL			n/s	PL			n/s
Young age dependency ratio		HU	PL	SR		HU	PL	SR
	CZ	P < .01	P < .01	P < .01	CZ	P < .01	P < .01	P < .01
	HU		P < .01	P < .01	HU		P < .01	P < .01
	PL			P < .01	PL			P < .01
Old age dependency ratio		HU	PL	SR		HU	PL	SR
	CZ	P < .05	P < .01	P < .01	CZ	P < .01	n/s	P < .01
	HU		n/s	P < .01	HU		n/s	n/s
	PL			P < .01	PL			P < .01
Unemployment rate		HU	PL	SR		HU	PL	SR
	CZ	P < .01	P < .01	P < .01	CZ	n/s	P < .01	n/s
	HU		n/s	P < .01	HU		P < .05	P < .01
	PL			P < .01	PL			P < .01

Tab. 5: Pair-wise comparisons using Tukey's HSD Test in One-Way ANOVA model (Note: n/s = non-significant)
Source: edited by authors

area between Bratislava and Budapest, where there are mostly stationary or progressive types of municipalities. One of the reasons could be the existence of the suburban zone in the hinterland of these capitals but it can also be affected by other unspecified factors. Significantly regressive areas can be found also along the eastern PL borderland and northeastern SK borderland. On the other hand, a significant cluster of progressive municipalities is concentrated along the SK/PL borderland.

Results of this analysis illustrated that the borderland has demonstrated high variability and diversity in all V4 countries. Only values between Slovakia and Poland (hence within the PL/SK borderland) show some similarity; however, distributions within specific areas or regions within the borderland differ from each other. Thus, while in certain parts of the borderland a cluster of stationary, regressive or progressive municipalities occur, ultimately, their overall average appears to be quite similar.

Since the development of the population is also affected by migration processes, the Crude rate of net migration (Fig. 4) was another variable in our analysis. The analysis revealed that the borderland can have a significant impact in terms of this indicator. While in all units (understood as all municipalities of the V4 countries), the mean values of the indicator were similar only between the Czech Republic and Hungary and between Hungary and Slovakia, this similarity disappeared when analyzing the borderland of these countries. Conversely, while in all units there was a slightly differentiated change in the mean values of this indicator (e.g. between the Czech Republic and Slovakia, or Poland and Hungary), in the borderland of these countries the values of the indicator were relatively similar. Their spatial differentiation is further demonstrated in Figure 4.

Basically, the entire borderland along the eastern (external) border of the EU recorded a decline in net migration, with the exception of the SK/HU borderland with minor changes only. Similarly, a downward trend can be seen in some areas of the PL borderland, especially in the eastern borderland, the eastern part of the PL/CZ and PL/SK borderland. Central parts of the PL/SK borderland and the southeastern SK/HU borderland, however, are characterized by greater stability in terms of this indicator. On the other hand, in localities near Bratislava there was even an increase in net migration resulting partially from labour migration into this region.

The other four indicators are based on age structure. The first one is the Ageing index (Fig. 5), which increased during the period 2001–2011, resulting in population ageing in most of the analyzed borderland. The exception is the southern, eastern and northeastern SK borderland where, in contrast, the majority of municipalities experienced the opposite trend. One of the reasons could be a higher concentration of the Roma ethnic group in this area, characterized by a higher birth rate and lower average age, meaning that the population is getting younger with the 'bottom-up' approach. In fact, it is the ageing process that can be considered as the most significant and, nowadays, also the most critical consequence of the current population processes that can be also recognised in the borderland.

Other indicators which use data on age structure are the Economic dependency ratio (Fig. 6), Young age dependency ratio and Old age dependency ratio. In the period 2001–2011 there was a slight increase of burden on the working

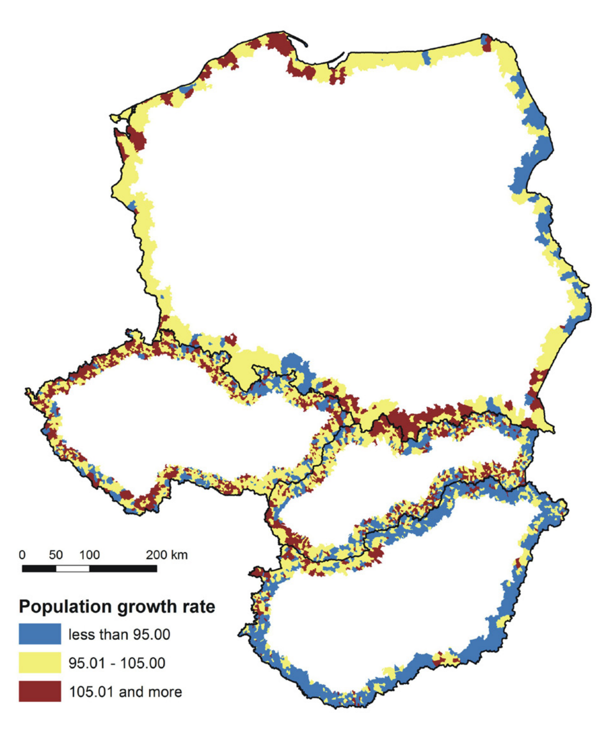

Fig. 3: Population growth rate. Source: authors

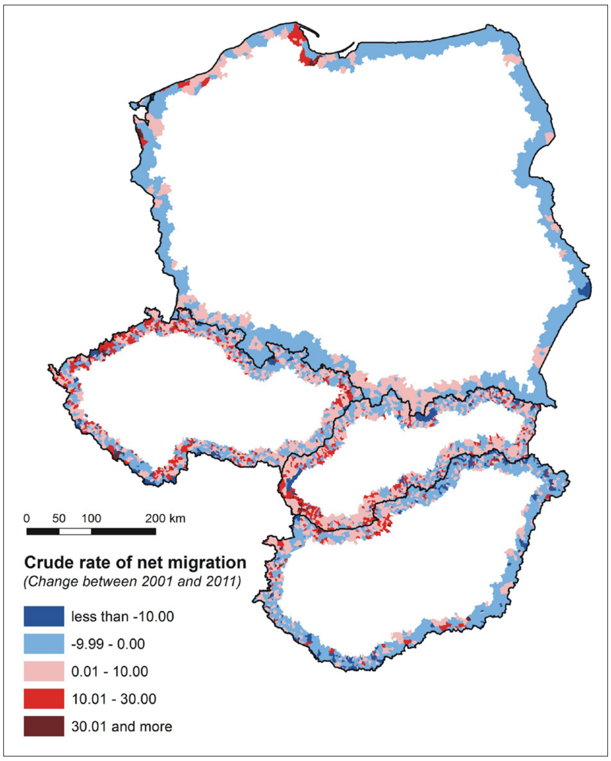

Fig. 4: Crude rate of net migration. Source: authors

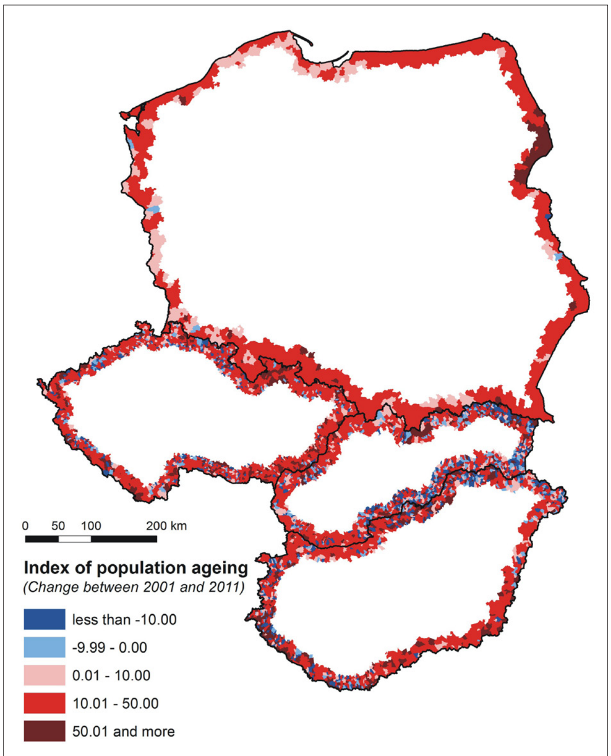

Fig. 5: Ageing index. Source: authors

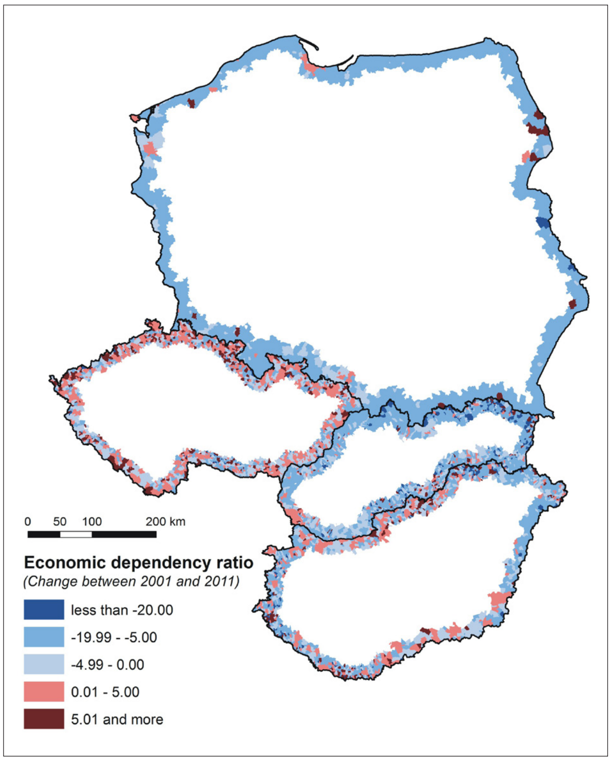

Fig. 6: Economic dependency ratio. Source: authors

population (productive age group) almost all over the CZ borderland and in the northwestern and southeastern parts of the HU borderland. In Bratislava and its surroundings the situation has evolved similarly, and the values of the economic dependency ratio have also increased compared to 2001 (a similar trend was also recorded in other capitals and the major cities of Poland and Hungary). As a consequence of the reduction in the natural increase across the borderland, the young age dependency ratio also decreased, while the influence of population ageing was reflected in the increase of the old age dependency ratio, especially in the CZ borderland, south parts of the HU borderland, and northeastern SK/HU borderland.

In relation to the indicators of age structure, this analysis shows that with the exception of Hungary and Slovakia, the mean values of Ageing index between each pair of states within the V4 countries were very similar. On the other hand, in the values of the Young age dependency ratio significantly different values were recorded (see Tab. 5 above). Moreover, as is clear from Figure 6, the analysis also showed that the changes in the value of the Economic dependency ratio in the borderland of Poland and Slovakia are relatively similar.

Last but not least, we analyzed the change in Unemployment rate (Fig. 7). The most positive change of this indicator was in almost all of the entire PL borderland as well as the SK borderland, except for the area located in its southeastern part where unemployment remained at the same level as 10 years previously or even declined. A slight increase was recorded along the CZ borderland, except for the northwestern part of CZ/DE borderland and the northeastern CZ/PL/SK borderland, and at the same time in the HU/AT (Austrian) borderland and the HU/SK borderland. The most significant rise of unemployment rate was in the central parts of the HU/SK borderland.

Resulting from the analysis of Unemployment rate, it is possible to follow a similar trend as in the Crude rate of net migration. While in all units the mean values of the indicator

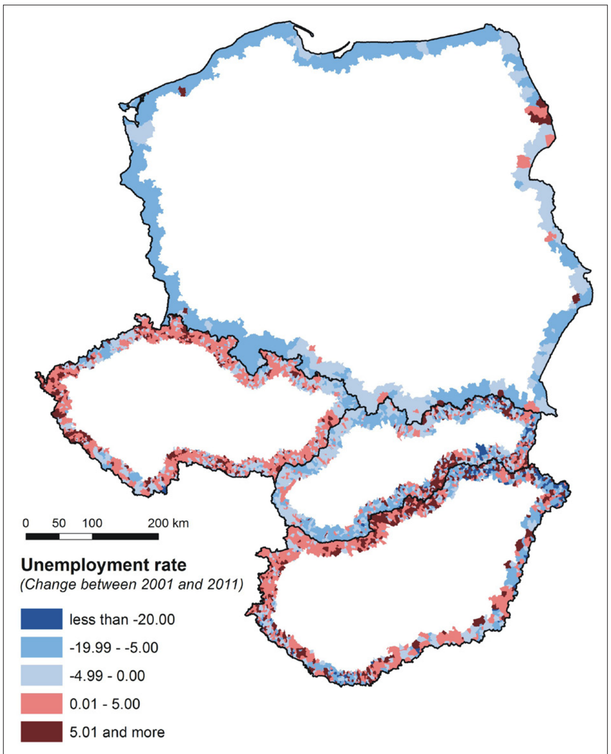

Fig. 7: Unemployment rate. Source: authors

were similar only between Poland and Hungary, greater differences appeared when analysing the borderland of these countries. Conversely, the values of the indicator were relatively similar between the Czech Republic and Hungary, as well as between the Czech Republic and Slovakia.

7. Concluding discussion

Despite de-bordering processes, as we pointed out in our study, borders and the borderland remain to play an important role in academic research. Thus, a number of authors are devoted to this phenomenon from different aspects. As already emphasized in the earlier work of Anderson and O´Dowd (1999), the importance of borders and borderland, as well as their geographic location, is changing significantly in space and time. Such diversity is well expressed in their statement that "they (meaning borders) are at once gateways and barriers to the 'outside world', protective and imprisoning areas of opportunity and/or insecurity, zones of contact and/or conflict, of co-operation and/or competition, of ambivalent identities and/or the aggressive assertion of difference" (Anderson and O´Dowd, 1999: 595).

Moreover, under the influence of globalization processes, the borderland becomes a particularly interesting area for research. Globalization becomes an argument that points to a kind of borderless and deterritorialized world, and thus allows the opening of borders that divided us previously (Newman, 2006).

Even now, the presence of boundaries can have a different influence on the area in the vicinity of the borders, the borderland. The borderlands differ from each other in their status so much that we can even recognize several types of borderland. This is especially the case if we take into account the change in the nature of the borderland, caused by the EU enlargement process, which brought together countries with different levels of economic development and integration, resulting in increased regional disparities. Spatial characteristics of the borderland of the EU have changed so much that many of these areas have become peripheral. This is particularly a problem of the eastern (external) borderland of the EU, while the western borderland represents, due to mitigation of its borders, a rather open space for cooperation in the area on both sides of the border (Xheneti et al., 2012).

In our reasearch, we have focused on the analysis of the V4 countries, whose borders and borderlands have played an important role not only in the past (the Iron Curtain), but also today (as the eastern, external border of the EU). We were interested in how the borderlands of these countries have developed over time, especially in relation to the selected group of indicators. In particular, we focused on both changes along the border (within the country) and changes between neighbouring areas on both sides of the border (cross-border relations). Using an Analysis of Variance model, we have shown the significance of selected indicators and their relevance to the study of the borderland of V4 countries, and thus we were able to determine similarities and differences in the changes of individual indicators within each of them. It is crucial, however, to highlight that although the analysis revealed homogeneity or heterogeneity of certain sets of indicators, this must still be regarded as a global analysis, which means that for detailed analysis of the adjacent regions across the border, further cartographic visualization and analysis of the indicators is required.

Further results from the analysis showed that geographically different borderlands have undertaken several paths in their development, and that the change of a particular indicator in the period 2001–2011 varied from state to state. A negative change of values of almost all monitored indicators occurred in the north-eastern CZ/PL borderland (on the Czech side), the central part of HU/SK borderland (on the Hungarian side), the southern part of the HU borderland, and the northern part of the eastern borderland of PL. In these areas in the period 2001–2011, the growth index declined and, in contrast, other indicators such as the ageing index, unemployment rate and the economic dependency ratio increased. Thus, these areas can be described as rather peripheral in relation to their situation in the group of selected indicators. Several authors have come to a similar conclusion, especially when talking about the CZ/PL borderland. For instance, Kladivo et al. (2012) described certain areas of the CZ/PL borderland as peripheral (especially mountainous rural areas with a population decline and an absence of major transport infrastructure and urban centers). On the other hand, the stronger peripheral position of the South Moravian borderland, as stressed by Vaishar et al. (2013), was not reflected in our analysis, although it is quite understandable since both studies are based on different delimitation criteria of the borderland.

In general, the most favorable changes in the value of indicators were recorded along the PL and SK borderland. Moreover, some areas within the borderland of these countries were identified by Johnson (2009) as the regions of prosperity (the triangle between PL/CZ/DE) or zone of active cross-border cooperation (especially the PL/SK borderland) by Wieckowski et al. (2012).

The general peripheralization of the eastern (external) border of the EU was neither fully confirmed nor rejected in our analysis, since only two of the four negative-evolving areas were identified along the HU/RS (Serbia) and partially PL/BY (Belarus) borderland. It would be interesting to follow the development of these and other indicators on the opposite side of the external border of the EU, in the borderland of non-EU countries such as Belarus and Ukraine, as well as along the northern borderland of Serbia and Bosnia and Herzegovina. Would such an analysis confirm the pronounced peripherialization of the external border of the EU? At this point in time, we can only argue about these and similar conclusions, especially due to current data availability. But a detailed analysis of the borderland is of vital importance and deserves more research attention. This would enrich the current research in the field of borders and borderlands and allow us to answer questions that have not yet been answered.

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Potential geo-ecological impacts of the proposed Danube–Oder–Elbe Canal on alluvial landscapes in the Czech Republic

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Abstract

The project of a canal connecting the three major Central European Rivers: the Danube, Oder and Elbe, is incorporated into a planned trans-European transport network system. Geographically, the course of the planned canal stretches into the territory of four Central European countries, predominantly that of the Czech Republic. The environmental impacts of the potential construction and operation of the Danube–Oder–Elbe (DOE) Canal is currently widely discussed by experts from various fields. This paper aims to assess some potential impacts of the canal on the alluvial landscapes in the Czech Republic. The method of geo-ecological assessment presented here applies GIS analyses at the larger landscape scale. The results of the geo-ecological assessment of potential impacts of the DOE Canal on the land-use of river floodplains, the fluvial dynamics of streams and the extent of their alluvial plains, and the quantified DOE Canal impact on protected areas and groundwater sources, are presented. The hydrological impact of the DOE Canal will affect a total of 1,975.4 km^2 of river basins in the Czech Republic. The DOE Canal will affect 157 sites significant from the perspective of landscape and nature conservation, 7 nature parks and 113 existing water points which are used as groundwater sources. The results show that the most significant disruption of fluvial dynamics of the stream sediment regime would occur in the Protected Landscape Area of Litovelské Pomoraví. In general, the geo-ecological impact of the DOE Canal on the landscape will be very important.

Keywords: *Geo-ecological assessment, GIS analysis, hydrological impact, protected areas, floodplain forests, DOE Canal, river floodplain, alluvial plain, Czech Republic*

1. Introduction

The project of a canal connecting the three largest Central European rivers – the Danube, Oder (Odra) and Elbe (Labe) – (hereinafter the DOE Canal) – presents a long-term risk to land use in the wide river floodplains in the Czech Republic (Buček and Machar, 2012). Both the extent of the expected impact on the landscape and the estimated investment costs of the DOE Canal, make it unprecedented in the Central European context (Tournaye et al., 2010).

The first serious proposal for a waterway connecting the Danube and Morava with the Oder, Vistula and Elbe Rivers was published in a Latin treatise by Lothar de Vogemont in Vienna in 1700 (Bartoš, 2004). The intention to build a canal connecting the Danube, Oder and Elbe was mentioned in the first Austrian Water Act of 1869 and the Moravian Provincial Water Act of 1870. Ing. Podhagský designed a project for the canalization of the Morava River at the request of the Moravian Province Committee in 1877. A complex project for the Morava river canalization, including a plan of connecting the Danube and the Oder, was presented by Provincial Building Councillor Ing. T. Nosek in 1882 (Nožička, 1957). In 1901, the Imperial Council in Vienna passed the Austro-Hungarian Waterway Act. Following its enactment, a canal was to be built between the Danube and the Oder, together with a navigation channel connecting it with the Elbe. In addition, a canal between the Danube and the Moldau (Vltava) was to be built near České Budějovice, together with a navigation channel between the Danube–Oder canal and the Vistula River and further as far as the navigable section of the Dniester River.

In 1931, the Czechoslovak Republic adopted a new Waterway Act. At that time the total costs of the DOE construction were estimated at three billion crowns. The construction was to take place in two six-year stages. During the first stage, the Danube-Oder canal was to be built, to be connected to the Elbe in the second stage of the construction. Nazi Germany decided to situate the main Danube port of the DOE Canal near Vienna. Between 1938 and 1943, three canal sections were built in Lobau on the eastern edge of Vienna, using concentration camp prisoners as labourers. In the long history of the proposed canal, these 9 kilometres represent the only section of the Danube–Oder–Elbe Canal constructed to date (Petrášová and Machalíková, 2013).

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In 1966–1968, a General Solution of the Danube–Oder–Elbe Canal Interconnection was produced, representing the most comprehensive and detailed design of the DOE Canal to date (Buček, 2005). The course of the canal was designed at 1:10 000 scale, with longitudinal profiles and blueprints of the main facilities. The General Solution served as the principal document for Government Decree No. 167/1971 and Presidium Decree No. 299/1972. These decrees, which are no longer valid, stipulated the protection of the future course of the DOE Canal in territorial plans of all levels. At present, the course of the DOE Canal is incorporated in several regional spatial planning strategies (the so-called Development Principles) and is part of the spatial planning documentation of a number of municipalities. The national concept of spatial planning in the Czech Republic (Spatial development policy of the CR) advises further examination of the DOE project (Machar, 2012).

The corridor of the planned DOE Canal in the Czech Republic includes wide river floodplains of eight biogeographical regions, within all four biogeographical sub-provinces of the Czech Republic (sensu Culek, 1996). The potential impact of the DOE Canal on the landscape of the Czech Republic has been subject to scientific research and assessment only in the past two decades (Buček and Kříž, 1989; Vlček, 1992).

The Gabčíkovo water reservoirs constructed on the Danube offer a partial geo-ecological analogy, albeit on a much lesser extent, to the situation which would arise after the completion of construction of the DOE Canal in the floodplains of large Central European Rivers (Zinke, 2002).

This paper deals with some of the potential geo-ecological impacts of the DOE Canal on the landscape of large lowland river floodplains in the Czech Republic, which can be assessed in a GIS environment. It focuses particularly on the potential impact of the DOE Canal on the land-use of river floodplains, the fluvial dynamics of streams and the extent of their alluvial plains, and it quantifies the DOE Canal impact on protected areas and groundwater sources. At present, the DOE Canal project is subject to political and, in particular, expert discussions, both in the Czech Republic and in the neighbouring states. These discussions should be based on scientific evidence. The present paper contributes to the discussions of potential impacts of the DOE project on the biodiversity and ecosystem functions of the Central European lowland alluvial landscape.

2. Study area

The DOE Canal project encompasses plans to build an artificial waterway of international importance which is incorporated into the Trans-European Transport Network ("Ten-T": European Commission, 2003). The route of the planned canal lies in the territory of five European countries – Czech Republic, Slovak Republic, Austria, Germany and Poland (Fig. 1). For the purposes of this paper, the defined study area encompasses the area of the Morava, Elbe (Labe) and Oder (Odra) River basins in the Czech Republic.

3. Material and methods

The analyses are based on the DOE Canal route designed in the General Solution of the Danube-Oder-Elbe Canal Interconnection (Hydroprojekt, 1968), adjusted to meet the specifications of current Development Principles of individual Czech regions. The DOE Canal route was digitized using ARC GIS 8.2 on maps of scale 1:10 000. The digitization and related GIS analyses were conducted in the period 2003–2005 (Obrdlík and Machar, 2005).

The technical parameters of the DOE Canal in the Czech Republic were adopted from a paper by Kubec (2002): a man-made canal of an average surface width of 60 m, with a year-round guaranteed minimum draft of 280 cm, suitable for cargo ships of 11.4 m in width, 110 m in length and 2,500 t tonnage, and for tug boats of 185 m in length. The highest elevation in the Oder branch is 285 m above sea level, in the Elbe branch 395 m. These elevations are to be reached

Fig. 1: Project of the DOE Canal in Central Europe – general situation. Source: authors' elaboration

through the construction of lock chambers with a minimum width of 12.5 m. The route of the canal is to incorporate a number of locks and dams (Kubec and Podzimek, 1988).

After reduction to scale 1:10 000, the digitized route of the DOE Canal was overlain on the digital version of the Basic Water Management Map of the Czech Republic, to locate the points where the DOE Canal route crosses watercourses in the Morava, Oder and Elbe river basins. The GIS analysis enabled categorization of watercourses according to the type of crossing with the route of the DOE Canal (see Tab. 2). The technical solution of the DOE Canal envisages two possibilities of a watercourse crossing the canal: the watercourse is either channelled under the canal body through an artificial conduit or it opens straight into the DOE Canal, thus providing water for the canal.

Watercourses opening into the canal will therefore be deprived of a certain (probably significant) part of their discharges in their sections downstream of the canal crossing. The area of the river basin which is drained by such a stream prior to the construction of the DOE Canal will therefore be subject to hydrological impact after the canal construction. This hydrological impact will be caused by the impoverishment of the water, which will supply the canal (from watercourses opening into the canal).The resulting impact on the entire basin of the affected stream is then expressed by the ratio between the hydrologically-affected area of the basin to the area of the entire basin of the stream. Experts consider values exceeding 60% to be a highly significant hydrological impact on a river basin (Jones and Mulholand, 2000).

In the following step, the area of floodplains subject to hydrological impact of the DOE Canal was identified by GIS analysis. This was carried out by overlaying the areas of affected basins with the areas of inundation (flood) plains, adopted from the Basic Water Management Map and specified within the land-use plans of individual settlements, including the current changes in the definition of flood areas at the time of conducting the GIS analysis in 2005.

By overlaying the areas of floodplains subject to hydrological impact with the vector layer of boundaries of specially protected areas valid in 2005, the GIS analysis identified areas important in terms of nature and landscape conservation, which will be affected hydrologically by the DOE Canal.

The impact of the DOE Canal on groundwater supplies was analysed in a similar manner by overlaying the canal route with hydrologically affected inundation plains.

To obtain information about the current land cover along the route of the DOE Canal, a digital CORINE map with the projected digitized DOE Canal route was used (Pechanec, 2012). This data layer was then applied in a preliminary analysis of the DOE impact on dominant fluvial processes, which condition the dynamics of the fluvial succession series of floodplain biotopes (Machar and Pechanec, 2011). A digital layer of landscape types according to the relative altitudinal zonation (Demek and Mackovčin, 2006) was used for the basic identification of dominant fluvial processes (Rosgen, 1996) in the river basins of the study area. Based on the overlays of river basin areas and altitudinal zonation, river basin types according to the dominant fluvial dynamics were identified. An overlay with the digitized canal route enabled a preliminary assessment of the potential impact of the canal on the dynamics of the fluvial processes in these alluvial landscapes.

In 2012–2013 the GIS analyses were complemented by preliminary field research in the study area. The field research focused on recording sites significant from the perspective of nature and landscape conservation, and which are at the same time potentially subject to impact on their streams' hydrologic and sediment regimes after the DOE Canal construction. A total of 338 sites were recorded in the course of the field research, during which a total of 1,560 jpg images were taken. The locations of individual recorded sites were then digitized and interlinked with the individual images in a GIS project, which enables their location and interactive viewing.

4. Results

The digitized route of the DOE Canal within the territory of the Czech Republic measures a total length of 418.1 km, with 44.6% in the Elbe River basin (186.4 km), 24.8% in the Oder River basin (103.6 km), and 30.6% in the Morava River basin (128.1 km).

The GIS analysis of watercourse categorization according to the type of crossing of the route of the DOE Canal (Tab. 1), shows that most watercourses (i.e. 1,650.6 km) are to be channelled into the canal (i.e. 83% of the total length of watercourses crossing the canal). Only 17% of watercourses are to be channelled under the canal body through a conduit (the discharge regime of these watercourses will therefore not be affected by the canal). From the environmental perspective it is significant that 19% of the total length of watercourses (i.e. 382.4 km) will be affected by discharge deprivation due to water channelled into the canal.

Categories of watercourse sections based on the DOE impact	Section	Length (km)
Watercourse sections between opening to the DOE Canal and opening to a higher-order stream	A	382.4
Watercourses opening to the DOE Canal (watercourse water is utilized)	B	654.4
Watercourses opening into streams opening into the DOE Canal	C	621.9
Watercourse sections between the conduit under the DOE Canal and opening into a higher-order stream	D	16.2
Watercourses opening into the conduit under the DOE Canal	E	79.4
Watercourses opening into watercourses opening into the conduit under the DOE Canal	F	234.4
TOTAL		*1,988.7 km*

Tab. 1: Classification of watercourses in the Czech Republic based on the type of crossing with the DOE Canal
Source: authors

The hydrological impact of the DOE Canal will affect a total of 1,975.4 km^2 of river basins in the Czech Republic (Tab. 2). A total of 629.6 km^2 of river basins will be subject to significant hydrological impact (over 60%, see Material and methods, above) caused by the DOE Canal.

The area of alluvial plains potentially subject to hydrological impact (see the section on Material and methods) of the DOE Canal in the Czech Republic is 682.02 km^2. Approximately half of this area (48%) will be subject to a very significant (over 60%) hydrological impact (Tab. 3).

The sites which will be highly affected include mainly segments of the alluvial landscape in the Morava River basin: Litovelské Pomoraví – 52.8 km^2 (Fig. 2, cover p. 2), floodplain at the confluence of the Morava and Bečva Rivers – 147.4 km^2, the Morava River floodplain at Uherské Hradiště – 7.9 km^2, the Morava River floodplain between Rohatec and the Dyje River confluence – 116.5 km^2, floodplain of the Třebůvka River – 1.2 km^2, and the floodplain at the confluence of the Oder and Olše Rivers in the Oder River basin – 3.0 km^2 (Fig. 3).

The DOE Canal will hydrologically affect 188.1 km^2 of sites significant from the perspective of landscape and nature conservation (157 sites, see Tab. 4). 35 specially protected areas (covering a total of 14.7 km^2) will be affected by the direct loss of land due to the canal construction (60 m canal width, plus a 100-metre-wide canal construction site and canal embankment).

The DOE route runs across seven nature parks (Tab. 4), whose role is to protect the preserved landscape character (Löw and Míchal, 2003). The construction of the DOE Canal as a line transportation route could radically change the landscape character of these sites.

The DOE route in the study area would directly affect 113 existing water points which are used as groundwater sources. A total of 346 groundwater sources are situated in the area potentially impacted by the DOE Canal. Impact on the natural groundwater flow caused by the canal construction cannot be ruled out in these water resources.

The current land uses along the planned DOE route are shown in Tab. 5. The dominant land-use forms around the DOE route are farming (55.7%) and nature conservation (27.4%), while human settlements account for only 2.3%.

Preliminary information on the potential impacts of the DOE Canal on the fluvial sediment dynamics of streams in the study area is provided in Tab. 6. Sediment sources of the study area streams fall predominantly within the areas of the Hrubý Jeseník, Nízký Jeseník and Beskydy Mts. The GIS analysis identified streams whose sediment transport from the source areas will be disrupted by the DOE Canal. The results shown the most significant disruption of fluvial dynamics of the stream sediment regime will occur in the Protected Landscape Area of Litovelské Pomoraví (Fig. 4, see cover p. 2). The disruption of fluvial dynamics of the stream

Hydrological impact (%)	Area of river basins subject to hydrological impact	
	km^2	%
0.001–10	678.54	34.4
10.001–20	288.52	14.6
20.001–30	202.83	10.3
30.001–40	16.07	0.8
40.001–50	38.89	2.0
50.001–60	116.24	5.9
60.001–70	4.77	0.2
70.001–80	165.85	8.3
80.001–90	28.26	1.4
90.001–100	435.46	22.1
TOTAL	*1,975.43*	*100.0*

Tab. 2: Hydrological impact on river basins in the Czech Republic after the construction of the DOE Canal
Source: authors

Alluvial landscapes subject to significant DOE impact	Area of alluvial landscape (km^2)	Hydrological impact (%)
Morava River floodplain above Olomouc	52.83	80.8
Morava River floodplain below Olomouc, confluence with the Bečva River	147.37	72.2
Morava River floodplain above Uherské Hradiště	7.92	93.9
Morava River floodplain below Rohatec, confluence with the Dyje River	116.52	78.8
Meanders of the Oder, confluence with the Olše River	3.03	72.2
Třebovka River floodplain	1.25	70.3

Tab. 3: Hydrological impact on inundation areas in the Czech Republic after the DOE Canal construction
Source: authors

Category	Number
Small-scale protected areas	94
Large-scale protected areas	4
Nature parks	7
Sites of European importance	47
Bird areas	5
TOTAL	*157*

Tab. 4: Protected Areas and Nature parks in the Czech Republic subject to hydrological impact by the DOE construction. Source: authors

sediment regime in the area would trigger gradual ecosystem changes in fluvisoil pedogenesis (Kulhavý and Sáňka, 2009), as well as in the river-bed forming processes within the anastomosed river system (Kirchner and Ivan, 1999).

5. Discussion

This paper outlines a relatively wide range of GIS analysis applications (Burrough and McDonnel, 1998) in the assessment of the expected DOE impact on the hydrological regime of the landscape. GIS analysis may objectify the expected DOE impacts on the landscape to a greater degree than has been achieved in other available landscape-ecological assessments to date (e.g. Hasik, 2008). The type

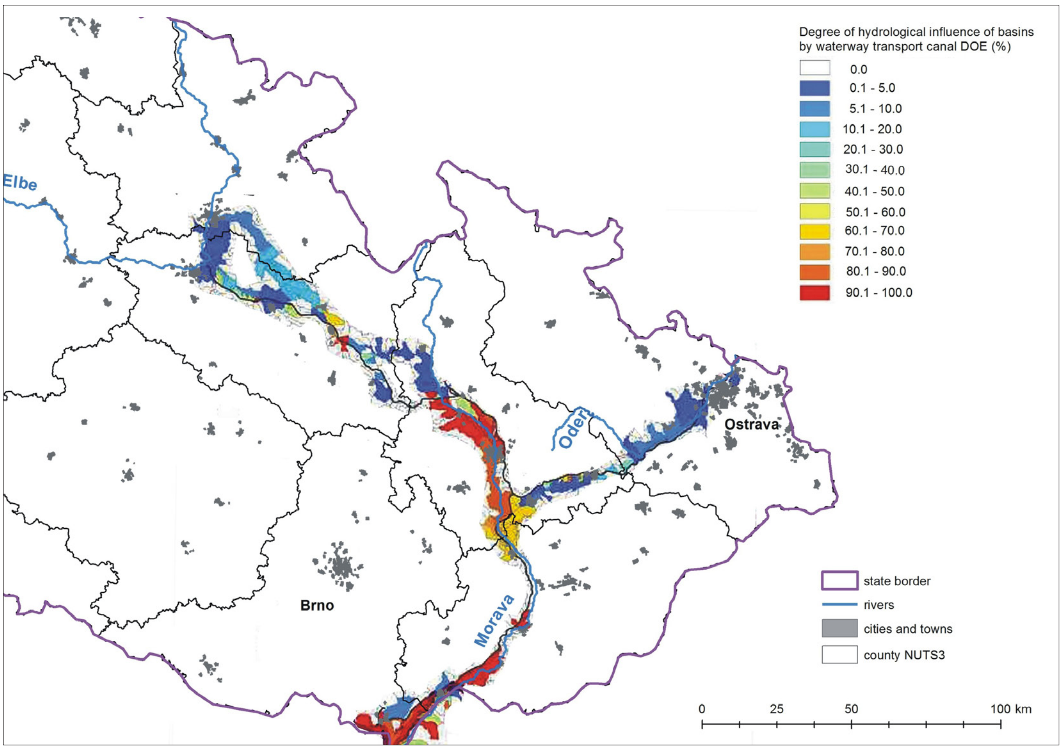

Fig. 3: Alluvial landscapes in the Czech Republic subject to significant hydrological impact of the DOE Canal project Source: authors' elaboration

Dominant land use along the DOE route	Length (km)	Proportion (%)
Built-up areas	9.84	2.33
Forest management, except for nature protection areas	20.92	5.01
Nature and landscape protection	114.79	27.44
Watercourses	39.74	9.52
Farmland	232.81	55.70

Tab. 5: Land use along the DOE route in the Czech Republic. Source: authors

Dominant fluvial processes in the river basins	Basin area (km^2)	Proportion (%)
Basins with dominant erosion processes (mountain areas)	2,102.95	7.15
Basins with erosion and transport processes (upland areas)	9,660.82	32.83
Basins with transport and accumulation processes (hilly areas)	14,271.50	48.50
Basins with dominant accumulation processes (lowlands, flatlands, plateaux)	3,389.79	11.52

Tab. 6: Proportion of dominant fluvial processes in river basins in the Czech Republic subject to hydrological impact of the DOE Canal. Source: authors

of GIS analysis used in this research has been increasingly applied in the process of strategic environmental assessments of investment project impacts on the landscape (Fischer, 2007). GIS applications support environmental analysis of the cumulative impacts of investment projects on the landscape, and applications in the frame of landscape planning (Kolejka and Pokorný, 2000; Sklenička, 2003).

The GIS analysis indicates that the construction and operation of the DOE Canal will trigger changes in the discharge conditions in 19% of the total length of all watercourses crossing the canal body in the landscape. These watercourses can provide their water to the canal. In order to safeguard a stable depth in the canal, discharges in these water courses will probably be permanently decreased and, moreover, the decreased discharges will fluctuate throughout the navigation season to meet the requirements of the canal. The DOE Canal will therefore affect the ecosystem functions (Pithart and Křováková, 2012) of at least 382.4 km of waterways. In this context, minimum ecological discharges will need to be maintained in the affected streams, which may pose problems particularly in small watercourses (Macklin and Lewin, 1997). Water which will be available for discharging out of the canal to improve or maintain the minimum discharges of the streams, will probably have altered physical and chemical properties due to its stagnation in the canal bed – it may be assumed that in the summer months the canal water will be warmer than water in the surrounding streams, it may contain increased concentrations of nutrients, etc. (Valett et al., 2014). Water discharged from the canal to the streams may have a significant impact on oxygen conditions, the self-purification capacity and eutrophication of the river ecosystems (Bridge, 2003).

Strategic environmental assessments of large investment projects (similar to the DOE Canal) in EU countries (Glasson et al., 2005) accentuate, among other things, the principles of the European Landscape Convention (Salašová, 2012) promoting an ecosystem approach (Yafee, 1999). The latter finds its optimum application at the landscape scale of river basins (Eiseltová and Biggs, 1995). Based on the GIS analysis, the DOE Canal may hydrologically impact a total of nearly 2,000 km^2 of river basins in the Czech Republic. The DOE Canal construction and its hydrological impact on the respective inundation areas may conflict with the concept of river landscape restoration (Molen and Buijse, 2007), which encompasses the issue of restoring the water retention capacity of river landscapes (Štěrba, 2008), drawing on the principles of close-to-nature flood control measures which have been widely discussed in relation to climate change and the related adaptation measures (Bren, 1993).

According to the GIS analysis, the DOE Canal will significantly affect a total of 157 sites for nature and landscape protection. The GIS analysis yields only approximate information, as the construction and operation of the canal may affect these sites in a different ways and with different intensity, depending on the subject of protection and the type of habitats in a given site (Roth, 2003). Some of these sites belong to the Natura 2000 network. A special legislative regime of assessing investment project impacts on species and habitats of European importance is valid for the sites within the Natura 2000 network (European Communities, 2002). This special assessment of the DOE project to Natura 2000 sites should be applied in the future.

Using a method of evaluating habitats of European importance and GIS analysis, Machar (2010a) determined the ecological damage caused by the DOE Canal construction amounting to 1.043 billion points (Seják and Pokorný, 2008). When considering the current point value (15.88 CZK/point in 2013), this represents a loss of CZK 16.5 billion. The annual loss in the most vulnerable regulation and supporting ecosystem services in the landscape of the Czech Republic, due to the DOE Canal construction, as estimated by the Environmental Committee of the Academy of Sciences of the Czech Republic using the energy-water-vegetation-based method, amounts to tens of billions Czech crowns (Šrám, 2014).

Nature parks, designated with the primary objective to protect landscape character, may be affected both by the DOE Canal construction itself and by the set of canal-related investment projects (high bridges, percolation channels, rerouting of roads, etc.). The DOE Canal would in all probability significantly affect the landscape character of the Morava, Oder and Elbe River floodplains in the entire study area.

The results of land-use analysis of areas lying in the proposed route of the DOE Canal have shown that, in line with the well-known land use in the Czech Republic (Bičík et al. 2010), utilized agricultural area represents the dominant land-use type in the affected floodplains. The second most widespread land-use form in the DOE Canal route is the area used for the purposes of nature and landscape protection (Tab. 4), which is highly relevant information for the environmental assessment of the DOE project. The fact that the DOE Canal may affect a significant part of protected areas tends to be one of the key arguments used by opponents of the DOE Canal project (Štěrba, 2004).

The GIS analysis can provide only preliminary information about the potential impact of the DOE Canal on the natural groundwater flow in the floodplains of the study area. Therefore, the analysis presented in this paper focused only on point groundwater sources. The aim of this analysis is to draw attention to the potential problems related to water sources in the area, which might be subject to hydrological impact of the DOE Canal, as part of the discussion about the possible consequences of climate change on water sources within the floodplains of large Central European rivers (Dvořák et al., 1997). The river alluvium of a watershed is the landscape-ecological backbone of a given catchment area (Haslam, 2008). The GIS analysis of the DOE project presented in this paper shows different degrees of impact on river alluvia in the Czech Republic, indicating that the key areas of ecological networks (Jongman, 1995) are among the most hydrologically affected segments of floodplain landscapes (Tab. 3). Floodplain forests represent one of the key ecosystems of the alluvial landscape (Klimo and Hager, 2001), as they act as important biota refuges in Central European cultural landscapes and enhance the ecological functions of lowland rivers as supra-regional bio-corridors. A study analysing the DOE project impact on the floodplain forest ecosystems in the Czech Republic (Machar, 2010b) showed that most floodplain forest geobiocenoses in the inundation plains of the Czech river alluvia would be subject to significant hydrological impact.

The hierarchical level of beta-diversity (Plesník, 2012) is important for the biodiversity of floodplain forests along lowland rivers (Klimo et al., 2008). The fluvial dynamics in European temperate zone floodplains, however, is radically influenced by anthropogenic landscape use, as it falls within the prehistoric oikumena, i.e., the zone of prehistoric settlements from the Neolithic to the present (Poláček, 1999). Within the Central European landscape, sites with preserved fluvial dynamics are very rare (Pedroli, 1999). Seen from the environmental perspective, the results of the GIS analysis identifying significant impacts of the DOE Canal on such areas in the Czech Republic (e.g. Litovelské Pomoraví, see Tab. 3) are therefore controversial.

The main problem identified by the GIS analysis comes in the form of the crossing between the Morava River and the canal, which envisages opening the river into the canal. An alternative, a theoretically possible technical solution of the crossing between the Morava River main stream and its branches and the canal (e.g. canal crossing the Morava floodplain via a suspension bridge), would necessitate a solution to deal with an over 100 m altitudinal difference in the canal level in the vicinity of Králová by Litovel. Some of the latest canal studies envisage a ship lift solution.

In the frame of assessing the DOE Canal impacts on floodplain habitats, the primary focus is on vegetation response to changes in the soil moisture regime (Maděra, 2001). In the past, the soil moisture regime in floodplain forests on river alluvia in the Czech Republic has undergone a number of dramatic changes caused by anthropogenic factors. Probably the most exact data related to this issue were obtained in the course of long-term detailed ecosystem research of the South Moravian Dyje River floodplain, conducted under the international Man and the Biosphere programme (Penka et al., 1985), the results of which may be used as a reference framework for assessing the anthropogenic impact on analogous river floodplain ecosystems. This is due to the fact that the first research stage took place at a time when the natural soil moisture regime, influenced by regular inundations from the natural channel of the Dyje River, still existed in the floodplain forests, while the second stage monitored the conditions and behaviour of the ecosystem under the impact of drastic water-management measures carried out on the Dyje River. Water-management-induced impact on recent soil processes in the floodplain forest ecosystem resulted in a decrease in the gravitational and capillary water content in the rhizosphere and an increase in the aeration of upper soil layers (Penka et al., 1991). The termination of floodplain forest inundations, with their regular production and deposition of sediments, had therefore changed not only the soil moisture regime but also the nutrient cycle and the specific pedogenetic process of humus horizon formation (Prax et al., 2008). Hydro-technical measures taken in the alluvial landscape, which result in a drop in groundwater levels and elimination of floods, significantly decrease the biodiversity of floodplain forest communities (Štěrba et al., 2000).

A certain analogy for the planned construction of the DOE Canal in the Central European geographical space may be found in the construction of the Gabčíkovo barrage system in the Slovak Republic (Holčík, 2001), the so-called System of Waterworks on the Danube (SWD). Upon completion of SWD, the course of the Danube was diverted into a sealed artificial navigation canal which prevents water infiltration into the subsoil, while the original riverbed is fed only the remaining water which is not used for the canal. Prior to the construction of SWD, floodplain forest ecosystems of the Danube formed an inland river delta with a branched-out river system, where a dynamic communication between the main channel, its lateral branches and the inundation area took place under the conditions unaffected by hydraulic engineering works. After the construction of SWD, however, the original landscape ecosystem of the Danube inland river delta has been gradually disappearing. In total, the change in hydrological regime due to SWD affects over 1,000 km^2 of river alluvium (Oszlányi, 1999). The entire belt of drained land spanning some 250 m along the old Danube is in a critical ecological situation as well. It is becoming apparent that simulated artificial irrigation has succeeded in preventing the predicted massive forest dieback to a certain extent so far (Oszlányi, 2000).

Naturally, when assessing major investment projects, the precautionary principle needs to be applied due to the fact that input data for environmental landscape analyses tend to contain a certain degree of uncertainty. Application of the precautionary principle seems to be warranted in this case, as the sheer scope of landscape impact, the estimated degree of environmental damage and required investment costs make the DOE project unprecedented in the context of the Czech Republic. The potential construction of the DOE Canal would probably be the most extensive and the most expensive development project in the history of the Czech Republic with a significant environmental impact. The DOE Canal route is situated in the landscape of large Central European river alluvia, which require rehabilitation of their ecosystem functions, particularly in the context of the expected consequences of climate change.

6. Conclusions

The results of this paper show that some environmental aspects of the planned DOE Canal may be assessed using GIS analysis of the available data. A synthesis of the results presented here has shown that some potential environmental impacts of the DOE Canal on the landscape may be at least preliminarily quantified and objectified.

The hydrological impact of the DOE Canal will affect a total of 1,975.4 km^2 of river basins in the Czech Republic. The DOE Canal will hydrologically affect 157 sites significant from the perspective of landscape and nature conservation, 7 nature parks and 113 existing water points which are used as groundwater sources. The results show that the most significant disruption of fluvial dynamics of the stream sediment regime would occur in the Protected Landscape Area of Litovelské Pomoraví. The results obtained are discussed in the context of known analogies from the Central European geographical space.

The issue of restoring the ecosystem functions of large river alluvia in the Czech Republic could be addressed, for example in a specialized landscape plan for the Morava, Oder and Elbe river floodplains, which might simultaneously be used as a reference for assessments of other plans related to the DOE Canal project.

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Modification of the potential production capabilities of agricultural terrace soils due to historical cultivation in the Budina cadastral area, Slovakia

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Abstract

The soil production attributes of historical agrarian terraced fields were examined in the Budina cadastral area of the Ostrozky Mountains. This landscape represents a unique sub-mountainous Carpathian landscape with farms that use a historically preserved triple-field agricultural system. We determined the geo-spatial parameters of different types of land cover and terraces using geographic information systems. The soil depth was measured in the field, and the skeleton content was determined in the laboratory. We compared data regarding the potential production capabilities of the soil with data from the national classification of agricultural soils. Our results indicated that the soil productivity attributes improved because the naturally less fertile cambisols were positively affected by terracing and long-term cultivation. We recommend the preservation of traditional agricultural activities in historical terraced fields because these terraces represent valuable features that improve the quality of the landscape.

Keywords: *Traditional land use, cultivated soils, production capability, physical soil attributes, classification of agricultural soils in Slovakia*

1. Introduction

This study focuses on valuable traditional rural landscapes in the sub-mountainous and mountainous Carpathian regions of Slovakia. The period of agricultural collectivisation (1950s–1970s) is regarded as one of the most important periods in terms of landscape development in Slovakia. Traditionally-managed agricultural landscapes, which once covered more than half of the Slovak territory, were transformed into large-scale fields. Only fragments of traditional agricultural landscapes have survived (Lieskovský et al., 2014). Agricultural intensification during the 1970s resulted in the abandonment of traditional agricultural practices, which reduced the biodiversity associated with historical land uses (Bezák and Halada, 2010). Heterogeneous historical agricultural landscapes are disappearing in Slovakia (Olah et al., 2012; Mojses and Petrovič, 2013) and in other European countries (Beilin et al., 2014), such as those in Scandinavia and Iberia. Land cover in traditional agricultural landscapes is heterogeneous, and historical agricultural activities have created conditions that promoted the vast diversity of biotope types (Lindborg and Eriksson, 2004). Zilioli et al. (2011) highlighted the fundamental role that soil science plays in the conservation of natural resources and in achieving sustainable management of mountain ecosystems. The study area considered in this paper surrounds Budina Village in the Ostrozky Mountains of Central Slovakia. Budina was founded in the 14th century during a wave of Wallachian colonisation. Traditional land use persists in this area (Fig. 1).

Frequently, terraced fields are formed by ploughing along contours (Stankoviansky, 2001). Terraces are a valuable feature of the cultural landscape of the study area (Slámova et al., 2013), and are a "landscape-resource" with high potential for sustainable development in many mountain areas (Lasanta et al., 2013). Terracing is used world-wide. The ages of terraces vary between different countries: some of the oldest terraces were established between 7400 and 4000 BC (the Late Neolithic and the Early Bronze Age) in Greece (van Andel et al., 1990); and terraces have been cultivated for 1,500 years in the Colca Valley of Peru (Dick et al., 1994).

Terraces are classified into different categories. Lasanta et al. (2013) observed bench terraces, in which the flat area is delimited in the lower part by a vertical step (a stone or talus wall covered by shrubs or fruit trees). A second type of terrace is represented by small slope gradients that are delimited by herbaceous vegetation, or a wall made from stones that were removed from the field. Critchley and Brommer (2003) documented the existence of bench terraces with small back slopes that allow excess runoff to drain away in countries with high rainfall (approximately 2,000 mm per year). In addition, Doolittle (1990) described important functional and design distinctions of different types of terraces, including hillside terraces and streamside gardens. The study area considered in this research is rich in contoured hillside terraces. These terraces were established primarily for agricultural use in Slovakia during the Walachian colonisation wave between the 14th and 16th centuries (Stankoviansky, 2011).

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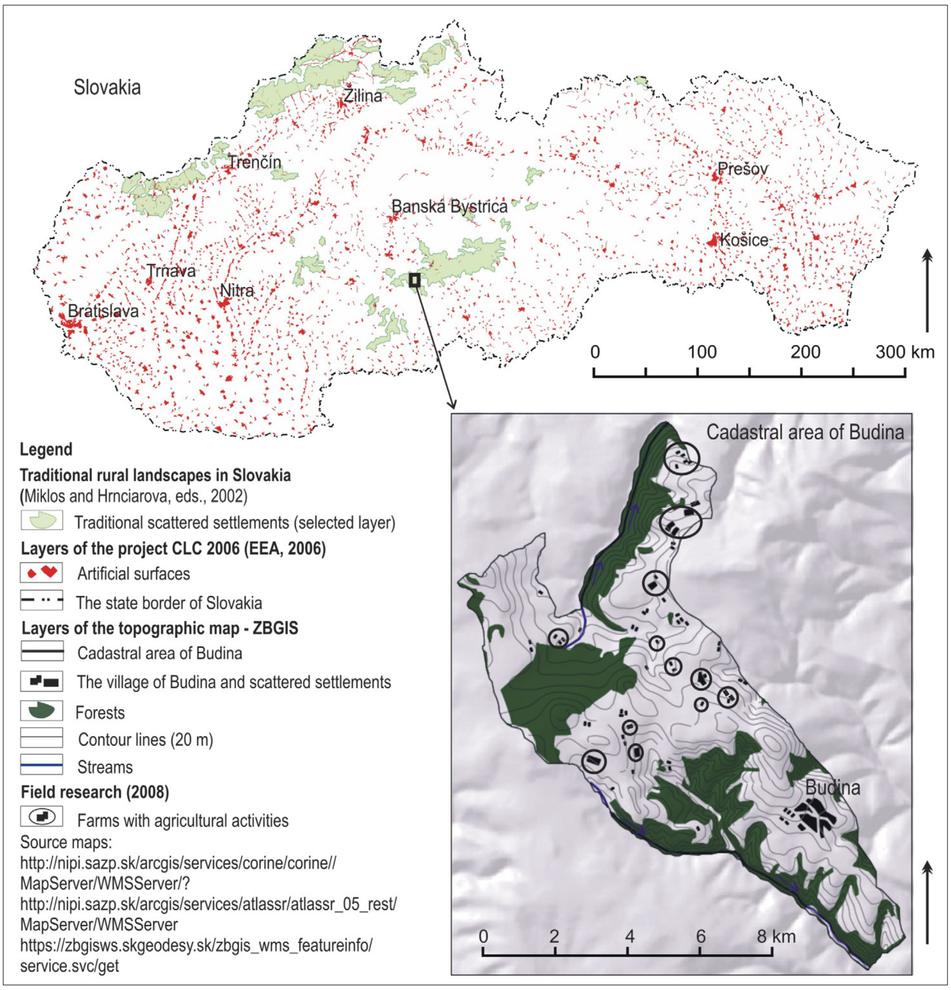

Fig. 1: Locations of the studied cultural landscape types in Slovakia; scattered settlements and farms with agricultural activities in the Budina cadastral area. Source: authors' elaboration

We identified farms that were cultivated in 2008 in the Budina area. Among the marginal agricultural areas in Slovakia, this area provides an ideal opportunity to observe the functional relationships of historical, triple-field agrarian systems, which are rarely used on farms today. The current socio-economic situation and demographic decline have resulted in the abandonment of traditional agricultural practices on terraces (Jakubec, 2011) (see Fig. 2 cover p. 4). The climate in this area is characterised by cold and wet summers. In this region, relatively high rainfall and temperatures ranging from 16–18 °C occur during July, the annual rainfall is 650–900 mm, and the annual mean temperature is 4–6 °C (Miklós and Hrnčiarová [eds.], 2002). The most abundant regional geological formations are neo-volcanic andesitic rocks with prevailing saturated and acid modal cambisols and cultisolic cambisols. Palaeozoic granodiorites are only found in the northern region of the mountains, which corresponds to the region in which ranker soils occur. Cultisolic cambisols cover the studied area, as stated in the Landscape Atlas of the Slovak republic (Miklós and Hrnčiarová [eds.], 2002).

2. Theoretical background

The term "cultisols" is used to classify basic soil ecological units (BSEUs) in Slovakia (Linkeš et al., 1996). BSEUs are relatively homogeneous units with similar ecological conditions for plant cultivation and are the basic units of agrarian land evaluation in the official classification system (Hraško and Bedrna, 1988). Although cultisols are classified in the official BSEU classification system, we did not find any cultisols in the study area. Terraces do occur, however. According to the World Reference Base for Soil Resources, the term "anthrosols" is used for cultivated soils. The parent material of anthrosols represents any soil material that has been modified by extensive cultivation or the addition of materials. The influences of humans are normally restricted to the surface horizon, but a buried soil may still be intact at some depth (IUSS Working Group WRB, 2006). Anthrosols include subtypes that have been studied by many authors, including those who have studied "plaggen soils" (Blume and Leinweber, 2004; Kalinina et al., 2009).

Generally, the topic of soils on historical agrarian terraces is not discussed broadly in Slovakia. Soils modified by human activities, however, have been the subject of several studies (Sobocká, 2011). Linkeš et al. (1996), the main authors of the manual for applying BSEU characteristics in practice, define cultisols as soils that have been substantially transformed by human activities, such as deep soil loosening and mixing of the soil profile, which are often associated with the construction of terraces. Krnáčová et al. (2013) define anthrosolic and cultisolic rendzinas, carbonate and lithosolic anthrosols and other soil subtypes in the study areas of traditional agricultural landscapes.

This research project considers the potential production capabilities of cultivated agricultural soils on historical terraces. Senjobi et al. (2007) showed how traditional farming practices affect the productive potentials of soils.

Several studies have discussed the improvement of soil attributes in historical agrarian terraces with long-term cultivation (Ciampalini et al., 2008; Goodman-Elgar, 2008; Ramos et al., 2007). Chen et al. (2012) documented why poor management and abandonment of terraced paddy fields result in major increases in soil erosion in mountainous areas. Antle et al., (2006) studied terraces in Peru and demonstrated that human activities are important driving factors behind soil formation that may positively or negatively affect soil productivity.

The potential production capability of agricultural soils in Slovakia is expressed in terms of the potential production categories or typologies of agricultural soils (Džatko, 2002). In our case, however, in which BSEU units do not refer to cultivated soils and cultisols on terraces only describe primary natural soils, we must establish whether the potential production capabilities of agricultural soils defined in the official typology reflect the current production potentials of cultivated soils in terrace systems. Furthermore, the typology provides recommendations on how to use agricultural soils within landscape-ecological limits.

We formulated the following two objectives for this research project: (i) to demonstrate the relationship between historical soil cultivation and the soils' current production capabilities based on selected physical attributes of the soil; and (ii) to propose amendments to the current classification system of agricultural soils in Slovakia to provide adequate financial subsidies.

3. Data and methods

3.1 Analysis of land-cover structures

The land cover structures used in this paper were analysed as part of a PhD thesis (Jakubec, 2011). We divided the agrarian structures into the following categories: ploughland on historical terraces (P-HLS-terraces); ploughland-fallow on historical terraces (PF-HLS-terraces); ploughland (P); ploughland-fallow (PF); intensively and extensively used grassland (G-1); grassland with a reversible succession to agrarian land use (G-2); grassland with irreversible succession to agrarian land use (G-3); mowed meadows; pastures; orchards; gardens; and wooded non-forest vegetation. The land uses of the studied agricultural plots are indicated in the European "Land Parcel Identification System" (LPIS). During the field research, however, we identified several agricultural plots that were not included in the LPIS. We included these plots as land-cover structures with agricultural land use; however, they were not considered when reclassifying the types of production categories.

All of the maps were analysed using GIS applications, including Quantum GIS Lisboa 1.8.0, which was released under general public licence, and ArcGIS 10.0TM (this software is multi-licensed). Ortho-photomaps were produced in 2010 by TU Zvolen for the CEX ITMS 26220120069 project and had a resolution of 0.2 × 0.2 m. Historical materials (aerial survey photographs, 1949) were provided by the Topographic Institution, Banska Bystrica (under student licence contract No. TOPU-90-16/2011, for PhD thesis work (Jakubec, 2011).

3.2 Evaluation of the potential production categories of agricultural soils

We vectorised the raster maps of the BSEU, which are available at http://www.podnemapy.sk, and created vector files of the BSEU polygons. Our research considered BSEU attributes, which are expressed in codes. In addition, we studied the soil depth and skeleton content. The collected parameters were classified and evaluated according to a guidebook (Linkeš et al., 1996). We used the following slope categories: very steep slopes (17–25 °) that are not suitable for agriculture; steep slopes (12–17 °) that are suitable for grasslands; moderate slopes (7–12 °) that are suitable for limited ploughland alternating with grasslands; gentle slopes (3–7 °) that are suitable for ploughland with few limits; planes with the possibility of water erosion processes (1–3 °) that are suitable for ploughland with few or no limits; and planes without the possibility of water erosion processes (0–1 °) that are suitable for ploughland without limits. Furthermore, we used the following categories for depth: deep soils (more than 60 cm), medium-depth soils (60–30 cm) and shallow soils (less than 30 cm). The skeleton content is expressed by weight. We used the following categories: no skeleton content (0) (up to a depth of 60 cm, no more than 10%); low skeleton content (1) (5–25% in the surface horizon, 10–25% in the subsurface horizon); moderate skeleton content (2) (25–50% in the surface and subsurface horizons); and high skeleton content (3) (25–50% in the surface horizon and more than 50% in the subsurface horizon).

The main soil types were divided into the following production categories according to the expected agricultural land use: moderately productive (P2) and slightly productive (P3), slightly productive ploughland alternated with highly productive grasslands (P3G1), highly productive grasslands (G1), moderately productive grasslands (G2), slightly productive grasslands (G), and agricultural soils that were not suitable for agricultural activities (N) (Džatko, 1981).

3.3 Field and laboratory research of the selected physical attributes of the soil samples

Field research was performed according to the handbook for mapping soils in the field (Čurlík and Šurina, 1998). We evaluated five terraces in June and July 2012 and calculated the arithmetic averages of each parameter for the terrace.

The selected attributes were described as a range, and the maximum depth at which the soil samples were collected was 30–35 cm. The soil depth was detected manually using an iron bar. The iron bar was marked in 10-cm intervals using a graduated scale, with a maximum measurable depth of 60 cm. When bedrock was not encountered at a depth of 60 cm, the depth of the soil was recorded as "more than 60 cm". The heights and widths of the terraces were measured using a measuring tape, and the slope grade was measured using a Suunto clinometer (PM-5/1520). Exposure and terrace length were analysed in GIS, and eight samples were collected from each terrace (40 total samples). The soil samples were obtained from agricultural terraces using a spade and were collected in a bag for further analysis in the laboratory. Bags containing soil had weights of 4.70–10.10 kg, with an average weight of 7.14 kg.

First, we evaluated the weight of the dried field soil samples in the laboratory. We separated the fine soils from the samples by passing the soil through a 2-mm sieve without grinding any primary particles. The remainder of the sieved soil sample consisted of skeletons. Previously authors have used the following skeleton categories: gravel fraction (2–32 mm), rocky fraction (32–256 mm) and boulders (more than 256 mm). Regarding the influences of cultivation on the skeleton content in agricultural soils, we separately evaluated the relative skeleton content with a size fraction of more than 32 mm and the relative skeleton content with a size fraction of 2–32 mm, which was not removed during cultivation. Špulerová et al. (2013) noted reduced amounts of skeletons and a poor representation of the skeleton categories in soils in terraced fields. We are interested in the removal of the rock and boulder fractions from the fields. Therefore, we compared the differences between the relative amounts of skeletons in the soil samples within these two groups (different values were expected).

We used the skeleton content evaluation method of Šály and Ciesarik (1991). The skeleton content was calculated from the relative percentage weight of the soil sample [%] using the following formula: A = (C × 100) / N, where A is the relative weight of the skeleton content, N is the weight of the unified soil sample between 500 g and 5,000 g, which is denoted as the solid phase [g], and C is the weight of the exsiccated skeleton. The weight of the 2–32 mm skeleton fraction was evaluated for a unified weight of 500 g. The weights of skeletons larger than 32 mm were evaluated for the entire soil sample because larger skeleton fractions in the soil samples could be heavier than 500 g. Before analysis, a sample was homogenised to obtain a representative soil sample. Approximately 500 g of a representative sample was collected from a larger sample by quartering.

3.4 Reclassification of the potential production categories of terraced agricultural soils

We compared the soil attribute data and terrain parameters, which were collected in the field and analysed in the laboratory, with the data that were included in the classification of agricultural soils. We expect the two following possible combinations of potential production on agricultural soils and land use on ploughland plots: (i) agreement with the limits of the plots used as ploughland (P2; P3), which are recommended for use as potential ploughland or ploughland that is alternated with grasslands; and (ii) discrepancies with the limits on ploughland plots that are used as ploughland while classified as grasslands or as not suitable for agriculture activity. Based on field and laboratory results, we suggest a hypothetical re-classification of land use for historical agrarian terraces.

4. Results

4.1 Historical terraces in the land-cover structures

All of the agricultural plots with the agricultural soils that were evaluated in the next step were listed in the LPIS and accounted for 931.21 ha (54.39%) of the cadastral area in 2010 (bold letters in Tab. 1). Grasslands prevailed across the agricultural landscape, accounting for 801.93 ha

Land-cover structures		1949		2010	
		Relative area [%]	Absolute area [ha]	Relative area [%]	Absolute area [ha]
1.	Hard surfaces	1.06	18.11	0.73	12.56
2.	Forests	14.17	241.15	36.44	623.92
3.	Wooded non-forest vegetation – points	0.34	5.74	0.10	1.75
4.	Wooded non-forest vegetation – lines	0.98	16.73	2.96	50.67
5.	Wooded non-forest vegetation – areas	1.88	31.96	3.80	65.11
6.	**Ploughland**	**-**	**-**	**1.52**	**26.00**
7.	**Ploughland on historical terraces**	**35.5**	**604.42**	**1.79**	**30.66**
8.	**Ploughland – fallow**	**-**	**-**	**1.43**	**24.48**
9.	**Ploughland – fallow on historical terraces**	**-**	**-**	**0.46**	**7.78**
10.	Services and buildings	0.06	0.99	0.07	1.14
11.	**Gardens in scattered settlements**	**1.25**	**21.35**	**1.88**	**32.01**
12.	**Gardens in compact settlements**	**0.43**	**7.28**	**0.48**	**8.24**
13.	Rocks and exposed substrate	1.11	18.96	0.26	4.40
14.	**Grassland with ruderal vegetation**	**-**	**-**	**0.26**	**4.44**
15.	**Grassland-1 (intensively and extensively used)**	**35.54**	**604.98**	**28.30**	**484.55**
16.	**Grassland-2 (succession, reversible to agrarian land use)**	**5.92**	**100.82**	**14.94**	**256.01**
17.	**Grassland-3 (succession, irreversible to agrarian land use)**	**1.19**	**20.23**	**3.33**	**56.93**
18.	Streams	0.07	1.11	0.08	1.43
19.	Agricultural buildings	-	-	0.50	8.54
20.	Compact settlements	0.34	5.74	0.43	7.44
21.	Scattered settlements	0.16	2.77	0.24	4.04
Total		*100.00*	*1,702.34**	*100.00*	*1,712.10**

*Tab. 1: Comparison of the total area of land-cover structures in the cadastral area of Budina (1949, 2010). Note: *The difference between the total areas of land-cover structures in the current (2010) and historical aerial survey photos of 1949 is 0.58 %. This error arises from uncertainty in the geodetic data that were derived from historical aerial survey photos and occurs because several structures could not be identified from the historical aerial photos.*
Source: authors

(46.83%) in 2010. The 931.21 ha of agricultural land that was identified in 2010 corresponded to 427.87 ha less land than the area that was present in 1949, which were 1,359.08 ha (79.84%). Ploughland covered a total area of 88.92 ha (5.19%) in 2010, and covered 604.42 ha (35.51%) in 1949. Ploughland on the historical terraces only represented 38.44 ha (2.25%) in 2010 (shaded in Tab. 1). The abundance of individual categories of land-cover structures in 1949 and 2010 is documented in Tab. 1.

4.2 Potential production categories of agricultural soils

Soils that were potentially suitable for moderately productive ploughland (P2) and slightly productive ploughland (P3) accounted for 465.69 ha (27.2%) of the cadastral area. Slightly productive ploughland alternated with highly productive grassland (P3G1) and covered 99.47 ha (5.81%) of the cadastral area. Highly productive grasslands (G1) covered 253.39 ha (14.8%) of the area, and the remaining area was covered by agrarian land (366.39 ha, i.e., 21.4%), which corresponded to moderately and slightly productive grassland (Fig. 3).

4.3 Field and laboratory research results

The terrace parameters are described in Tab. 2. The average terrace altitude was 714 m a.s.l., which is not suitable for agricultural land use in Slovakia due to the climatic conditions, as shown by the BSEU codes. Two terraces have southeast-facing exposures, two terraces have southwest-facing exposures and one terrace has a northeast-facing exposure. During the field research, we identified the heights of the terraces, which averaged 1.62 m. We found that the maximum slope grade of the terraces is relevant to the critical slope grade, which is optimal for cultivation and planting without creating erosion risks due to water movement. The width of the terraces ranged from 8 to 20 m (average 14.67 m), and the slope of the terraces ranged from 0.14 ° to 1.85 ° (planes with or without the possibility of erosion processes) (Tab. 2).

These slope values were different from the natural slope of the surrounding area, which ranged from 7 ° to 25 °. We observed no relationship between soil cultivation and soil depth, and all of the soils were naturally deep. Deep sandy and loamy cambisols are typically found on andesitic and crystalline granodiorite rocks. When we compared our skeleton content data that were obtained in the field with data from the official classification, we observed several consistencies. Detailed analyses of the skeleton content demonstrated that four of the five localities (No. 2, 3, 4 and 5) were disproportionate relative to the gravel fraction (2–32 mm) contents and the relative rocky fraction (33–256 mm). At these four locations, the gravel fraction was more common than the rocky fraction. Locations 2, 3 and 5 had relatively lower rocky skeleton contents (i.e. 20.34%, 15.08% and 11.89%, respectively) than what was described in the official classification, which ranged from 25% to 50% (Tab. 2). The official classification does not differentiate between the skeleton-gravel fraction and the rocky fraction; however, these results confirm our assumption that the rocky fraction could be removed from agrarian fields during cultivation. The largest rocks were 50 mm, and no boulders were found in the soil samples.

4.4 Reclassification of agricultural soils on historical terraces

In 2010, agricultural land decreased in area and ploughland became scarce compared with 1949. Thus, we decided to present hypothetical proposals for reclassifying agricultural soils, which were originally classified based on their use in 1949. We evaluated plots that were used as ploughland in 1949 and classified them into the potential production category types. Ploughland with optimal land use without limits accounted for 204.64 ha (34.77%) of the plots, while ploughland with optimal land use with limits accounted for 34.07 ha (5.79%) of the plots. Thus, these categories could be used as ploughland alternated with grassland. Moreover, 308.85 ha (52.48%) of the ploughland were not

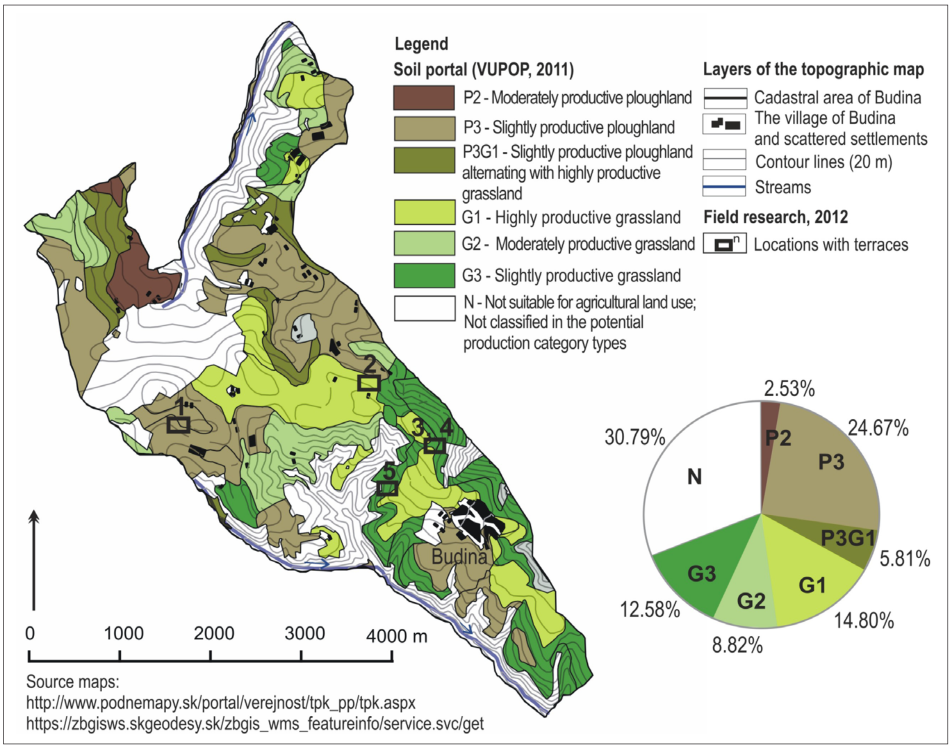

Fig. 3: Production category typology (VUPOP, 2011) for agricultural soils in the cadastral area. Source: authors

	Localities	1	2	3	4	5
BSEU codes	Soil skeleton content classes	Poorly skeletal (5–25%)	Moderately skeletal (25–50%)	Moderately to highly skeletal (25–50%)	Moderately to highly skeletal (25–50%)	Moderately to highly skeletal (25–50%)
	Soil depth classes	Deep (60 cm or more	Medium depth (30–60 cm)	Deep (60 cm or more and locally shallow (less than 30 cm)	Deep (60 cm or more) and locally shallow (less than 30 cm)	Deep (60 cm or more) and locally shallow (less than 30 cm)
	Slope grade classes	Moderate slope (7–12°)	Gentle slope (3–7°)	Steep slope (14–17°)	Very steep slope (17–25°)	Steep slope (14–17°)
	Climatic region classes	Cold and wet	Very cold and wet	Cold and wet	Cold and wet	Cold and wet
	Main soil unit classes	Cambisol typical on andesitic rocks	Cambisol typical on andesitic rocks	Cambisol typical on crystalline rocks	Cambisol typical on crystalline rocks	Cambisol typical on crystalline rocks
	Production category types*	P3	G1	G3	G3	G3
	Relative weight of skeleton content [%]	15.22	27.22	44.49	38.67	30.86
	Relative weight of skeleton content more than 32 mm [%]	49.75	20.34	15.08	31.28	11.89
	Relative weight of skeleton content in the range 2–32 mm [%]	50.25	79.66	84.92	68.72	88.11
	Soil depth [cm]	54	59	59	>60	>60
	Slope grade [°]	0.75°	1.34°	0.14°	1.85°	1.28°
	Production category types after reclassification	P2	P3G1	P3G1	P2; P3; P3G1	P3; P3G1
Additional terrace parameters						
	Length/width/height (average) [m]	417.67/17.4/1.5	168.P3/ 19.6 /2	337.98/8.72 /1.66	156.44/22.6 m in the wider area and 9.3 in the narrower area / 1.55	259.27/10.41/1.4
	Exposure/altitude [m] ASL	SW/730	NE/723	SE/716	SE/708	SW/646

*Tab. 2: Terrace parameters collected in the field in 2012. Note: * P2 – moderately productive ploughland; P3 – slightly productive ploughland; P3G1 – slightly productive ploughland alternating with highly productive grassland; G1 – highly productive grassland; and G3 – slightly productive grassland*
Source: authors

used in accordance with the potential production category type, and the predominant suitable land use type should be grassland. In addition, 6.96% of the ploughland fell outside of the LPIS (Fig. 4a).

Considering the modified, sloping terrain and the soil conditions on the terraces, we enumerated the following potential land uses of the agricultural landscape in the cadastral area from 1949. Optimal land use of ploughland without limits accounted for 237.12 ha (40.29%) of the plots, and an optimal land use of ploughland with limits accounted for 307.94 ha (52.33%) of the plots. This category could be used as ploughland that alternated with grasslands. Comparing this production category with the situation in which the changed parameters of the cultivated soils were ignored suggests that an additional 273.87 ha could be used as ploughland that is alternated with grasslands. Only 2.50 ha(0.43%) was not suitable for ploughland or ploughland alternated with grasslands. This land should be classified as grassland or as unsuitable for agricultural activities (Fig. 4b).

5. Discussion

The construction of terraces varied in the study area. We found it interesting that the high terraces (approximately 2 m and more) were not constructed as dry-stone walls but were formed by long-term ploughing (Fig. 5 – see cover p. 4). No relationship was observed between soil cultivation and the soil depths. Furthermore, we did not observe any pronounced differences between the skeleton contents as defined in the BSEU codes and as evaluated in the soil samples. Our detailed analyses, however, indicated that the gravel fraction prevailed over the rocky fraction and that boulders were not present in the soil samples. Additionally, we found substantial differences between the slope-grade data that were included in the potential production categories of the soil and the data that were collected in the field. According to our results, terraces have an optimal slope grade for arable soils (planes or gentle slopes with little to no risk of water-based erosion). Thus, we concluded that human inhabitants have improved the soil conditions, primarily by removing the rocky fractions from agricultural terrace soils.

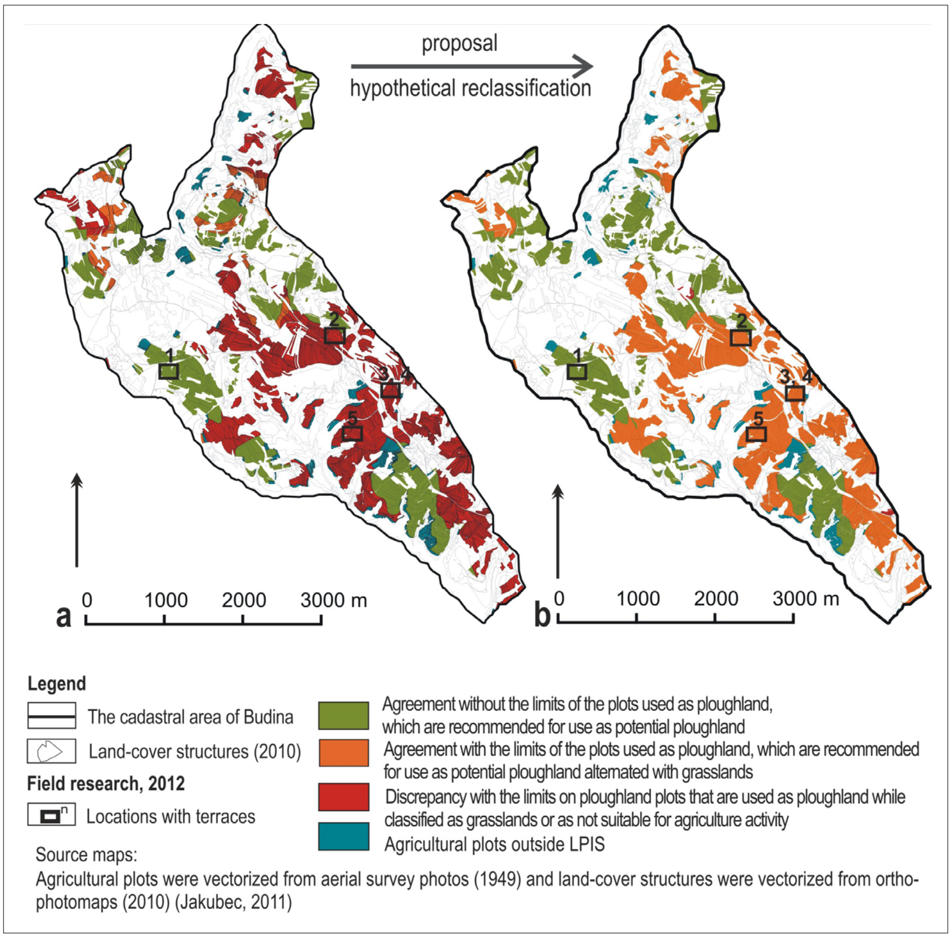

Fig. 4: Evaluation of ploughland plots (1949) for the production category types (a), and the hypothetical re-classification of ploughland plots (1949) for the production category types (b)
Source: authors

In addition, we concluded that only a small fraction of agricultural soils has exhibited over-limited land use based on the hypothetical reclassification map of the agricultural plots. According to the production-category map which was developed according to the criteria of the official classification, over-limited land uses account for 308.85 ha of agricultural soils (Fig. 4a). On the other hand, according to the proposed reclassification (Fig. 4b), only a small portion of agricultural soils (2.50 ha) exhibited over-limited land use.

Kaluz and Šimonides (2000) highlighted the risk of data inaccuracy in BSEU codes. Based on the data collected in the field (Tab. 2), the relevant potential BSEU code does not exist for the agricultural soil type found on the terraces in the cadastral area of Budina. The explanation for this finding is simple. The BSEU codes were established as combinations of natural conditions in regions that typically include agricultural activities; however, the studied area is not a typical agricultural region. Cambisols are typical in agricultural sub-mountainous and mountainous regions in Slovakia (Vilček, 2007). Thus, we propose that cultivated soils on terraces should be classified as cultisols (Linkeš et al., 1996) or cultisolic cambisols (Miklós and Hrnčiarová, [eds.], 2002), according to available official maps. Alternatively, both of these terms could be replaced by a term from the international classification of soils WRB, anthrosols (IUSS Working Group WRB, 2006), and a relevant subtype in this group. We recommend creating a new BSEU code for cultivated terrace soils in the study area.

Land evaluation, which attempts to predict the land behaviour for each particular use, is distinct from soil-quality assessment. In addition, because the biological parameters of a soil are not considered by land evaluation, agro-ecological land evaluation has much to offer (Rosa, 2005). We have evaluated several soil physical attributes in this study. Matečný et al. (2010) have explained, however, how soil-ecological unit parameters are implemented in the financial soil-evaluation process, through several case studies. This relationship demonstrates the importance of adequately classifying soils.

Pardini and Gispert (2012) documented transformation processes in agricultural areas where the colonisation of disorganised spontaneous vegetation has buried a valuable rural patrimony. An interesting view on the application of land evaluations, including soil evaluations, was reported by Fu et al. (2014). These authors proposed using land-use delimitation of the available marginal land for growing energy plants in compliance with the principle that bioenergy development should not compete with cropland and ecologically protected land. The maintenance of traditional land uses and cultural practices that are sustainable should be considered for designing management strategies that are oriented towards conserving landscapes and biodiversity (Stobbelaar and van Mansvelt, 2000). Preserving farms with the unique triple-field system in the study region is important in the cadastral area of Budina. Slámová et al. (2013) studied the same area and reported a heterogeneous agricultural landscape (i.e., a semi-natural agricultural landscape with a high inner level of heterogeneity that has transitioned into homogeneous forests). Terrace soils are distinctive features of the agricultural landscape in Europe. Due to their historical and aesthetic significance, terraces are a resource for agriculture and tourism; however, they also pose challenges for land conservation and management (Stanchi et al., 2012).

6. Conclusions

By considering the climatic conditions in the study area, we can pragmatically suggest that grasslands are more suitable than ploughlands on terraces. The agricultural landscape considered in this research project is located in a cold and humid climatic region, which strongly limits agricultural activities. With respect to the soils in this area, we expected that additional over-limited agricultural soils would not appear in the cadastral area after the agricultural plots were spatially and functionally optimised. We propose reclassifying the production categories of agricultural terrace soils using specific production category types because the BSEU parameters determine the process of valuing soil. These parameters should be corrected to achieve suitable financial support for agriculture. With these results, we aim to create a vision for the sustainable use of historical terraces by employing innovative agri-technical practices. Currently, agrarian terraces require financial support for retention. Regions with naturally disadvantaged production are significantly supported by agri-environmental payments in Slovakia. We do not consider this manner of allocating subsidies to agriculture sustainable; however, agri-environmental payments are useful in the initial phases of agricultural revival. Historical agrarian terraces represent characteristic features of the landscape because these terraces support the heterogeneity and biodiversity of sub-mountainous landscapes. Thus, we should preserve the diversity of European landscapes as a common resource of natural and cultural heritage, as defined by the European Landscape Convention (Council of Europe, 2000) that Slovakia adopted in 2005.

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A universal meteorological method to identify potential risk of wind erosion on heavy-textured soils

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Abstract

The climate of Central Europe, mainly winter seasons with no snow cover at lower altitudes and a spring drought as well, might cause erosion events on heavy-textured soils. The aim of this paper is to define a universal method to identify the potential risk of wind erosion on heavy-textured soils. The categorization of potential wind erosion risk due to meteorological conditions is based on: (i) an evaluation of the number of freeze-thaw episodes forming bare soil surfaces during the cold period of year; and (ii), an evaluation of the number of days with wet soil surfaces during the cold period of year. In the period 2001–2012 (from November to March), episodes with temperature changes from positive to negative and vice versa (thaw-freeze and freeze-thaw cycles) and the effects of wet soil surfaces in connection with aggregate disintegration, are identified. The data are spatially interpolated by GIS tools for areas in the Czech Republic with heavy-textured soils. Blending critical categories is used to locate potential risks. The level of risk is divided into six classes. Those areas identified as potentially most vulnerable are the same localities where the highest number of erosive episodes on heavy-textured soils was documented.

Keywords: *freeze-thaw cycle, soil moisture, aggregate stability, clay soil, meteorological conditions, GIS tools*

1. Introduction

The erodibility of soil by wind depends primarily on soil texture, or the relative proportion of sand, silt and clay (Chepil, 1952), the size and stability of soil aggregates (Skidmore and Powers, 1982; Colazo and Buschiazzo, 2010, Amézketa et al., 2003), and crusting (Fan et al., 2008). Key factors for the degradation of aggregate stability and deterioration of soil structure are excess water, stability and water resistance of aggregates given by the content of bonding compounds (organic matter, divalent cations), pH, crop residues and mechanical cultivation interventions. These processes (effects of water, drought, frost, $CaCO_3$, and organic matter on the stability of aggregates, etc.) were studied and their principles were described in the scientific literature from the 1930s to the 1950s (Yoder, 1936; Chepil, 1951, 1952, 1953, 1954, 1958).

In loams and clay loams, seals and crusts decrease roughness but increase surface soil strength, generally decreasing wind erosion (Singer and Shainberg, 2004). The clay-loam soil in a study by Anderson and Wenhardt (1966) was significantly less erodible in the spring than it was in the previous fall, indicating overwinter aggregation of the erodible fraction. On the contrary, Bullock et al. (2001) found an increasing amount of erodible particles after winter and spring seasons of up to 25% in heavy-textured clay-loam soils. The greatest change of erodibility occurred during the period with snow cover, when the occasional snowmelt increased water content and allowed a more effective disintegration of aggregates in the cycle of freeze-thaw.

It is thus clear that the course of meteorological characteristics in winter is a factor that contributes to wind erosion on heavy-textured soils. Changes in soil surface aggregation during winter can result in surface conditions highly susceptible or resistant to wind erosion, depending on the overwinter processes (Tatarko et al., 2001).

Due to alternating freezing and thawing of the soil surface, there occurs a significant collapse of soil structure on Haplic Chernozem (Siltic), Haplic Chernozem (Clayic), Haplic Cambisol (Clayic) (IUSS, 2006; Vopravil et al., 2007) primarily in the winter period, and so soils generally considered as invulnerable to wind erosion (Chepil, 1953) due to grain size, are highly threatened by wind erosion. These represent an anomaly, because heavy-textured soils are generally not susceptible to wind erosion. In certain weather conditions, however, and due to improper management, wind erosion also affects clay soils (Bullock et al., 1999).

There are many studies dealing with the effects of freeze-thaw processes on different soil characteristics (e.g. Logsdail and Webber, 1959; DeLuca et al., 1992; Grogan et al., 2004; Bechmann et al., 2005; Oztas and Fayetorbay, 2003; Sjursen et al., 2005; Melick and Seppelt, 1992; Xiuqing and Flerchinger, 2001; Bullock et al., 1999; Kværnø and Øygarden, 2006). The destructive effects of alternate freezing and thawing, in general, increase with increasing moisture in well-aggregated soils (Logsdail and Webber, 1959). Oztas and Fayetorbay (2003) confirmed that the moisture content of aggregate samples significantly influenced their stability on freezing. The aggregates in soils having a moisture content near saturation on freezing will be easily dispersed after thawing. These results agree with others. Benoit (1973) reported that the largest decrease in aggregate stability occurred when soil was at the maximum water holding content, and Lehrsch et al. (1991) found that the aggregate stability of fine- and medium-textured soils decreased linearly with increasing initial moisture content.

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In this context, water content is also one of the major factors involved in the aggregation process (Hartmann and de Boodt, 1974) and soil cohesion (Nimmo, 2005). Bravo-Garza et al. (2009) showed the important role of wetting and drying cycles in the formation and stabilization of large macro-aggregates after organic amendment. Another role of moisture in wind erosion is that rain often carries some of the finely dispersed, water-soluble cementing materials downward in the profile, leaving coarse particles such as sand and water-stable aggregates at the top (Hagen et al., 1988), and moving water has also the capacity to destroy soil aggregates (Murray and Grant, 2007). Quick wetting of aggregates leads to aggregate breakdown (Borůvka et al., 2002; Diaz-Zorita et al., 2002; Kemper and Rosenau, 1986). The laboratory analyses of heavy-textured soils (Bullock et al., 1999) showed the considerable importance of sublimation drying on the destruction of soil aggregates. The conclusions from the experiment of Dagesse (2013) showed that the freezing-induced desiccation process improves aggregate stability, while the addition of a thaw component following freezing, with the attendant liquid water, is responsible for the degradation of aggregate stability.

The main objectives of this paper are as follows: (i) to develop a relevant method for estimation of potential risk of wind erosion on heavy-textured soils based on commonly-available meteorological data; (ii) to categorize areas in the Czech Republic according to the potential risk of wind erosion on heavy-textured soils, using GIS; and (iii) to compare the results obtained with historical observations of actual wind erosion records on heavy-textured soils.

2. Materials and methods

The specification of endangered areas and categorization of potential erosion risk on clay soils and clay loam soils (further, heavy-textured soils) due to meteorological conditions is based on an evaluation of the "condition of bare soil surface" layer (Tab. 1), in combination with temperature conditions. The condition of the bare soil surface is a phenomenon observed at stations of the Czech Hydrometeorological Institute. The condition of the soil surface signifies the consistency properties of the surface soil layer, i.e. the state and moisture of the bare soil surface (Mužíková et al., 2013; Spáčilová et al., 2014). In frost-free periods, it is mainly determined by liquid precipitation in winter, by frost, snow cover and its parameters (i.e. snow covering, rate of snow-thawing, snow-water content: Pokladníková et al., 2008). The greatest advantage of these data is their continuous everyday information (observed at 7 AM, at 2 PM, at 9 PM) on the surface soil layer. Observation of the soil is done at the station plots and in their vicinities.

For each cold part of the year, from November to March, for the period 2001–2012, the number of episodes with observed changes in temperature from positive to negative and vice versa (i.e. freeze-thaw and thaw-freeze episodes) was identified. Hourly data on air temperature at 2 m above the ground were used. A measurement height at 1.2–2.0 m above ground is the standard recommended by the World Meteorological Organization (WMO, 2008), and land surface temperatures are found to be very well correlated with air temperatures 1–3 m above the ground (Hachem et al., 2012). Applications of the described method are thus possible in wide range of countries. With respect to the thermal insulative properties of snow, the number of episodes of 'freeze-thaw' was evaluated only for days without snow cover.

This study evaluated data for each year but from a different number of stations, because since the year 2000 automatic stations have been gradually added into the network (for the season 2001–2002 only 71 stations were used, but for the season 2011–2012, 142 stations were used). Meteorological point measurements and observations were interpolated by using GIS tools (ArcGIS 10.3). On the basis of these data, 11 raster layers for each cold period were created, using the method of local linear regression depending on the altitude and corrected estimated value with variation, in order to preserve the values corresponding to the location of the station. These layers at a spatial resolution of 100 × 100 m were then averaged for the entire period 2001–2012, and the values were assigned to the given areas with occurrence of heavy-textured soils (Vopravil, 2011).

Similarly, the effect of the dispersion of aggregates due to the wet soil surface was evaluated. With regard to this, the following soil surface states were defined as the critical conditions: number of days with soil condition 2 (wet soil surface – soaked – water in smaller or larger pools); soil condition 5 (snow or melting snow with ice or without ice covers less soil surface than a half); and soil condition 6 (snow or melting snow with ice or without ice covers more than a half of soil surface, but not entirely: see Tab. 1). A concurrent condition was the maximum daily air temperature exceeding 0 °C (liquid water). Data from 126 stations across the country were evaluated. Interpolation was carried out for the whole territory of the Czech Republic and the resulting values were assigned to the given areas with occurrence of heavy-textured soils.

Code	Characterization
0	Dry soil surface
1	Wet soil surface
2	Wet (soaked) soil surface (water is present in puddles)
3	Soil surface is bare and frozen
4	Soil covered by ice, without snow or thawing snow
5	Snow or thawing snow (with or without ice) covers less than half of soil surface
6	Snow or thawing snow (with or without ice) covers more than half of soil surface, but not completely
7	Snow or thawing snow (with or without ice) covers soil surface completely
8	Dry, loose snow covers more than half of soil surface, but not completely
9	Dry, loose snow covers soil surface completely

Tab. 1: Condition of bare soil surface classification. Source: based on Slabá, 1972

To ensure compatibility with erosion risk on light soils (Podhrázská et al., 2013), both characteristic values were divided into five categories, from the lowest to the highest number of days or episodes. Erosive risk evaluation requires taking into consideration the synergic effect of critical conditions. Blending the categories (Tab. 2) was used to locate potential risks in the cadastre with an occurrence of heavy-textured soils. Six categories were defined to quantify the level of risk. Category 1 signifies the lowest risk, labelled "No threat soils", category 2 is labelled "Susceptible soils", category 3 "Slightly susceptible soils", category 4 "Endangered soils", category 5 "Severely endangered soils", and category 6 represents the highest erosion risk, labelled as "Most endangered soils".

3. Results and discussion

The results, presented cartographically, show the regional differences in winter conditions that lead to increased potential soil erodibility. According to the data on soil conditions from meteorological stations across the country, five categories of occurrence of episodes with air temperature changes from positive to negative and vice versa during the days without snow, were identified (Fig. 1). Soil freezing causes disintegration of aggregates due to physical forces, while thawing causes aggregate disintegration by liquid water. Therefore, the episodes freeze-thaw and thaw-freeze were taken into consideration, and their number and interrelations were evaluated.

The highest values are 95 episodes and they decrease to 35 episodes in the cold part of the year (Fig. 1). Similarly, Hershfield (1974) used data from 1300 climatic stations to construct a map of annual frequency of freeze-thaw cycles in the USA. The number of freeze-thaw cycles (days per year) ranged from less than 20 to 250.

Heavy-textured soils with the highest number of episodes (about 90 episodes with such conditions of soil: red colour in the Fig. 1) were found in the southeast part of the Czech Republic, and there is also a small area in the north-western part of the Czech Republic. These results correspond very well with the fact that wind erosion has been often observed and measured at these localities (Mužíková et al., 2010; Švehlík, 1985; Vopravil et al., 2007). In specific areas, the erosion loss of 2 mm aggregates could be expected. This size is the limit of erodibility in heavy-textured soils of the Czech Republic under certain conditions (Švehlík, 1985). Edwards (2013) stated that practically no change in soil aggregate size fraction after 15 freeze-thaw cycles for a size aggregate less than 2 mm could be observed. Although a certain number of freeze-thaw cycles may be beneficial for the surface soil structures of wet soil, Oztas and Fayetorbay (2003) reported that wet aggregate stability generally increased when the number of freezing and thawing cycles increased from 3 to 6, but decreased after that point. Similarly, Lehrsch (1998) pointed out that aggregate stability would be greatest after two or three freeze-thaw cycles. Wang et al. (2012) found that after nine cycles of freezing and thawing, the mean weight diameter of wet aggregates and stability increased slightly compared with three cycles of freezing and thawing.

The wind erosion occurs during the dormancy period when the fields are without plant cover, especially at the beginning of the year and in early spring. The greatest number of days with wind erosion occurs in this area in

		Categories according to Fig. 1				
		1	2	3	4	5
Categories according to Fig. 2	1	1	1	2	3	4
	2	1	2	3	4	5
	3	2	3	4	5	6
	4	3	4	5	6	6
	5	4	5	6	6	6

Tab. 2: Categorization of the potential risk to wind erosion based on input data (Figs. 1 and 2). Source: authors

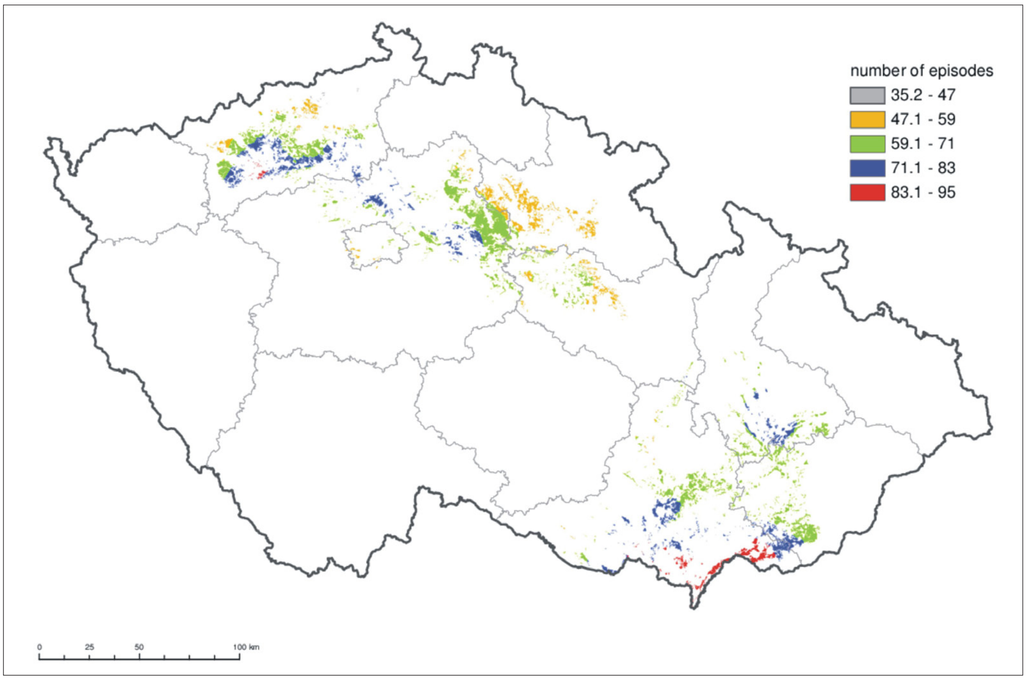

Fig. 1: Average seasonal number of episodes freeze-thaw and thaw-freeze during the days without snow cover
Source: authors

March (up to 30%), January (23%), and 20% in February and April (Mužíková et al., 2010). Moreover, Středová et al. (2011) found out an increasing drought event probability (mainly in spring) in the period 1961–2010, compared to 1961–1990 for the Czech Republic.

In a second step, the number of days with vulnerable soil conditions (2, 5 and 6) during days with maximum daily air temperature exceeding 0 °C (liquid water), was evaluated. Some regions are characterized by the occurrence of only a few days with such conditions in winter and early spring. On the other hand, in the central part of the Czech Republic there are many localities with more than 50 days of such conditions. The high number of days with wet soil surface (blue colour in Fig. 2) was identified in the southeast part of the Czech Republic (just as in the case of freeze-thaw).

The synergic effect of individual factors (number of episodes freeze-thaw and number of days with wet soil surface) must be also taken into account. Laboratory investigation of a clay soil indicated that the percentage of aggregates less than 1mm might be influenced by freezing and thawing depending on the initial moisture content (Hinman and Bisal, 1968). It was one of the reasons to create Fig. 3, which represents the synergic effect of both factors. A synthetic map (Fig. 3) presents potential wind erosion risk of heavy-textured soils

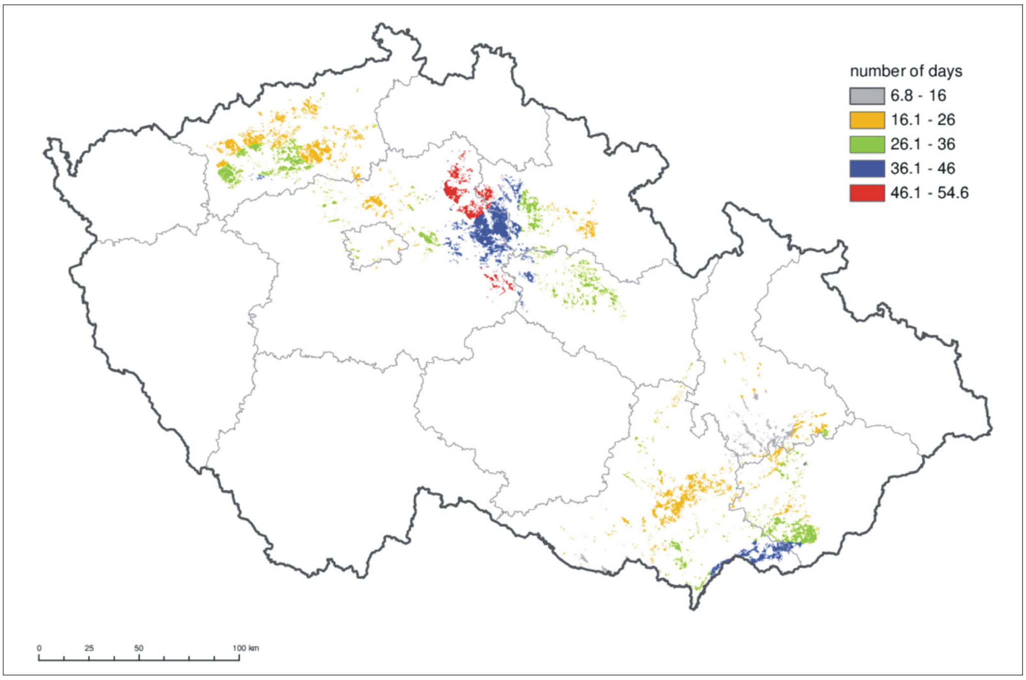

Fig. 2: Average seasonal number of days with wet soil surface, allowing the soil aggregates dispersion
Source: authors

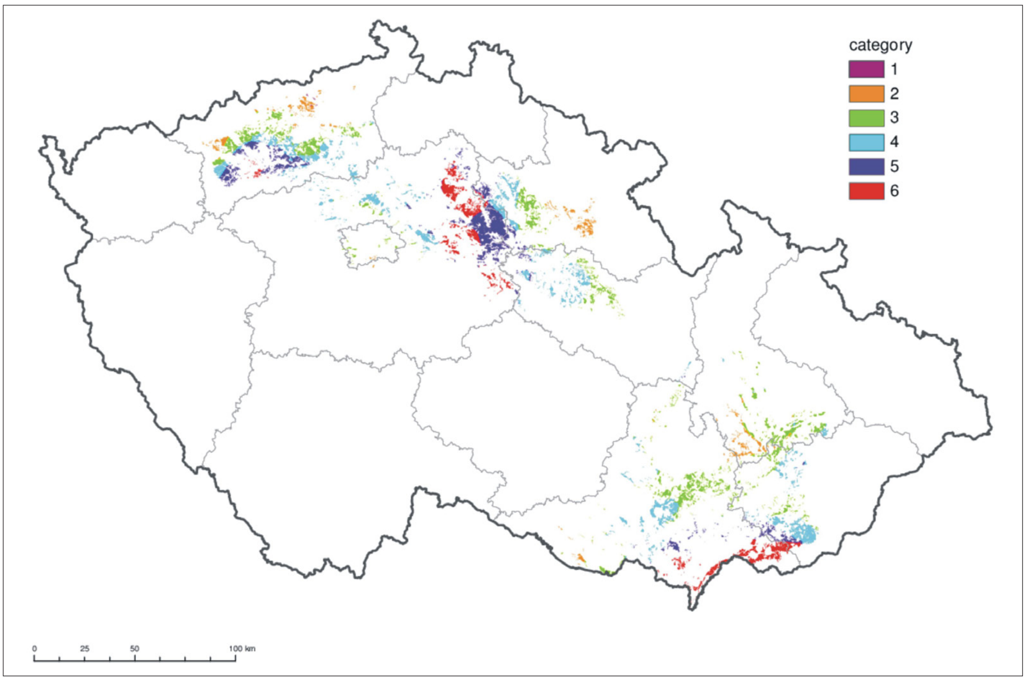

Fig. 3: Resulting map of potential wind erosion risk on heavy-textured soils
Source: authors

on the basis of the relevant meteorological characteristics presented above. It was formed as an intersection of two map layers – Figs. 1 and 2 – categorized into six categories based on the erosion risk matrix in Tab. 2.

An analogical attitude to the evaluation of spatial erosion risk, including the effects of vegetation and relief, has been applied and recommended by Kong and Yu (2013). Using a similar concept (GIS and remote sensing analysis of the number of snow cover days, soil erodibility, aridity and other factors), the study by Zhou et al. (2015) reveals that wind erosion has aggravated recently. Applications to available extensions provide a flexible model for a wide range of pedological, microbiological, environmental, agricultural and other analyses.

Current sophisticated maps of erosion risk in European countries (for example, Borelli et al. (2014) for 25 member states of the European Union, or Bielek et al. (2005) for the Slovak Republic), do not take into account erosion risk on heavy textured soils. It is generally assumed that wind erosion risk is relevant only for sandy and loamy-sand soils. The methodology presented in this study, however, enables an erosion risk determination for European countries also for heavy textured soils.

4. Conclusions

Meteorological data from stations across the Czech Republic enabled the spatial characterization of winter conditions, which may lead to wind erosion events on heavy-textured soils.

The most vulnerable areas according to the high number of days with occurrence of soil conditions, allowing for the soil aggregates dispersion, are in the north-western and south-eastern part of the Czech Republic. These areas are often also locations with a high number of episodes of freeze-thaw cycles during winter and early spring, and are therefore the areas with the highest potential wind erosion risk. These results correspond very well with the fact that wind erosion has been often observed and measured at these localities.

Applications of the methods described above are possible in a wide range of countries with similar approaches to and methodologies of climatic elements monitoring.

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MORAVIAN GEOGRAPHICAL REPORTS

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Fig. 2: Traditional agricultural landscapes have been affected by successional processes in many submountain and mountain regions of Slovakia, as well as in the Ostrozky Mountains, in the part with a dispersed form of settlement called Budinske lazy. (Photo: M. Slámová)

Fig. 5: Terraces on Jasenie Mt. (771 m a.s.l.) have an optimal slope grade for arable soil with little to no risk of water erosion processes. High terraces (2 m and more) were not constructed as dry-stone walls; instead, they were formed by long-term ploughing. (Photo: M. Slámová)

Illustrations related to the paper by. M. Slámová et al.