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CONTENTS

THE ROLE OF DEVELOPERS IN THE FORMATION OF GATED COMMUNITIES IN PRAGUE

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ABSTRACT

Existing literature on the formation of gated communities primarily focuses on the demand side. Mainstream theories pay attention to the fear of crime or social prestige. However, little attention has been paid to the role of supply factors. Prague, as a post-socialist city, has experienced a rapid growth of gated communities in recent years. This paper identifies the main driving forces behind the creation of gated communities in Prague. Our empirical research demonstrates that the creation of gated communities was not primarily initiated from supply side. We argue that the role of developers was critical in the formation of gated communities in Prague during the 2000s.

Keywords: Gated communities, Prague, Czechia, developers, postsocialist city

1. Introduction

This article discusses the role of developers in the emergence of gated communities in Czechia, with a dominant focus on Prague's residential market. The results of our research suggest that the neglected role of developers in literature may lead to an underestimation of the role of supply factors in the socio-spatial adaptation of the post-socialist city under capitalist conditions. Therefore, the main aim of this paper is to investigate the role of developers in the creation of gated communities, and to offer an explanation of the main driving forces, which stood behind the significant increase of gated communities in Prague during the first decade of the new millennium.

One of the main research questions related to gated communities is to clarify the cause of their emergence. The most frequently mentioned causes of their origin include fear of crime, ambitions to raise one's social status or popularization of neoliberal economics (Cséfalvay, Webster 2012). Literature thus concentrates on the demand side and highlights the role of residents (Blakely, Snyder 1997; Low 2003; Xu, Yang 2008). However, we believe that one of the main driving forces behind gated communities in Central and Eastern European countries is the role of the development industry. Based on our research we propose that the supply side played a critical role in the creation of gated communities in Prague during the investigated time period.

In this paper we understand by gated communities residential objects which consist of at least two separated residential houses (condominiums, family houses, block of flats), which are fenced or access into or through such properties can be regulated by private security agencies. These objects usually have special covenants and restrictions for their inhabitants and people who neither reside nor have approval to enter cannot enter without authority (Blakely, Snyder 1997; Atkinson, Blandy 2005).

The gated community concept that originated in the USA is significantly different from those we find in post-socialist cities of Central and Eastern Europe. In the USA, Latin America or South Africa gated communities are strongly separated by high walls. The ones in Central and Easter Europe are smaller and the character of separation is not so severe. The walls are not always of great height; security agencies are sometimes completely missing (Hegedűs 2009). We suggest, however, that 'gated community' is a suitable term for enclosed housing in post-socialist cities and it does not contradict the most commonly used definitions (Blakely, Snyder 1997; Atkinson, Blandy 2005).

The term is widely accepted and used for communities in residential formations, which separate themselves from the neighbouring environment. Now, we may speculate to what extent or if at all in post-socialist context gated communities really are communities. Moreover, we know that in the case of Prague the vast majority of existing gated communities are newly built. Therefore, inner social integration, which turns out to be a community, is not necessary implied. However, the built up environment in the form of gated communities persists in urban milieu long enough to give sufficient preconditions, which contribute to creation of integrated communities. From the long-term perspective we therefore prefer to accept the term gated communities, in contrast to gated properties, in order to avoid misunderstandings in international

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discourse, overemphasis of local temporary peculiarities, and with the prediction that we expect that in such residential formations the creation of communities can be expected.

The article is divided into three main sections. Firstly, the article discusses the theoretical approaches to the origin of gated communities. The second section focuses on the role and influence of developers in the creation of the city environment. In the third part, we discuss the causes of gated community origin in Prague and the main driving force behind their quantitative growth. It is important to underline that in the article we focus primarily on the capital city of Czechia and its hinterland, as the majority of gated communities are concentrated in Prague.

2. Causes of and conditions for the emergence of gated communities

There are several explanations of the development of gated communities (e.g. Blakely, Snyder 1997; Cséfalvay 2011; Cséfalvay, Webster 2012; Low 2003; Xu, Yang 2008), but we should distinguish between specific causes and general conditions of the emergence of gated communities. While the conditions for the origin of gated communities are practically universal all over the world, e.g. various processes of post-industrial transformation such as the internationalization of capital and work forces, technological advance, growing insecurity, social polarization, innovative economics, globalization of the real estate market or neoliberal policy, the causes of origin are different in distinct geographical locations and it is impossible to form a universal theory for them (Hirt, Petrović 2011; Low 2003).

People move to gated communities because they have a fear of crime, related either to violence or property and they feel that enclosed or guarded homes are safer (Blakely, Snyder 1998; Landman 2000; Low 2003). In USA, Latin America or Africa – the fear of crime and violence is constantly growing. People fear the growing numbers of poor, immigrants, ethnic minorities and terrorists (Low 2003). Residents assume that a secure gated community environment will protect them from the world full of malignancy and violence (Blakely, Snyder 1997). This approach is very popular in countries with a high crime rate such as South Africa (Landman, Schönteich 2002), USA (Blakely, Snyder 1998) or Latin America (Roitman 2005; Durington 2006). The fear of crime is an important factor in gated community origin, but it can hardly be the only factor. Gated communities exist also in times of low crime occurrence (Blakely, Snyder 1997) and we can find them in places with relatively low crime rates (eg. Chile, rich countries of the Middle East or Western, Central and Eastern Europe). There is also an opposite situation – countries with higher crime rates, but with no occurrence of gated communities.

Another often mentioned cause of the origin of gated communities is the neoliberal theory of club goods, which explains their origin by the economic rationality of all involved participants (Glasze 2005; Webster 2001). According to this theory, gated communities are advantageous for local authorities that can profit from them. The main advantage is the liberation from public property and general services provision, such as maintenance of roads and sidewalks, snow plowing or securing safety (Glasze 2005). Local administration supports new residential construction because it does not have to bear the expenses for the construction of infrastructure and the construction raises the municipal income from concentrating socially strong tax payers (Le Goix 2005). Life in gated communities brings many positives for their residents. They use private administration, which in many aspects can be more effective than the local administration and they also profit from utilizing common facilities (swimming pool, tennis court). They feel safer here. The developers can profit from a successful project. The problem of the club goods theory is its inability to explain why gated communities expanded in the last two or three decades and only in some countries (Cséfalvay 2011). One of the theories might be that using club goods is directly connected to neoliberal politics preaching maximal economic freedom and enabling economically rational behavior for all individuals. Some other reasons for moving into gated communities are: improving social status (Blakely, Snyder 1997; Kajdanek 2009), securing better privacy with no outside cars, strange people or animals despoiling the surroundings (Blakely, Snyder 1997; Le Goix 2005). Residents are also attracted to gated communities by the social coexistence factor (Blakely, Snyder 1997) or sharing their living surroundings with equals. The origin of gated communities can be also understood as an escape behind the fences from all problems of the city and society (Atkinson, Blandy 2005). Another motivation for buying an enclosed and guarded property is its higher probability of revenue (Atkinson, Blandy 2005). Nowadays, people buy real estate as an investment and gated communities are safe (or at least people feel that it is the safest available option) from devaluation.

Only a few authors pay attention to the fact that gated communities can be driven by developers (Low 2003; Leisch 2002). However, developers can play a significant role in the origin of gated communities and therefore they are a relevant subject for a deeper analysis and understanding of their influence on these properties. In contemporary economics, innovations are the crucial factor to success and this refers also to the real estate market. Builders are under constant pressure to come up with new products. Although housing cannot be considered a frequent commodity (unlike a car or a telephone) it still requires innovation – such as launching gated communities on the residential market.

3. The influence of developers on urban environment

With the city changing from a place of production into a place of consumption, the role of demand and supply has changed. Satisfying necessary housing needs has been replaced by individual expectations, wishes and desires of customers that want to live in a place that fulfills their requirements. This change from satisfying needs to fulfilling desires has significantly strengthened the role of developers because the needs are always limited but wishes and desires are limitless (Coiacetto 2007a). The change was enabled by the modern production system, which uses sophisticated tools to convince people to buy or more precisely live in such districts and buildings that they in fact cannot afford (Ambrose 1994). The development industry plays an important role in urban development, in creation of new areas, influencing the value of land and creation of social and spatial city structure. Harvey (1975 quoted in Coiacetto 2007b) argues that the formation of social and spatial differentiation is rather created by a capitalist way of production than by autonomic spontaneous preferences of people. Coiacetto (2007b) summarized the role of developers in new development in the following points:

1. They have the ability to create a new community by organizing social events.

2. The key role of developers is to create an urbanized environment.

3. Development creates new space, which is mostly relevant to social homogeneity as a result of market specification and segmentation.

Developers like important real estate players make decisions, which emanate from market analyses, risk rates, financial demands, perception and opportunities. With every project the developer has to evaluate factors influencing investments, such as location, financial availability, land use permissions and marketing, while the goal to maximize profits remains (Ambrose 1994). The same applies to other areas of the economy, to be capable of competing means to be specialized. Smaller developers are usually more flexible and able to approach the customers more individually. On the other hand, bigger developers focus on big projects where they are able to apply mechanized procedures and volume effectiveness with larger projects. New players have a difficult position trying to fight the competition of new and well-established developers on the market. If the goal of a new developer is to strengthen his position in the market, then as a result of limited access to land he is forced to overpay for land and increase the price of the final product (see e.g. Coiacetto 2007b).

The role of marketing in development has gained importance with the active endeavor of developers to maximize their profits by increasing the credit of owned land. It is common for the developer to own the lot first and only then look for opportunity on the market (Coiacetto 2007b). For that reason, project marketing becomes more relevant, because it increases the prestige of the area and so the price (referring to strong characteristics of the project: quality of material, design, lifestyle etc.). Developers actively influence the price of the land with their marketing strategy in relation to the target group intended for the project. Marketing creates desires and expectations from customers and is a powerful tool influencing the preferences of the customer. Branding is used by developers to effectively "cover" the value of the area, while demand is aimed at the product instead of the location (Coiacetto 2007a); development and associating new projects with the lifestyle of its future customers is a part of actively influencing consumers' expectations. Branding of individual gated communities (Residence, Villa, Park) tries to emphasize the individuality and luxuriousness of the project itself, distracting the focus from the neighborhood. To distract the customers from neighborhood and to be able to raise the capital price per unit, developers use physical separation, active creation and emphasize the strengths of the project.

The active role of the developers in the urban space is also visible in the socio-spatial structure of the city. Coiacetto (2006) drew attention to the segmentation of selected groups of customers by the developers, which creates social homogeneity in residential areas. It is created by aiming the marketing strategy at a selected group of customers for which the residential area is created. However, it doesn't have to be income segmentation, but it can be based on for example lifestyle, life cycle phase, sexual orientation and career. Developers do not only create the urban area, they also form its social structure and while the new buildings form only a small part of all real estate, their influence on the actual market with their specific segmentation characteristics is much broader (Ball 1983; Healey 1998; Coiacetto 2007a).

4. Methodology

The role of developers in gated communities is analyzed through stories of the development of individual gated communities. Additionally, we describe the evolution of construction, spatial distribution and partly also social structure of gated communities in Prague and Czechia. For these purposes we have created a database of all gated communities within Czechia. Although we focus primarily on Prague, for the argument it is also important to evaluate the development of construction and the spatial distribution of gated communities in the whole of Czechia. This database was created by a content analysis of advertising materials from developers, real estate advertising and web pages and it contains all gated community objects with the following characteristics – name, location, name of the developer (investor), date of construction, number of housing units, average price of a housing unit per square meter, degree of physical separation (if it is a guarded or fenced area). The content analysis was updated with a field survey of almost every object, which confirmed whether individual objects really match all the criteria of a gated community or not. The database has been created continuously from 2007 and updated annually (mostly with information based on gated communities outside of Prague).

We used the database to evaluate the development of construction and spatial distribution of gated communities in Czechia and also for categorization of developers according to their scale (number of projects) into small and large. The rough categorization between small and large developers helps to distinguish between the more fragile real estate cycles and project oriented developers and those more established and procedurally mechanized large-scale developers. A clear line in such a division is hard to define. We decided to make the division according to number of realized projects at 10, which created a group of 8 big developers and 33 small ones. However, it became obvious also from interviews and documents (Ekospol 2013) that there are three big players (Central Group, Finep, Ekospol) in the Prague real estate market, which in recent years have controlled nearly half of the market.

Additionally, we have created a typology of Prague's gated communities that was used for the selection of case studies. According to the created database, we found a total of 59 residential projects with elements of gated communities (fenced, guarded). However, there is a significant internal heterogeneity, so for purposes of this article we decided to focus only on one type of gated community. These are gated communities with the highest physical separation – fenced and guarded residential objects, whose physical separation is clearly visible and physically are similar to those we know from the U.S., Latin America or South Africa. We found 20 such projects, for which we created a typology, according to available characteristics. We roughly divided the projects according to their age (year of construction) into old and new ones (the cut off year was 2006), according to their average price for luxury gated communities and less luxurious (the cut off amount was established at 100,000 CZK per m^2, which is typically used to define luxury real estate) by the size of the large and smaller (100 housing units) and different types of land on the horizontal (houses) and vertical (apartment buildings). Out of these four characteristics we could create a maximum of 16 types. However, in Prague we found five types of gated communities out of 16 theoretically possible and we could neglect the size of the object as this characteristic played a negligible role.

The interviewed developers reflected previously mentioned categorization of gated communities into five types. We therefore did five different interviews with developers representing created typology. During the interviews we tried to investigate the origin of the gated communities: what were the main reasons for designing the project as enclosed or guarded; to what extent these characteristics are requested from the demand side; how strong are the relations between gated community builders and their occupants; and to what extent can gated communities be considered as successful projects in comparison to other residential estates.

Because we wanted to verify information we used triangulation; we conducted interviews with professionals from Prague's real estate market, real estate agents and representatives of local administration (all together 7 interviews). Experts were selected primarily according to recommendations we got. During the summer 2013, 12 interviews with experts took place. Additionally, we conducted inquiries among residents of one of the gated communities in Prague. All together, we asked 20 respondents (between May and June 2009) how important was for them the fact that the project is fenced and guarded. However, the main emphasis of our research was on the development industry.

5. The development and spatial distribution of gated communities in Czechia

The first gated communities in Czechia started in Prague in the 1990s with the construction of Malá Šárka and Trinity Garden. These projects were aimed mainly at rich foreigners. After the revolution in 1989, a large number of qualified foreigners with high incomes from Western Europe started to move to Czechia, working as managers or employees of international companies (Sýkora 2001). These foreigners had little or no information about the security situation in Prague but they required higher privacy standards, as stressed by one of our respondents (a real estate agent):

> At the beginning the market evolved in a certain way, these foreigners were coming to the Czech Republic and in many cases they looked for safety, because they were new. The Czech Republic as a country also went through development and changes. Those clients had a little feeling that they will be in a safer environment there.
> Prague, 23. 7. 2012

The fact that the foreigners wanted to live in a closed neighborhood was also of great influence. We encounter such cases also in other countries, when foreign employees from western countries require a certain standard of living. These are mainly countries like Saudi Arabia (Glasze 2006) or China (Wu, Webber 2004), where we can find greater cultural differences in comparison with western standards. Further construction was undertaken in 2002. These were always very luxurious projects made for well off Czechs and foreigners. The year 2004 brought significant changes, the new construction of gated communities started to be accessible to less wealthy citizens. Since 2007 gated communities have slowly become standard on the real estate market in Prague. From this time

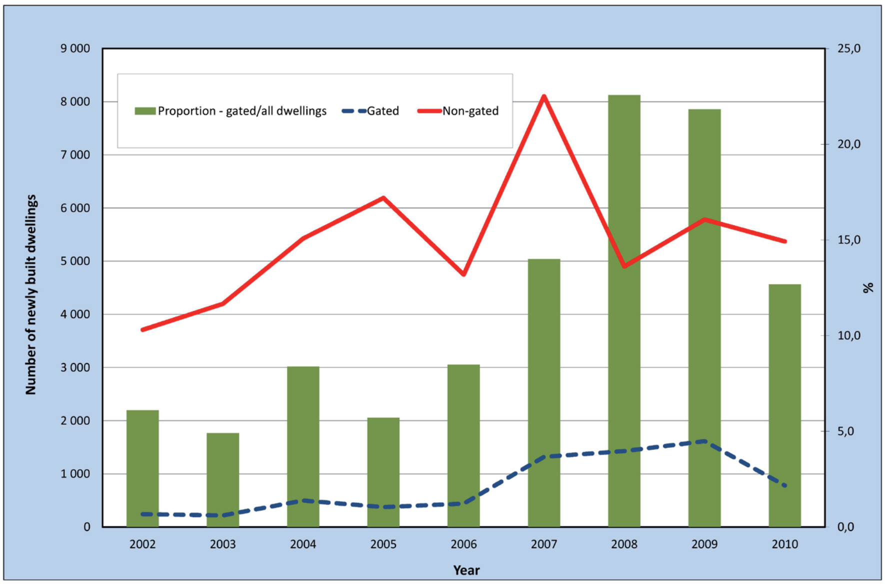

Fig. 1 Housing construction in Prague (2002–2010).
Source: own research; Bytová výstavba v územích České republiky v letech 1997–2011 Czech statistical office (2013)

Fig. 2 Territorial distributions of gated communities in Czechia, 2012.
Source: own research

15–22% of all newly built residential properties in Prague contains elements of gated communities (Figure 1). The majority of the new projects are designed in a less pompous way than the first gated communities in Prague. In total, the prices of properties in gated communities are still higher than in non-closed residential complexes. However, the differences between prices are not too high (see Kolarikova 2010). Since 2008, gated communities have also been constructed in other parts of Czechia.

Gated communities occur in various parts of Czechia (Figure 2). The highest occurrence is in Prague and its surroundings. Overall, we have identified 59 residential areas in Prague, which can be considered gated communities. Another 14 can be found in the remaining area of Czechia (5 of them are in the suburban area of Prague). Another cluster of gated communities can be found in Karlovy Vary (4 objects in total). However, this is specific to that city. In the previous few years, the city has experienced a significant inflow of wealthy Russians who buy flats or houses mostly as an investment (Sýkora et al. 2010). Two gated communities can be found in Brno, and one each in Plzeň, Liberec and Olomouc.

6. The causes of gated community development in Prague

As previously mentioned, the emergence of gated communities is a complex process that is conditioned by multiple factors such as social demand (fear of crime, social prestige), support from the local municipality and interests of private developers. Causes for the emergence of gated communities lie on the intersection between the demand and supply side. However, as we try to explain in various time-space conditions different sides can be dominant. We therefore want to avoid the simplification that one single factor (resident, local administration or developer) represents the cause of the emergence of gated communities. Moreover, it also cannot be excluded that the role and influence of the individual parties responsible for origination of gated communities in Czechia can change over time. However, our research clearly shows the dominance of developers as the most influential party during the first decade of the 21st century in Prague.

According to our respondents (experts on the real estate market), the origin of gated communities is produced mostly by small developers that try to compete in the market with innovative products. As we previously explained, smaller developers in particular have higher motivations and reasons to be involved in the emergence of gated communities. They usually do not own high quality land; or they as newcomers are forced to overpay for land and therefore segment more and focus on well off customers; their access to liquidity is not as accessible as large scale developers, so they try to maximize the capital value of the land; and obviously they are more flexible to customers' specific preferences than large developers with well-established procedures. On the other hand, large developers are more resistant to real estate cycles and are more predictable because as professionals they rely on market research and not only on the moods of the market. In the case of Prague, the real estate boom (Figure 1) was the time period when the mushrooming of gated communities happened.

The statement that smaller developers have a higher tendency to create gated communities has been also proved by analysis of our database. Since the 1990s, 59 residential projects with the elements of a gated community were built in Prague. Only three projects have been built by the biggest developers in Czechia, such as Central Group and Finep (none by Ekospol). In the case of Prague, 43 developers participated in the creation of gated communities, and nine of these can be considered as large developers (13 gated communities). The rest, about 78% of Prague gated communities were built by small and medium-sized developers. Approximately half of these residential objects were built as the first developers' projects (23 projects). This shows that smaller developers are trying to penetrate on the real estate market through innovation.

We have also mentioned that the biggest quantitative growth of gated communities on the real estate market was observed between 2007 and 2009. At this time many new developers emerged; the market was flooded with relatively easily accessible liquidity, which led to overconsumption. Developers during this real estate boom were affected by the general optimistic mood in the market and actively entered the process of gated community creation without deeper market analyses of demand. At that time gated communities still represented an innovative product in Prague's real estate market.

The heterogeneity among developers was confirmed during an interview with one of the biggest and most well established local developers:

> [Big developers] have their own business model, built on something different than the smaller ones. They aim for volume, addressing the biggest masses of people that need to live somewhere.
> Prague, 24. 7. 2012

Moreover, due to the high costs of reliable market analysis which only the big players in the real estate market can afford, smaller developers have a higher tendency to behave speculatively and according to the market mood and period of real estate cycle. It is even difficult to say who these small developers really are and many of them just enter the market during booms to extend their capital even if they have nothing to do with development. This aspect was pointed out several times during our interviews, especially by an expert from the agency for evaluation of real estate and small business market.

> From time to time some of them make amateur questionnaires, but they have so many mistakes that no relevant information can be gathered, some even make no questionnaires. The problem is connected with a real estate bubble; the developers have too much work when they have projects. They don't want information showing that the market is currently full and their project is not suitable.
> Prague, 24. 7. 2012

Another developer (a large foreign firm but not established in Czechia) has also pointed out that the decision-making process concerning the gated communities did not include asking people about their interest in safety and fencing. A real estate expert from Prague defined most developers on the local market as so called "gamblers" as they do not behave rationally according to market analysis. The interviews with representatives from the development industry showed that only a small group of developers conducts or orders a specific, deep market analysis surveying the preferences of consumers. This supports the idea of a weak connection between supply and demand side.

The spatial concentration of gated communities in Prague shows a higher rate of real estate market competition than in other Czech cities. Smaller developers using branding strategy effectively influence people to focus on the particular project and its strong advantages – innovations, which differentiate the project from its competitors.

The role of other parties has its influence as well. The position of the local administration is rather vague. Some representatives of local municipalities do not support the privatization of public spaces and, therefore, the creation of gated communities. On the other hand, others see no problem in the development of gated communities. Additionally, our research shows weak motivation of consumers to live in fenced areas. It can be proven by the fact that gated communities in Prague do not originate from existing residential properties, but are practically all newly built residential objects. Furthermore, there are also cases when the developer promised to build a residential project with elements of gated communities, but the residents decided not to have a private security agency or fence. Life inside gated communities brings also additional costs in the form of charges for the administration of a reception room or maintenance of common areas and not every person is willing to pay extra for this. It is especially true for residential properties of lower standard, which was confirmed by a real estate agent:

> In our experience, the fact they put a reception desk into an object of a lower standard with surveillance, higher privacy and safety led to the cancellation of the project because of the expenses they brought for the clients. Not that they moved out, but the services were cancelled.
> Prague, 23. 7. 2012

Additionally, a representative survey of public opinion on consumer preferences was performed by the INCOMA Company and shows similar results. This survey found that there is no strong demand for characteristics of gated communities, such as camera systems or area fencing. People would rather pay extra for storage areas, a nice view or better kitchen equipment than for higher household security. The main factors in housing selection are price, the size of the home, location or financing options. It is noticeable that higher security is required mainly by low-income households, as a consequence of fear of crime (INCOMA 2010). Yet these do not belong to the most frequent residents of gated communities. Our non-representative survey among the residents of one gated community in Prague has shown that residents were not highlighting fencing and a security agency as key factors. All residents considered the presence of fencing or security agency as "nice to have" but not a "must". According to the contacted professionals the security characteristics, enclosure or areas general protection have only a small influence on the choice of these estates.

The interviewed representatives of the development industry declared that the interest of their clients in gated communities was justified by the preference of higher quality physical and social environment with sufficient privacy rather than higher security. Residents of gated communities put more stress on utilizing different services such as a reception desk, someone to sign for your mail if you are not there, dog walking etc. Fences and physical barriers proved to be no key or primary factor for the decision process of the residents and were of little importance for them. The reasons in favor of physical fencing may be often very trivial: "The basic topic in Prague is dog turds", proclaimed one of the developers answering the question about enclosure of the residential areas. Other motives discussed above can also influence the origin of gated communities in Czechia. However, it is mostly the pursuit of social prestige that is difficult to quantify. The demand for gated communities is more of a condition for origin than the cause.

7. Conclusion

In this paper we primarily focus on the role of the development industry – especially developers – in the emergence of gated communities in Prague. We look closely at the role of the supply side in the creation of socio-spatial structure of the city, which we think is frequently overlooked in the literature. Our results have convinced us that developers play a vital role in the formation of these specific residential objects in the urban milieu. On the one hand, they communicate and actively influence their customers through marketing and branding in order to increase their desire to live in offered projects. This project-centered view in combination with a targeted segmentation of the client market causes social homogeneity of gated communities. *On* the other hand, the vast majority of developers do not have proper records and analysis about the market, so they rely on market moods in combination with the real estate cycle. The physical separation of objects from their surroundings has other benefits for the supply side, for instance increasing the capital value of the land, which can significantly differ from the neighborhood where the gated community is situated.

The emergence of gated communities is a complex process caused and conditioned by multiple factors such as social demand, the development industry or support form municipal authorities. Our research shows only a weak connection between the supply and demand sides and disputed the comfortable consensus that gated communities are a purely demand-driven phenomenon.

We came to the conclusion that during the first decade of the 21st century developers were the main driving force behind the construction of gated communities in Prague. The origin of gated communities is mostly in the interests of small and less experienced developers, as they are more flexible and adaptable than large mechanized developers primarily specializing in volume.

Despite many scientific articles published on this topic we still see future perspectives in researching the role of the supply and demand side in the creation of gated communities as well as their influence on the existing socio-spatial structure of the postsocialist city. However, this research must include all parties involved. Only complex evaluation can lead us to better justification and understanding of the socio-spatial transformation of postsocialist cities. In comparison with other postsocialist countries, there is still very little focus on this form of living in Czechia. This article wanted to fill this gap, but there are still many area of interest left, e.g. the role of the local municipality and developers in the socio-spatial structure of the built up environment, the sense of community in those residential objects, the consequences of gated communities on the social and physical environment.

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REFERENCES

AMBROSE, P. (1994): Urban Process and Power. Routledge, London. http://dx.doi.org/10.4324/9780203331002

ATKINSON, R., BLANDY, S. (2005): Introduction: International Perspectives on The New Enclavism and the Rise of Gated Communities. Housing Studies 20 (2), 177–186. http://dx.doi.org/10.1080/0267303042000331718

BALL, M. (1983) Housing Policy and Economic Power: The Political Economy of Owner Occupation. Methuen, London. http://dx.doi.org/10.4324/9780203472613

BLAKELY, E. J., SNYDER, M. G. (1997): Fortress America: Gated Residential Communities in the United States. Brookings/John Hopkins Press, Washington, D.C.

BLAKELY, E. J., SNYDER, M. G. (1998): Separate places: Crime and security in gated communities. In: M. Felson, R. B. Peiser (eds.): Reducing crime through real estate development and management (53–70). Urban Land Institute, Washington, D.C.

BYTOVÁ VÝSTAVBA. Český statistický úřad. Praha.

COIACETTO, E. (2007a): Residential Sub-market Targeting by Developers in Brisbane. Urban Policy and Research 25 (2), 257–274. http://dx.doi.org/10.1080/08111140701344833

COIACETTO, E. (2007b): The Role of the Development Industry in Shaping Urban Social Space: a Conceptual Model. Geographical Research 45 (4), 340–347. http://dx.doi.org/10.1111/j.1745-5871.2007.00473.x

COIACETTO, E. (2006): Real estate development industry structure: Is it competitive and why? Urban Research Program (Research Paper 10), 1–26.

CSÉFALVAY, Z. (2011): Searching for Economic Rationale behind Gated Communities: A Public Choice Approach. Urban Studies 48 (4), 749–764. http://dx.doi.org/10.1177/0042098010366763

CSÉFALVAY, Z., WEBSTER, C. (2012): Gates or No Gates? A Cross-European Enquiry into the Driving Forces behind Gated Communities. Regional Studies, 46 (3), 293–308. http://dx.doi.org/10.1080/00343404.2010.505917

DURINGTON, M. (2006): Race, space and place in suburban Durban: an ethnographic assessment of gated community environments and residents. GeoJournal 66 (1–2), 147–160. http://dx.doi.org/10.1007/s10708-006-9021-4

HEALEY, P. (1998): Regulating property development and the capacity of the development industry. Journal of Property Research 15 (3), 211–227. http://dx.doi.org/10.1080/095999198368374

HEGEDŰS, G. (2009): A Review of Gated Communities in Some Hungarian Cities. Geographica Pannonica 13 (3), 85–96.

HIRT, S., PETROVIĆ, M. (2011): The Belgrade Wall: The Proliferation of Gated Housing in the Serbian Capital after Socialism. International Journal of Urban and Regional Research 34 (4), 753–777. http://dx.doi.org/10.1111/j.1468-2427.2011.01056.x

GLASZE, G. (2005): Some Reflections on the Economic and Political Organisation of Private Neighbourhoods. Housing Studies 20 (2), 221–230. http://dx.doi.org/10.1080/026730303042000331745

GLASZE, G. (2006): Segregation and seclusion: the case of compounds for western expatriates in Saudi Arabia. GeoJournal 66 (1–2), 83–88. http://dx.doi.org/10.1007/s10708-006-9018-z

GLASZE, G., WEBSTER, C., FRANTZ, K. (2006): Private cities: global and local perspectives. Routledge, London.

INCOMA (2010): Potenciál rezidenčního trhu. Praha.

KAJDANEK, K. (2009): Is suburban housing in Wroclaw gated and why? In: Smigel, C. (ed.): Gated and Guarded Housing in Eastern Europe. Forum IFL, Heft 11. Selbstverlag Leibniz-Institut für Länderkunde, Leipzig, 39–47.

KOLARIKOVA, T. (2010): Gated communities in Prague -general overview and econometric analysis. Master of Science Thesis, Department of Real Estate and Construction Management, Division of Building and Real Estate Economics, Royal Institute of Technology, Stockholm, 61 p.

LE GOIX, R. (2005): Gated Communities: Sprawl and Social Segregation in Southern California. Housing Studies 20 (2), 323–343. http://dx.doi.org/10.1080/026730303042000331808

LANDMAN, K. (2000): An overview of enclosed neighbourhoods in South Africa. CSIR publication BOU/I 187, Pretoria.

LANDMAN, K., SCHÖNTEICH, M. (2002): Urban Fortresses: Gated Communities as a reaction to crime. African Security Review 11 (4), 71–85. http://dx.doi.org/10.1080/10246029.2002.9628147

LOW, S. M. (2003): Behind the Gates: Life, Security, and the Pursuit of Happiness in Fortress America. Routledge, New York.

POLICIE ČR. Statistiky kriminality. Praha.

ROITMAN, S. (2005): Who Segregates Whom? The Analysis of a Gated Community in Mendoza, Argentina. Housing Studies 20 (2), 303–321. http://dx.doi.org/10.1080/026730303042000331790

SÝKORA, L. (2001): Proměny prostorové struktury Prahy v kontextu postkomunistické transformace. In: Hampl, M a kol.: Regionální vývoj: specifika české transformace, evropská integrace a obecné teorie (127–166). Přírodovědecká fakulta University Karlovy. Katedra sociální geografie a regionálního rozvoje. Praha.

SÝKORA, L., BRABEC, T., ČERMÁKOVÁ D., FIEDLEROVÁ, K., MATOUŠEK, R., POSOVÁ, D. (2010): Případová studie segregace v Karlových Varech. Výzkumná zpráva pro Ministerstvo pro místní rozvoj ČR a Ministerstvo vnitra ČR, Praha.

WEBSTER, C. (2001): Gated Cities of Tomorrow. Town Planning Review 72 (2), 149-169.

WU, F., WEBBER, K. (2004): The Rise of "Foreign Gated Communities" in Beijing: Between Economic Globalization and Local Institutions. Cities 21 (3), 203–213. http://dx.doi.org/10.1016/j.cities.2004.03.002

XU, M., YANG, Z. (2008): Theoretical debate on gated communities: genesis, controversies, and the way forward. URBAN DESIGN International 13 (4), 213–226. http://dx.doi.org/10.1057/udi.2008.29

RESUMÉ

Role developerů na vytváření uzavřených rezidenčních areálů (gated communities) v Praze

Článek hodnotí příčiny a podmíněnosti vzniku uzavřených rezidenčních areálů (anglicky gated communities) v současném Česku, a to především v Praze, kde je koncentrace těchto areálů nejvyšší. Výzkumy v USA, Latinské Americe či Jihoafrické republice zdůrazňují, že na vzniku uzavřených rezidenčních areálů mají hlavní vliv rezidenti, kteří si tento typ bydlení vybírají, především ze strachu z kriminality či zvyšováním sociální prestiže spojeného s prostorovým odlišováním se od majoritní společnosti. Role developerů při výstavbě uzavřených rezidenčních areálů je v literatuře podceňována. Přitom jejich vliv na vytváření prostorové struktury města a vznik uzavřených areálů je mimořádný. Jsou aktérem, který aktivně ovlivňuje a vytváří očekávání a touhy zákazníků.

V článku jsme vycházeli z několika výzkumných metod. Jednak jsme za pomocí obsahové analýzy vytvořili databázi všech uzavřených rezidenčních areálů v Česku a jednak jsme provedli několik rozhovorů s developery, zástupci místních samospráv, odborníky na pražský realitní trh a rezidenty vybraného uzavřeného areálu. První uzavřené rezidenční areály v Česku začaly vznikat v Praze ve druhé polovině 90. let 20. století, přičemž se jednalo o luxusní rezidenční projekty určené především pro bohaté Čechy a cizince ze západní Evropy a USA. Od roku 2004 postupně dochází k zásadnímu přerodu, kdy začíná nová výstavba uzavřených rezidenčních areálů, které jsou dostupnější i méně majetným obyvatelům. Od roku 2007 se uzavřené rezidenční areály pomalu stávají standardem na pražském realitním trhu. Od této doby 15–22 % ze všech nově postavených rezidenčních objektů v Praze má prvky, jako je uzavření areálu nebo přítomnost soukromé bezpečností agentury. Postupem času také dochází k rozšiřování uzavřených rezidenčních areálů do dalších českých měst (82 % ze všech českých uzavřených rezidenčních areálů je ovšem stále lokalizováno v Praze).

Náš výzkum ukázal, že lidé nevyžadují nadstandardní prvky, jako je uzavření areálu či přítomnost bezpečností agentury. Jedinými poptávajícími po tomto nadstandardním bydlení byli relativně bohatší západní cizinci (především zaměstnanci nadnárodních firem), kteří vyžadovali vyšší bezpečnostní vybavení, protože nebyli tolik obeznámeni se situací v postsocialistickém prostoru. Hlavním motivem zákazníků ochotných si připlatit za tyto nadstandardní prvky, není primárně strach z kriminality. Rezidenti od bydlení v uzavřených rezidenčních areálech spíše očekávají kvalitnější fyzické a sociální prostředí s dostatkem soukromí.

Ukázalo se, že jsou to především developeři, kteří jsou hlavní hnací silou při výstavbě uzavřených rezidenčních areálů v Praze. Tento typ bydlení je chápán jako inovativní realitní produkt, jako něco, čím se odlišují od své konkurence. Na vzniku uzavřených areálů v Praze mají zájem především menší a častokrát i méně zkušení developeři, kteří se tak snaží proniknout na realitní trh. Menší developeři jsou flexibilnější a přizpůsobivější než developeři s mechanizovanými procesy produkce bydlení. Poptávka po uzavřených rezidenčních areálech není v Praze vysoká.

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AN ANALYSIS OF THE MACRO- AND MICRO-MECHANISMS AFFECTING THE RELATIONSHIP BETWEEN EDUCATION AND DEVELOPMENT

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ABSTRACT

The aim of this study is to discuss the role of education in the process of development of poor countries. The study is dividend into five sections, each of which is concerned with the relationship of education with one of the development indicators. Sections frame the given issue within a macro perspective, analyse the underlying micromechanisms and present specific examples found in the case studies. Overall, it has been illustrated that while the macrorelationship between education and development at the global level is quite evident, the specific individual mechanisms which enable such relationship are very diverse and dependent on the context in which they work.

Keywords: education, development, economic behavior, demographic behavior, inequality

1. Introduction

Our lives are constantly entangled with the process of education – everyday, we learn of something new, to do something new, or to use something new. Even though we might not always be consciously aware of it, this sum of knowledge, skills and attitudes, influenced by our abilities and experiences – education – affects our behaviour and impacts on our lives, especially in terms of their quality. The contemporary world has seen a dramatic increase in the importance of education as a lifelong process. Therefore, it is not surprising that a rising number of experts have started to consider economic capital or natural resources as a rather passive ingredient in the development process; instead, they favour human resources as the principal factor determining economic growth and social development (Todaro 2000).

Especially in the developing countries, education is the principal (and often singular) way to escape the so-called poverty trap. Who lacks in the necessary knowledge or skills is unlikely to succeed on labour market, which makes it rather difficult to provide material security for one self and one's family. Hanjra et al. (2009b) further suggest that education enables a person to adapt and modify their knowledge according to new situations, wherefore, for an educated person, it is easier to survive in a constantly changing world by adapting to changing conditions.

Education is one of the most important dimensions of human development, especially through its influence on human behaviour. As such, it shapes a wide range of human activities and attitudes – hygiene related habits, cultural and social values, economic behaviour, migratory activity, demographic trends or their environmental consciousness. Although the universal right to education has been listed in the Universal declaration of human rights since1948, yet even after the dawn of the 21st century, it is still not accessible to all. This is the reason why education has become a topic of global proportions, frequently featured in debates on the state of developing countries and followed attentively by a variety of international institutions lead by the UN.

It has become generally accepted that education brings significant benefits to the prospects of social development – more educated find it easier to get jobs, to provide for their families, have healthier lifestyles and subsequently live longer, too. (e.g. Silles 2009; Gyimah 2003).

It follows that, on average, more educated societies also tend to be more developed (according to both economic and noneconomic development indicators). If, however, we explore this relationship in more depth, we discover that things are not as straightforward as the previous assertion would lead us to believe. Specific local factors also have an impact on the way this relationship plays out. The successful impact of education on development can sometimes be determined by a detail, condition or event, which triggers the whole process of development through education. In this study, the application of education to development against the backdrop of such unique features is called a micromechanism.

Through an overview of available literature and selected case studies, this study seeks to analyse chosen micromechanisms of the relationship between education and development and to paint a detailed picture of their mutual interconnection.

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The Study presents the following hypothesis – frequently accepted even within the wider public (media, schools) – which will be subjected to an analysis and either confirmed or rejected.

1. We expect a strong correlation between the level of education and the basic development indicators (GDP, gender equality index, rate of migration, fertility rate, infant mortality, contraception use) measured on the level of states.

2. We expect that, due to the complexity of development problems in different contexts, it will be impossible to identify a single dominant micromechanism defining the relationship between education and development. However, due to their frequent mention in literature (e.g. Breierova and Duflo 2002; Glewwe and Miguel 2007), the study will attempt to confirm the influence of health and hygiene as the most significant microfactors of development.

The study is divided into five chapters (economic activities of the population, migration, gender inequality, demographic trends, health), each of which is concerned with the relationship of education with one of the development indicators. Each chapter is then composed of two parts. The first frames the given issue within a macro-perspective (determines the relationship between education and the selected development indicator on the level of states) and graphically illustrates the correlation, while the second analyses the underlying micromechanisms and presents specific examples found in the case studies.

The study aims to provide a logical categorisation of the individual micromechanisms according to the aspect of human development they are related to. The purpose of this is to give a synoptic overview of the mechanisms through which various components of human development and education interact. Of course, it is impossible to capture all of these mechanisms, however, through the overview of available literature, the study seeks to identify and discuss as many of them as possible.

2. Sources of data and methodology

Summary reports of world organisations (UN, WB), which to quantify the current state of education and its trends across the world, serve as the primary data source for the adequate framing of the debate on the global level. The study has also made use of the UNDP (United Nations Development Program – a UN development project) annual reports. This program has helped to promote the use of the HDI (human development index) indicator and also oversees the fulfilment of the millennium development goals, which include the provision of basic education to all persons. Specifically, the study used data from the 2009 Human Development Report.

The World Bank provides information of the ongoing initiative to provide education for all on its Internet portal, which also served as a data-source. The study also made use of data from the PRB (Population Reference Bureau) portal, the 2009 World Population Data Sheet, specifically.

The study is based on an analysis of roughly one hundred academic articles, the overwhelming majority of which are foreign studies focused on the countries of southern Asia and sub-Saharan Africa and tend to be relatively recent (1990–2010). The used studies have been collected from roughly 80 different sources, usually peer-reviewed academic journals. The following sources have provided the greatest amount of used articles: Social Science & Medicine, World Development, Journal o Development Economics, Economics of Education Review, Journal of Policy Modelling. Less frequently (At least two articles from the given journal were used in the study) appearing periodicals include e.g. Agricultural Water Management, Economics Letters or Health & Place.

During the analysis, it is necessary to zoom in on the lowest possible level of analysis of the relationship between education and development. Attention is devoted to case studies and reports from various parts of the world (mostly from the developing countries). Appropriate articles concerned with the relevant issue were identified through the use of relevant keywords (education, development). A Systematic analysis of these articles then gave shape to the structure of this study. As some mechanisms appeared repeatedly, they came to form the individual chapters (effectively mirroring the fields of human development) – economic activity, demographic trends, health, gender inequality and migration. Categorisation has been uneasy in this case – individual micromechanisms frequently overlap and one item might fall within multiple categories. In certain specific cases, the decision regarding the relevant categorisation might have been somewhat subjective. Here, using the case study analysis, authors are trying to confirm the second hypothesis of this study. To confirm or to reject the first hypothesis, the relationship between education, here represented by the level of literacy, and the selected indicator of human development has been determined via regular methods of assessing interactions between variables (correlation analysis and regression analysis). A scatter plot has been constructed for each pair of variables (Literacy and a selected development indicator) and the regression line has been inserted into it. The combination of the scatter plot and the regression line already tells us a great deal about the interdependence of the involved variables. However, in order to get a better measure of the strength of the obtained relationship, the Pearson correlation coefficient (denoted as 'r') has also been calculated. The relationship between the given variables has then been expressed through the linear regression, defined by the regression equation:

$$y = a + bx$$

where:

x is the independent (explanatory) variable (in this case the level of literacy),

y is the dependent (explained) variable (in this case the selected human development indicator),

a is a constant, which determines the distance of the y axis intersection from the coordinate origin (the value of the function for $x = 0$),

b is a constant, which determines the slope of the angle of the regression line to the x axis.

The least squares method, which aims to minimise the sum of the squares of residual values (Hendl 2004), has been used to find the values of the *a* and *b* parameters. In order to further confirm whether the regression equation sufficiently explains the relationship between the two variables, the coefficient of determination (denoted as R^2), which states the share of variability of the *y* variable explained by the *x* variable (Hendl 2004), has been calculated, too. Both correlation analysis and regression analysis have been calculated with use of the SPSS program.

Of course, there are limitations in the methods of research, particularly in the analysis of micromechanisms that stand behind the relationship between education and development. The study is based on a large number (about 100) of case studies – it means that high validity of collected data is guaranteed, but at the price of non-repeatability of research. However, for the research of mechanisms which stand behind the relationship of education and development, the methods and data collection are perfectly adequate, because the attempt in this case is to get to the lowest possible level of the issues of the relationship between education and development. So the method of analysis of case studies seems to be the best option.

3. Mechanisms determining the relationship between education and development

As mentioned above, individual micromechanisms have been organised into categories mirroring fields of human development. Towards the purpose of this study, this categorisation is logical and expedient. It enabled the identification of fields where the influence of education is strong, and those where it is weaker.

3.1 Economic activity of inhabitants

Primarily, education encourages the personal development of the individual and of human capital in general. An educated person finds it easier to find work and the country's labour force improves as a result. This filters into an overall increase in productivity of the country's economy (Hanushek and Wössmann 2008).

Figure 1 illustrates the relationship between education and the GDP per capita indicator (for purchasing power

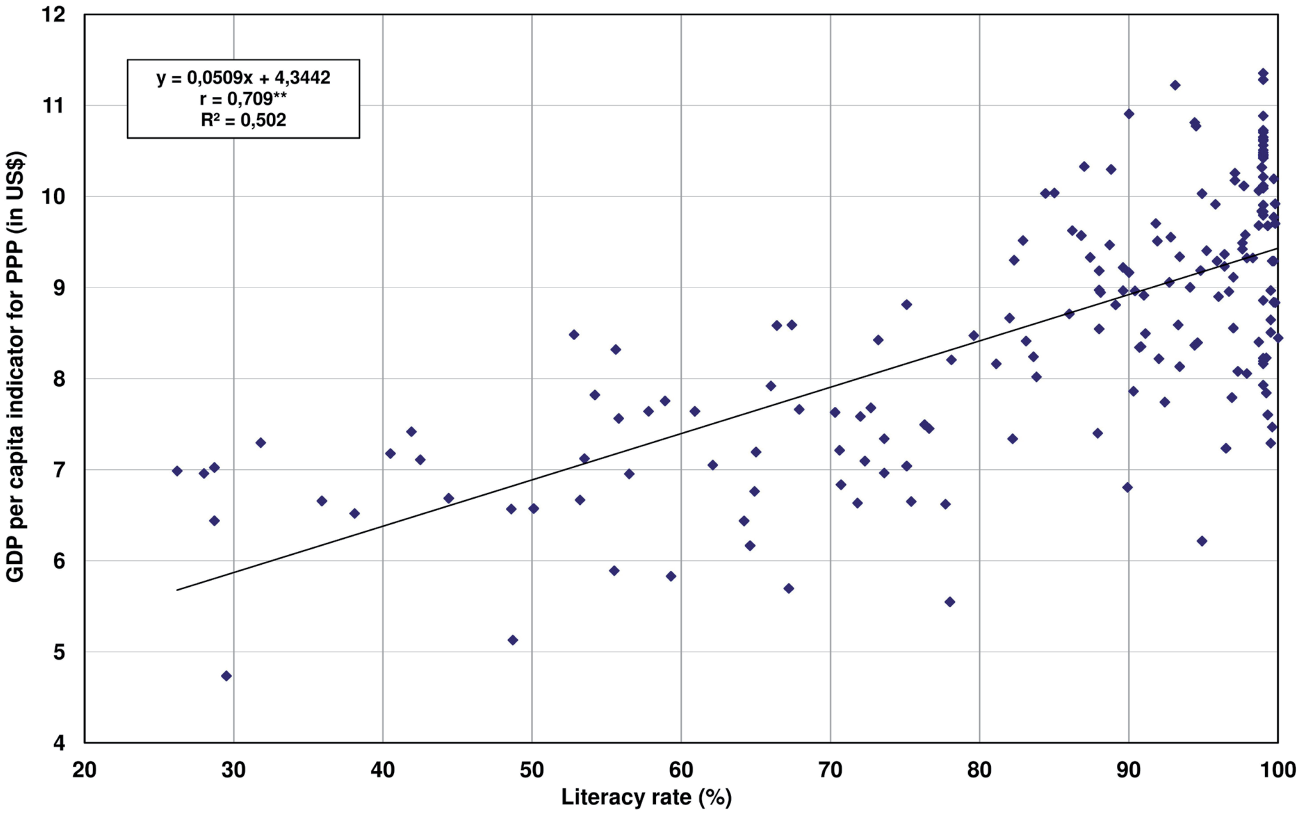

Fig. 1 Relationship between literacy rate and the GDP per capita indicator (PPP) by world's countries 2009.
Source: PRB 2009, HDR 2009

parity) on the global level. Increase in the level of literacy also indicates a higher level of GDP per capita in a given country. Countries with the lowest literacy levels are concentrated on the left side of the graph and it can be observed that their GDP per capita levels are also rather low indeed (e.g. Mali – literacy level 26.2% and GDP ppp of 1083 USD, Afghanistan – 28.0% literacy, 1053 USD of GDP ppp). In comparison, the right side of the graph concentrates countries with literacy levels reaching up to 100% and an average GDP ppp of 35,000 USD.

According to Hanjara et al. (2009b), people with more education tend to be more flexible in terms of technological changes. This increases the innovative capacity of the economy, because educated people can accept and apply new technology (modern agricultural technologies, artificial fertilisers), but also to improve upon it and spread it. For literate farmers, flexibility mostly implies the ability to adapt to changes (e.g. climatic changes). As a result, outputs achieved by literate farmers exceed those achieved by illiterate ones. For example, farmers who use reasonable amounts of artificial fertilisers experience returnability of seasonal production of 36% and 69.5% of annual production (Duflo et al. 2008). Hanjra et al. (2009b) argue that educated farmers, who soon acquainted themselves with modern varieties of rice and wheat, were a chief cause of large outputs and surpluses achieved in some parts of developing Asia and a subsequent reduction in poverty. Azhar (1991 cited in Hanjra at al. 2009b) claims that 1 year of extra education for a farmer in Pakistan (applied to farmers with 4 or more years of completed school attendance) increases the agricultural output of wheat (by 1.28%) and rice (by 1.25%). According to Birdsall (1993 cited in Ranis et al. 2000), farmers with 4 or more years of completed education are three times more likely to use artificial fertilisers and other modern technologies then farmer without formal education. A Nepalese study (Jamison and Moock 1984 cited in Ranis et al. 2000) presents the evidence that farmers who have completed at least 7 years of school attendance experience an increase in productivity – wheat production is up by a quarter, rice production by 13%. An Ethiopian study (Asfew and Admassie 2004) asserts that an extra year spent in education increases the likelihood of artificial fertiliser utilisation by 2.7 % for all adult members of a household and by 1.5% for heads of households.

Education changes a person's behaviour, which affects their economic activity by a changed attitude to the management of money. More educated persons have an increased propensity towards business and investment. Whereas illiterate persons tend to spend their finances on consumer goods, those with more education are more likely to 'use' their money more productively – such as investment, which has been confirmed for example in an American study by Cho (Cho 2009). The study demonstrated, among other claims, that education also increases the level of saving security, from no savings at all, through secure savings, to luxury oriented savings.

The micromechanisms of economic behaviour are associated with the frequently discussed topic of microcredit. Microcredit provides access to loans to people who would have otherwise never been able to obtain them. This includes primarily small loans to farmers in order to support their agricultural activities. Microfinancing, as a mechanism, is not directly influenced by education, but it serves as a springboard. The way a person is able to make use of such springboard, however, is determined by their skills abilities, which can be significantly expanded through education. An educated person can make better use of their talents, as well as of the microcredit system, for their benefit. In this case then, it could be argued that education presents an opportunity to escape the poverty trap, with the system of microcredit serving as a useful tool in the process.

3.2 Migration

Although education transforms people's migratory habits, the connection between education and migration is far from unambiguous (Williams 2006). The following lines will reveal that while is some instances education actively encourages migration, in other situation it exercises quite the opposite effect and migration remains the domain of the less educated in such case.

Figure 2 demonstrates that no general assertion can be made about the relationship between education (represented by literacy) and migration (represented by the level of emigration) on the global level.

Generally, migrants tend to gravitate towards destinations with a higher value of HDI than their place of origin (HDR 2009). Migration from developing countries to the developed ones therefore appears as most beneficial. In such case, the migrants' income is on average going to increase 15 times (up to 15,000 USD annually), the amount of their children enrolled in school doubles (increases by 47–95%) and infant mortality among their offspring decreases from 112 to 7‰ (HDR 2009).

Education can have a positive effect on migration in the case that educated people cannot find satisfactory employment in their country ad migrate to a more developed country, where their chances of attending a higher quality educational institution or obtaining a more lucrative job increase significantly (HDR 2009). This migratory effect would be positive in a scenario under which these educated migrants return to their countries of origin enriched by new experiences. If, however, these migrants do not return, possible positive effects are limited to the impact of ' remittances' – finances send back home to provide for families left behind (HDR 2009).

On the other hand, the second most numerous group of migrants is comprised of the poorest and most vulnerable. Reasons for such migration usually include attempts to escape internal upheavals in the country of origin – natural catastrophes, political instability or

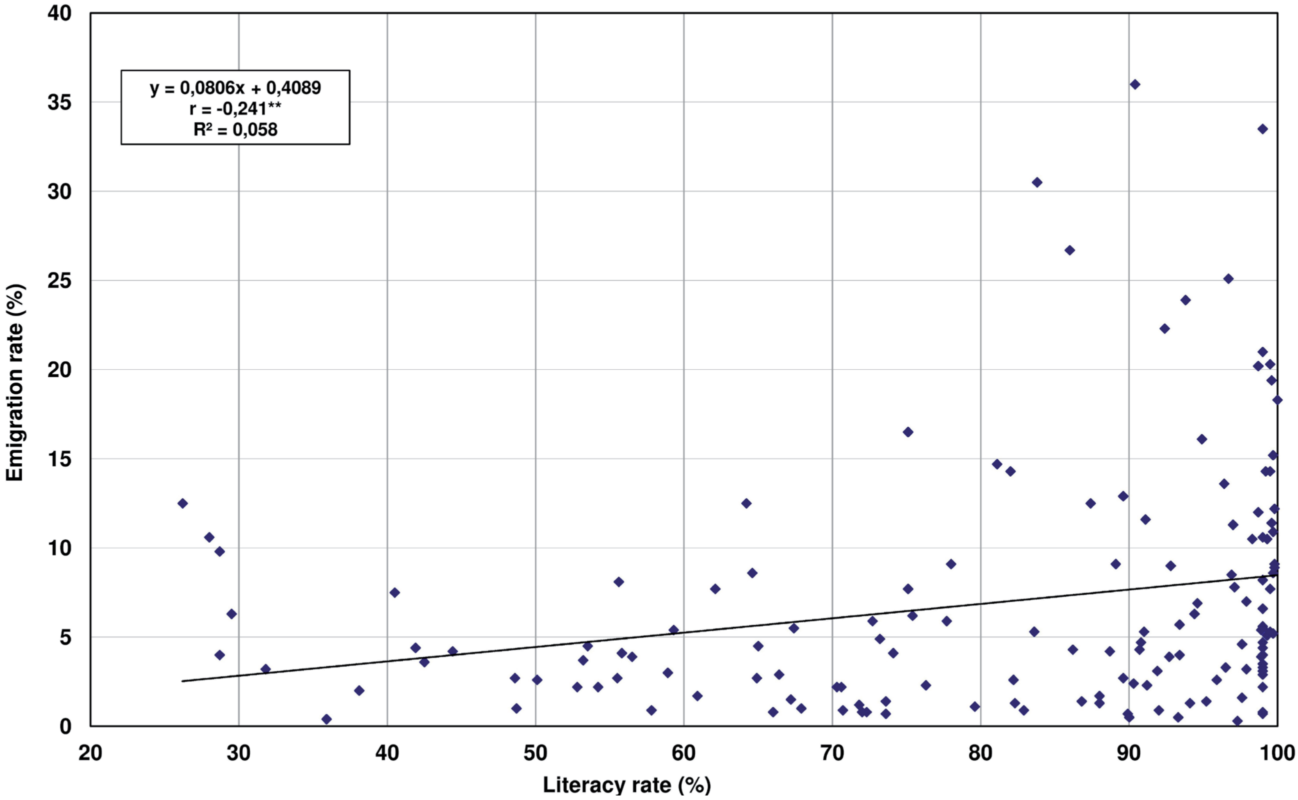

Fig. 2 Relationship between literacy rate and the level of emigration by world's countries 2009.
Source: PRB 2009, HDR 2009

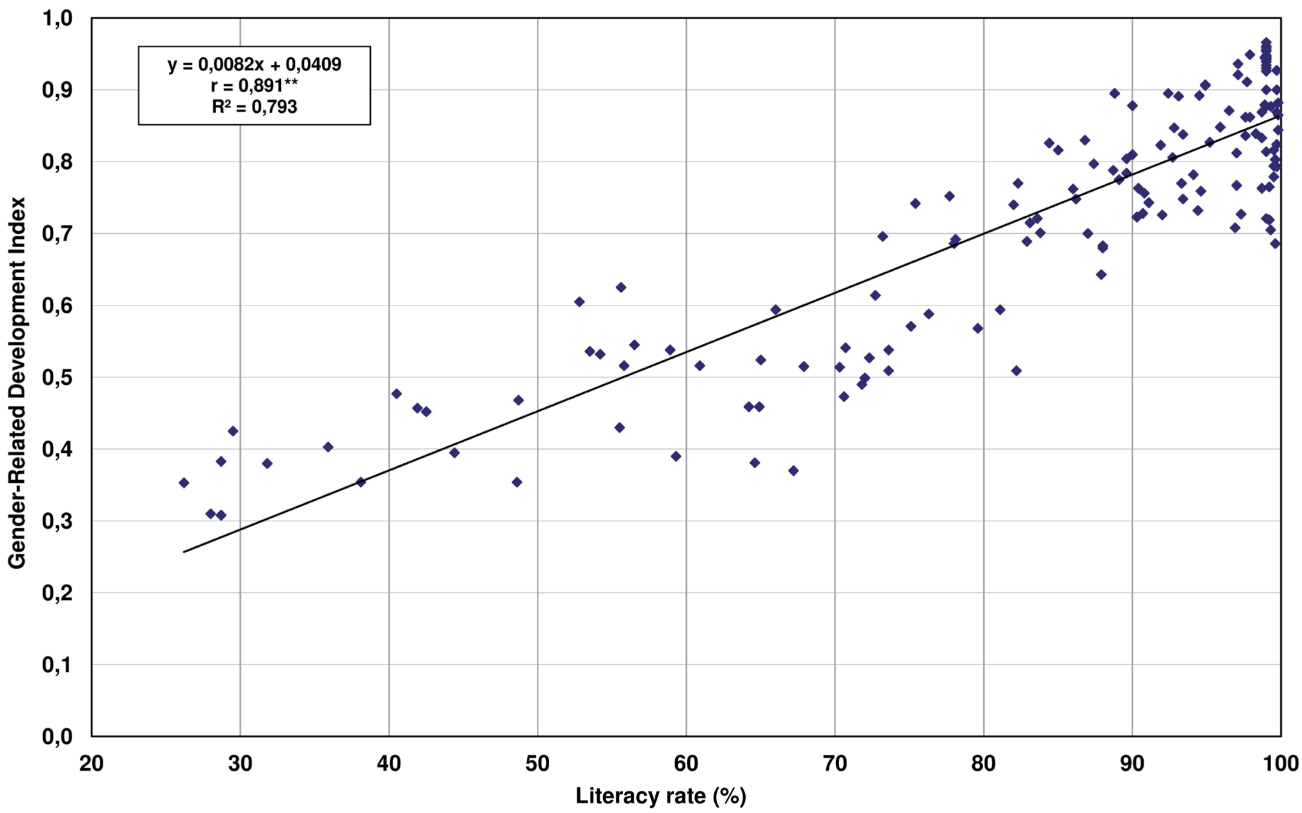

Fig. 3 Relationship between literacy rate and Gender-Related Development Index by world's countries 2009.
Source: PRB 2009, HDR 2009

armed conflict (HDR, 2009). Due to a lack of resources, these migrants rarely travel very far and frequently settle right beyond the borders of their home country (does not necessarily entail a migration to a country with a higher HDI). In such case, the influence of education on rates of migration cannot be verified.

According to a Nepalese study (Williams 2006), the achieved level of education influences migratory behaviour of both men and women. A man who has completed 1 year of formal education has a 1.06 times higher chance to migrate than a man without any formal education. A man with 5 years of education has 1.34 times the chance and a man with 10 years of education has 1.79 times the chance of an uneducated man. However, in terms of school attendance, men who never started school attendance are 1.5 times more likely to emigrate, for women; the chance is 2.33 times higher.

3.3 Gender inequality

The most significant behavioural changes affected by education are to be found in the field of cultural patterns. Education significantly improves the status of women, who in countless societies lack even the most basic of rights. The under-education of women in particular often has very negative consequences for the development prospects of a country.

Figure 3 sheds light on the relationship between education (here represented by the level of literacy) and the gender equality index (Gender-Related Development Index, GDI). GDI is calculated as an aggregate value of gender equality in three aspects of the Human Development Index: possibility of a long and healthy life (health), knowledge (education) and adequate living standard (GDP). A GDI value of 1.00 indicates an absolute equality between genders in all three dimensions of human development (HDR 2009). The graph then demonstrates the positive correlation of the two variables – the higher the literacy rate in a country, the closer such country is to achieving gender equality in health, education and living standards.

The growth of female education has a large impact on a number of social activities. In very general terms, it could be argued that education helps to combat the myth that women should be confined to their households. Literate women become actively engaged in the labour market and earn money, which significantly contributes to reducing gender inequality. Women who work and earn money contribute financially to the life of the household, which increases their position and status (Asfaw and Admassie 2004). Salary provides women with freedom and independence and their potential can develop more easily then is the case for women without economic resources of their own.

Public education can also help in the struggle for greater gender equality. According to Geo-JaJa et al. (2009), countries which have undergone market reforms with significant cuts to public education, exhibited a clear tendency towards a negative ration of boys and girls enrolled in schools. This further confirms the role education has in terms of reducing gender inequality.

A number of studies concern themselves with the influence of mothers' literacy on their children. According to Borooah (2004), daughters of illiterate mothers tend to be discriminated – they are 5 per cent less likely to receive inoculation. Similarly, their caloric intake is 5 per cent less likely to be equivalent to the caloric intake of the sons.

Educated people find it easier to get better jobs. In certain cases, this has a fundamental impact on gender equality, especially the growth of women's social status. According to the Population Council (2001 cited in Geo-JaJa et al. 2009) and Blackden and Bhanu (1990 cited in Geo-JaJa et al. 2009), every year of formal education increases a woman's salary by 10–20%.

A study from Thailand (Nakavachara 2010) demonstrated that an increase in women's education helped to bring about a significant decrease in the uneven rewarding of men and women for their work – whereas in 1985, an average male worker would earn 34% more than an average female worker, in 2005, this difference amounted to only 9%. We need to keep in mind, however, that the decrease in inequality has also been facilitated by an overall increase in female participation in the workforce, where women have come to form a majority.

On the other hand, possible negative impacts of female literacy may include a decrease in the amount of time mothers spend with their children, since women who do not go to work tend to spend more time caring for their children (such as a longer nursing period) (Leslie, 1988).

3.4 Demographic behaviour and trends

Rise in the status of Woman is often reflected in a declining fertility rate. Figure 4 displays the apparent negative correlation between the rate of literacy and the Total fertility rate for countries in the world. Numerous studies (McCrary and Royer 2006; Grimm 2005; Roth and Ngugi 2005) confirm that the higher a level of education a woman achieves, the lower on average tends to be the amount of children she gives birth to.

Osili and Long (2008), for example, argue that every extra year a woman spends educating herself decreases her fertility by 0.26 (for children born before the age of 25). Educated women are more likely to plan their families – increasing levels of education are also accompanied by a higher percentage of women using some kind of birth control (Murthi 2002). A study conducted in Pakistani slums (Sarmad et al. 2007) documents that 61% of literate women use some form of contraception, but only 38.5% of illiterate ones adopted such measures. The fertility rate of literate women then stood at 2.7 children per

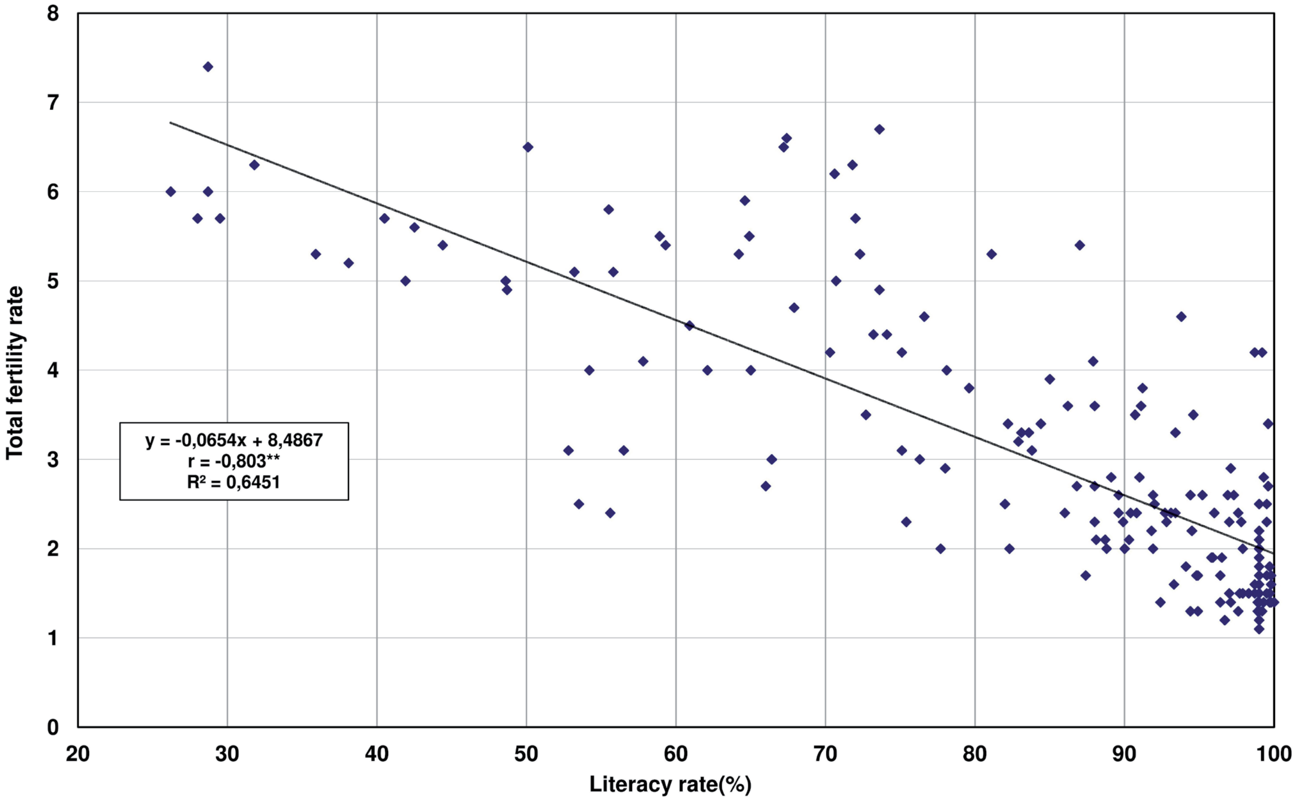

Fig. 4 Relationship between literacy rate and total fertility by world's countries 2009.
Source: PRB 2009, HDR 2009

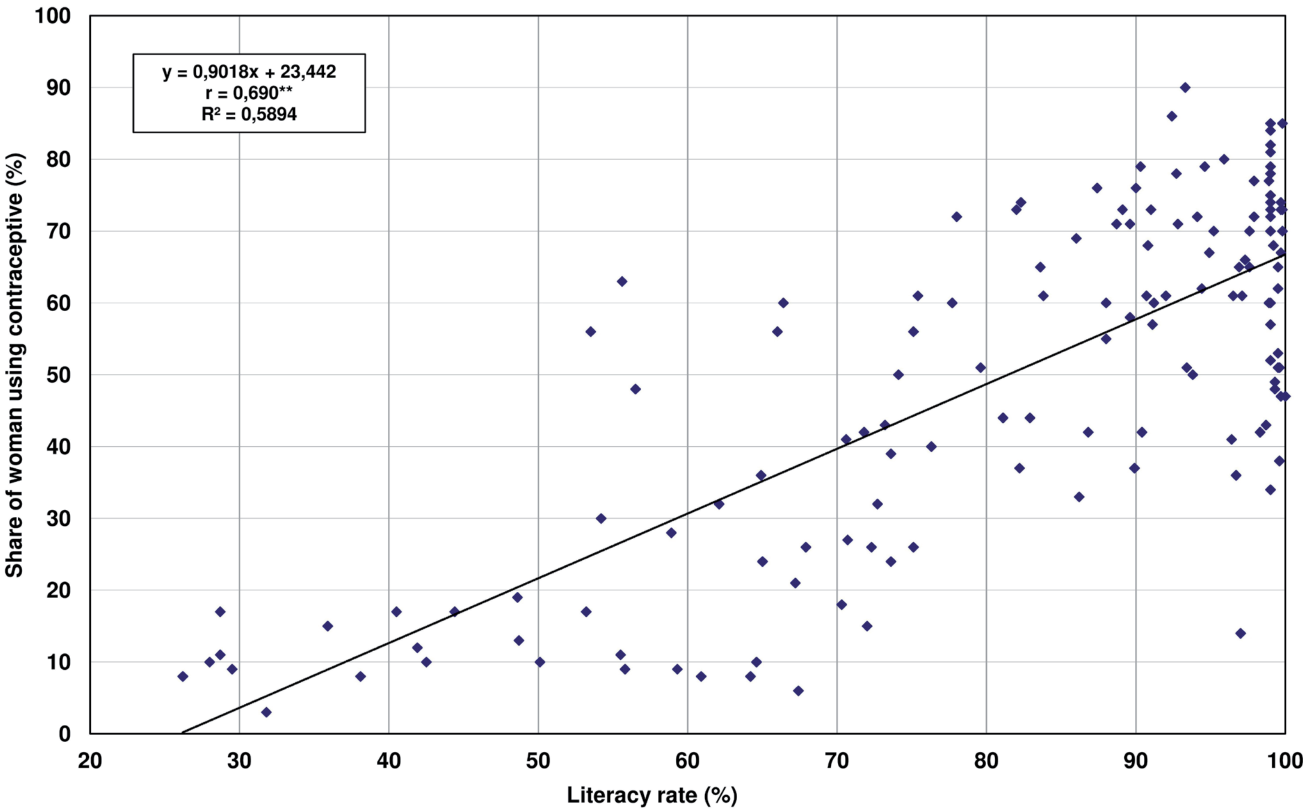

Fig. 5 Relationship between literacy rate and the share of women using contraceptives by world's countries 2009.
Source: PRB 2009, HDR 2009

woman, whereas illiterate women gave birth to 4 children on average.

Family planning has a serious impact on the lowering of fertility, as well as the delay of sexual activity. Therefore, educated women possess a greater reproductive autonomy than women without education (Basu 2002).

Educated women tend to plan their lives better, including the most expedient time to have children – longer education proportionately affects the age in which a woman enters marriage or the length of the intervals between pregnancies. Every year of school attendance, according to Breierova and Duflo (2002), delays the age of marriage for a woman by 0.38 years.

Aside from this, a decline in fertility is vital for an improved financial security of many households. High fertility needs to be put in the context of considerable costs associated with raising a child. Moreover, children from big families have a much smaller chance of attending school, because their family cannot afford it (Hanjra et al. 2009).

Figure 5 captures the connection between literacy and the share of women using contraceptives. For the developed countries, the share of women using contraceptives oscillates around 80%. These countries are located on the right side of the graph. The least developed countries, on the other hand, are located on the left side of the graph and their share of women using contraceptives reaches less than 20%. Again, a general assertion can be made that increased education fosters a growing number of women who protect themselves from unwanted pregnancies by contraceptive measures.

Educated women are better able to care for their children – understand doctor's instructions, allow their children to be inoculated or provide them with better quality food (Buor 2003). All of this helps to reduce infant or child mortality. Silles (2009) claims that one year spent is school increases the likelihood of being in good health by 4.5 to 5.5 per cent (depending on the exact approach towards measuring health).

Family planning and contraception use have further impacts on the lives of women – aside from the direct effect of protection form unexpected pregnancies, they positively affect the health of both adults and children. There is a negative correlation between the incidence of disease and the level of education (Vandermoortele and Delamonica 2000). The use of condoms reduces the risks of sexually transmitted diseases (e.g. HIV/AIDS). Furthermore, the reduction of incidence of such diseases is further facilitated by education through a delayed age of sexual activity and a lesser amount of sexual partners.

It has also been confirmed (Ozalp et al. 1999) that more educated women frequently use combined peroral contraception, whereas less educated women prefer condoms and intrauterine devices.

The influence of education on the use of contraceptives is also recognisable among men. According to an Ethiopian study (Tuloro et al. 2006), literate men use contraceptive measures 3.7 times more often than illiterate men.

However, the achieved level of education does not guarantee a positive change in women's behaviour. The positive effect can 'wear off', as some studies have documented. For example, if the woman lives in a secluded rural area, upon the completion of the relevant educational level (primary level, in this scenario), she may simply return to entrenched stereotypical behavioural patterns and the effect of education can simply evaporate (Buor 2003). This risk is further exacerbated if the woman lacks the opportunity to practice her new-found knowledge and gradually regresses back into illiteracy. The quality of the educational institution also plays an important role in preventing or abetting such occurrences.

Education affects reproductive behaviour in other ways, too. A more educated women is more likely to chose a partner how is better able to provide for their children (Breier and Duflo 2002). Also, literate women are less likely to enter relationships with their relatives.

Education also affects the issue of preferential attitudes towards the gender of expected children. In a number of (predominantly developing) countries, the child's gender is an issue of concern, with boys being uniformly preferred. This attitude can be altered through a painstaking process of which education is an integral part (Murthi 2002)

3.5 Health of inhabitants

Education should definitely be considered among the principal factors affecting people's health and hygiene. Illiterate persons tend to have an unfavourable view towards modern medicine and remain dedicated to their traditional healing practices. Education helps to remove this barrier and promotes the use of modern medicine and methods.

Figure 6 expresses the negative correlation between the level of literacy and infant mortality. Generally, in can be asserted that with a rising level of education in a country, infant mortality declines. Infant mortality serves as a very useful indicator of development, since it reflects the health conditions within the researched area. Some studies (Glewwe and Miguel 2007) have confirmed that ill health and diet reduce the length of school attendance in years, as well as the amount of time children spend by studying and school preparations.

Education also plays a pivotal role in the combat against one of the most devastating diseases in the (not only) developing world – HIV/AIDS (Vandemoortele and Delamonica 2000). Lack of understanding (especially among women) represents the greatest risk in terms of contracting the disease. Illiterate women are 3 times more likely to assume that a healthy looking person cannot be HIV positive. Similarly, illiterate women tend to be 4 times more likely to believe in the inevitability of

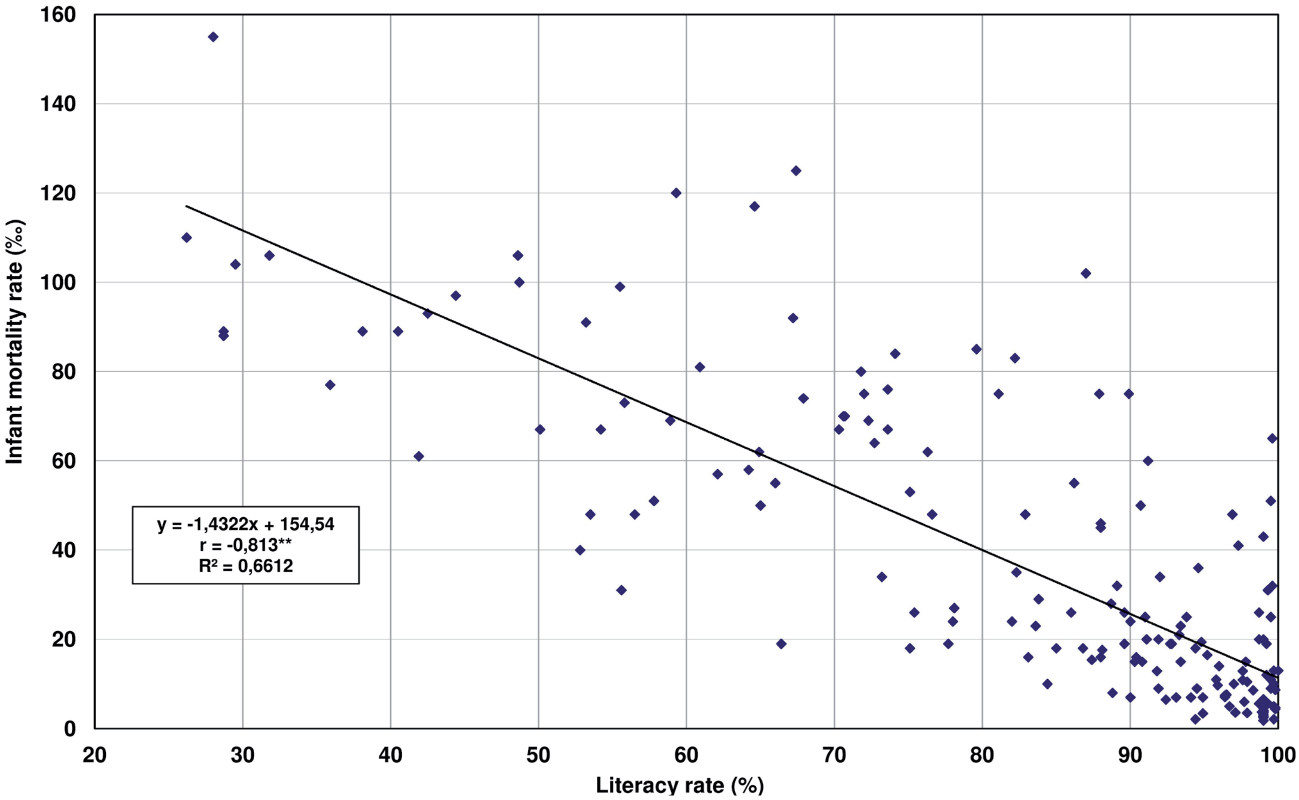

Fig. 6 Relationship between literacy rate and infant mortality rate by world's countries 2009.
Source: PRB 2009, HDR 2009

HIV/AIDS than educated women are. Illiterate women are also on average 3 times more likely to assume that HIV/AIDS cannot be passed on from a mother to her child (Vandemoortele and Delamonica 2000). According to De Walque (2007), educated women are more likely to react positively to information campaigns on HIV/AIDS.

The topic of education and decreasing child mortality has been picked up by Bhuiya and Stretfield (1991 cited in Buor 2003), who present evidence of a difference between child mortality of children of uneducated mothers and those who have completed 1 to 5 years of primary education. The chance of death is reduced by 45% for boys born to literate mothers and by 7% for their daughters. The difference made to child mortality by attending more than 6 years of school is even more pronounced – The chance of death of a child of a mother who completed 6 or more years of formal education is 70% lower for boys and 32% lower for girls. Geo-JaJa et al. (2009) assert that child mortality in the developing countries decreases by 5 to 10% for every year of the mother's education. According to Basu and Stephenson (2005), even a low education on the part of the mother significantly increases the child's chance of survival.

There are a few rare studies, which show a positive correlation between education and child mortality – e.g. Macassa et al. 2003, Adetunji 1994). This occurrence can be explained by a tumultuous situation within the country (Macassa et al. 2003), or might be related to social pitfalls of young women, who, after the completion of their education, opt for having a child rather than searching for a job. The potential inability to find an adequate work opportunity can be psychologically rather taxing and frustrating, and this might transfer on to the child. (Adetunji 1994).

Certain studies also stress the role of the father's education on child mortality. In an analysis from Mozambique (Macassa et al. 2003), it emerged that children of fathers with primary education are 1.93 times more likely to not survive than children of fathers with secondary or university education. Children of illiterate fathers are 2.57 times more likely to dies than children of fathers with secondary or university education.

Education also seems to have a positive impact on the development of progressive social norms. This way, education achieved by a group of women can affect the behaviour of other women in their community. The norm of lower fertility, which can spread throughout an entire community thanks to the influence of some educated women, might serve as an example of this. (Murthi 2002) On the other hand, in areas where education is not widespread, educated women might suffer from the very absence of norms which would legitimise lower fertility.

It seems as generally valid to accept that even a low level of education is better than straight up illiteracy, because, in certain situations, it can save lives. There have been, however, also confirmed case when low education

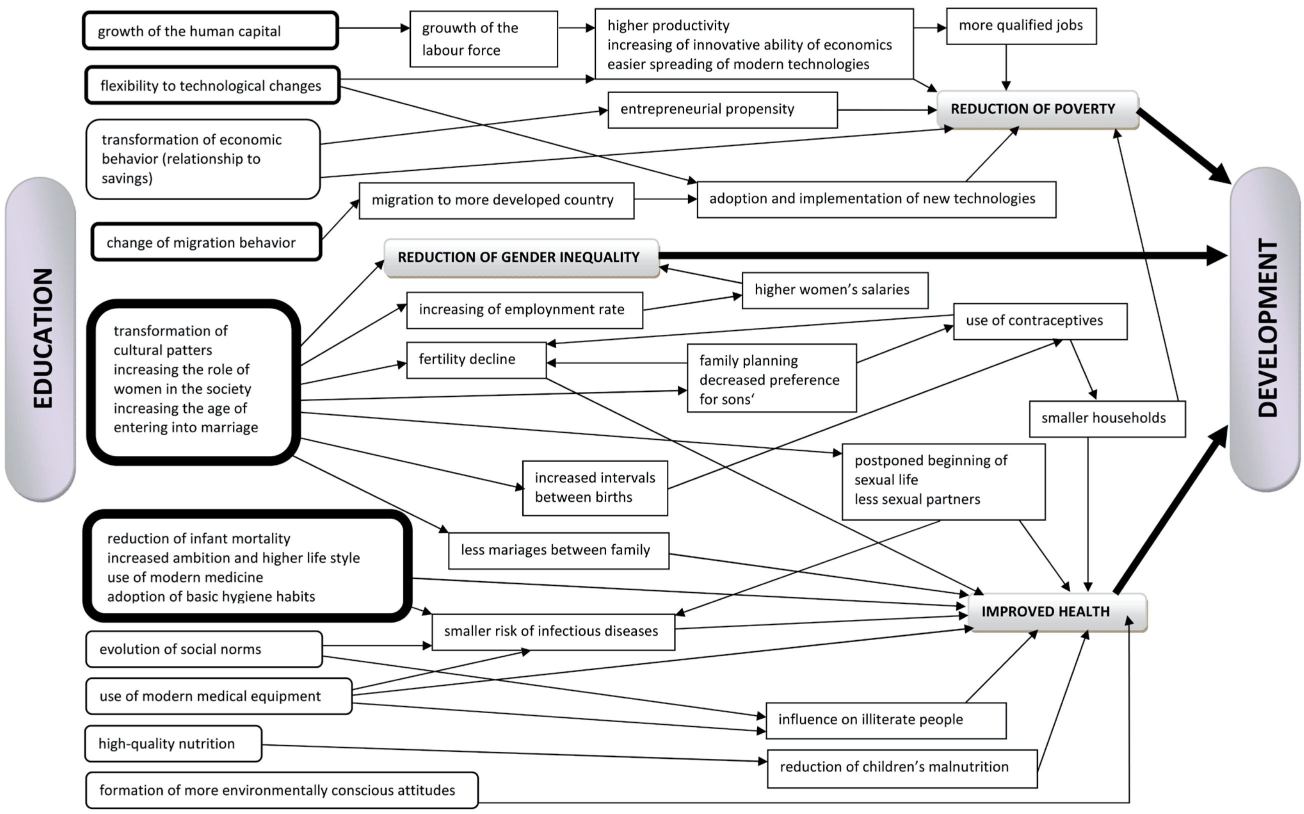

Fig. 7 The selected mechanisms facilitating the relationship between education and development.
Source: author's research

proved to be somewhat counterproductive – e.g. a study of the Brazilian slums (Kaufmann 1991 cited in Basu and Stephenson 2005) uncovered occurrences when women tried to protect their families from the encroaching cholera epidemic by washing their cutlery and food with water. They did not, however, understand that the quality of the water is also of importance, wherefore the epidemic kept on spreading even more vigorously.

4. Conclusion

Education has an undeniable impact on human behaviour. Educated persons have access to extensive opportunities to improve their lives, be it a more rewarding job, better health or higher social status. A number of works cited in this study stress the importance of even elementary education as an effective facilitator of positive developments. Even a trivial understanding of hygienic practices can save lives by tens of thousands. The knowledge of the written word then helps a person to understand the world around them and to (figuratively or literally) survive in it.

Even through education can be generally considered to be a very positive factor in the facilitation of human development, in certain cases, this assertion is not without its ambiguity. This can be demonstrated on the case of migration, where education influences people's migratory habits, but whether that is a positive or a negative occurrence is subject to debate.

Nevertheless, a clear majority of articles and studies from various parts of the world analysed here affirms the position of education as a chief component in the process of human development. Directly or indirectly, it influences human behaviour and subsequently contributes to human development.

Hypothesis 1 has been verified in the beginning of the individual chapters, where the relationship between education and the selected development indicators is illustrated by graphs. It is apparent that all of the presented graphs (with the exception of the rate of emigration) demonstrate a clear correlation between education and the development indicators concerned.

In terms of education and its relation to migration (literacy rate and rate of emigration), only a negligible correlation has been established. This is cause by a somewhat double-edged impact education seems to have on migratory behaviour – people with high levels of education predominate among the migrants who migrate to countries with a higher HDI in search of opportunity, whereas persons with the lowest measure of education for a sizable group of migrants engaged in forced migration due to political instability, conflicts, or natural catastrophes.

Subsequent sections of the individual chapters then sought to illuminate the relationship between education and the development indicators through an analysis of the underlying microfactors. Due to a strong degree of specificity of every country (or location) in the world in terms of culture, religion, demographic character or geographic location, it is impossible to formulate general conclusions, which could categorise these mechanisms into categories applicable to all countries of the world. Mechanisms can differ region to region and are locally specific. In one area of the world, a given mechanism can act as an engine of development, whereas in another place can have the opposite effect.

Figure 7 presents a simple schema of the relationship between education and the individual development indicators. It also includes the most important mechanisms involved in such relationship (selected according to the frequency of their appearance in the studied literature).

The left side concentrates mechanisms directly triggered by education. These are then connected with intermediate mechanisms through the use of directional arrows. Development then represents the final goal, which mechanisms seek to influence. This final stage, however, is directly preceded by three principal mechanisms with direct influence on development, and which stand as superordinate to the micromechanisms that lead up to them. These are: reduction of poverty, reduction of gender inequality and improved health.

Mechanisms directly affected by education (those in rounded boxes) are further divided in to three categories, which is expressed by the width of the circuit line. The wider the line, the stronger the relationship between education and the given mechanism – the more evidence has been found to substantiate such relationship. The weakest line symbolises that 3–5 studies have been found to support the relationship between education and the given mechanism, a line of average width represents the support of 6–15 studies and the thickest circuit line is reserved for mechanism supported by at least 16 studies.

The strongest relationship (37 studies) has been confirmed between education and the transformation of cultural social patters primarily associated with the improving perception and position of women. The influence of education on the reduction of child mortality and adoption of hygienic habits also belongs among the strongest relationships (29 studies) identified during the analysis. Both mechanisms relate primary to health and hygiene – through decline of fertility, reduction of child mortality or the use of contraception etc. This topic certainly belongs amongst those most frequently discussed, since it relates directly to quality of life of an individual (and may often decide the very difference between life and death. Moreover, the issue of a growing status of women in some parts of the world (especially in the Islamic world) can be in itself rather controversial. A transformation of social structures and patters is a complex and uneasy process, in which education plays a necessary, yet not a sufficient role.

On the other hand, the relationship between education and a propensity towards entrepreneurship, evolution of social norms or a formation of more environmentally conscious attitudes appears considerably weaker. The less frequent appearance of these mechanisms in literature can be partially explained by their limited direct involvement with the issue of human survival, since they relate to a somewhat less fundamental field of human activity. This does not, however, imply that such mechanisms would be insignificant; they simply touch upon a slightly different area of human development.

It has been confirmed that due to the complex nature of development, no single micromechanism can be used to fully explain the relationship between education and development from a general perspective. Furthermore, based on the information obtained through the analyzed literature, it cannot be confirmed the factor of health and hygiene plays a dominant role in the relationship between education and development. After all, Figure 7 determines that the strongest relationship can be found between education and the transformation of sociocultural patterns. Therefore, **Hypothesis 2** cannot be confirmed.

Should it be required to highlight an area of human development which is affected by education and designate it as most significant, it would come down to a very subjective decision. It seems correct to assert that process of development needs to be supported in all of its aspects. Education is a principal agent in the process of development, which is facilitated by a score of mechanisms this study sought to discuss. These mechanisms, however, need to be considered as very locally specific. On its own, education is hardly sufficient – without socioeconomic, cultural and political within society, its effect can be rather limited.

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REFERENCES

ADETUNJI, J. A. (1994): Infant mortality and mother's education in Ondo State, Nigeria. Social Science & Medicine, 40(2), 253–263. http://dx.doi.org/10.1016/0277-9536(94)E0067-3

ASFAW, A., ADMASSIE, A. (2004): The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia. Agricultural Economics, 30(3), 215–228. http://dx.doi.org/10.1111/j.1574-0862.2004.tb00190.x

BASU, A. M. (2002): Why does Education Lead to Lower Fertility? A Critical Review of Some of the Possibilities. World Development, 30 (10), 1779–1790. http://dx.doi.org/10.1016/S0305-750X(02)00072-4

BASU, A. M., STEPHENSON, R. (2005): Low levels of maternal education and the proximate determinants of childhood mortality: a little learning is not a dangerous thing. Social Science & Medicine, 60(9), 2011–2023. http://dx.doi.org/10.1016/j.socscimed.2004.08.057

BOROOAH, V. K. (2004): Gender bias among children in India in their diet and immunization against disease. Social Science & Medicine, 58(9), 1719–1731. http://dx.doi.org/10.1016/S0277-9536(03)00342-3

BREIEROVA, L., DUFLO, E. (2002): The Impact of Education on Fertility and Child Mortality: Do Fathers really Matter less than Mothers? NBER Working Paper, v. W10513. Massachusetts Institute of Technology.

BUOR, D. (2003): Mothers' education and childhood mortality in Ghana. Health Policy, 64(3), 297–309. http://dx.doi.org/10.1016/S0168-8510(02)00178-1

DE WALQUE, D. (2007): How does the impact of an HIV/AIDS information campaign vary with educational attainment? Evidence from rural Uganda. Journal of Development Economics, 84, 686–714. http://dx.doi.org/10.1016/j.jdeveco.2006.12.003

DUFLO, E., KREMER, M., ROBINSON, J. (2008): How High are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya. American Economic Review, 98(2), 482–88. http://dx.doi.org/10.1257/aer.98.2.482

GEO-JAJA, M. A., PAYNE, S. J., HALLAM, P. R., BAUM, D. R. (2009): Gender Equity and Women Empowerment in Africa: The Education and Economic Globalization Nexus. In: ZAJDA, J., FREEMAN, K.: Race, Ethnicity,and Gender in Education. Cross-Cultural Understandings. Globalisation, Comparative Education and Policy Research, 6, 97–121.

GLEWWE, P., MIGUEL, E. (2007): The Impact of Child Health and Nutrition on Education in less Developed Countries. Handbook of Development Economics, 4, 3561–3606. http://dx.doi.org/10.1016/S1573-4471(07)04056-9

GRIMM, M. (2005): Educational policies and poverty reduction in Côte d'Ivoire. Journal of Policy Modeling, 27(2), 231–247. http://dx.doi.org/10.1016/j.jpolmod.2004.12.002

GYIMAH, S. O. (2003): A cohort analysis of the timing of first birth and fertility in Ghana. Population Research and Policy Review, 22(3), 251–266. http://dx.doi.org/10.1023/A:1026008912138

HANJRA, M. A., FEREDE, T., GUTTA, D. G. (2009a): Pathways to breaking the poverty trap in Ethiopia: Investments in agricultural water, education, and markets. Agricultural Water Management, 96(11), 1596–1604. http://dx.doi.org/10.1016/j.agwat.2009.06.008

HANJRA, M. A., FEREDE, T., GUTTA, D. G. (2009b): Reducing poverty in sub-Saharan Africa through investments in water and other priorities. Agricultural Water Management, 96(7), 1062–1070. http://dx.doi.org/10.1016/j.agwat.2009.03.001

HANUSHEK, E. A., WÖSSMANN, L. (2008): Education and Economic Growth. Education Next 8(2), 62–70.

HENDL, J. (2004): Přehled statistických metod zpracovávání dat. Praha, Portál. 584 p.

CHO, S. H. (2009): Role of Saving Goals in Savings Behavior: Regulatory Focus Approach. Dissertation. College of Education and Human Ecology, The Ohio State University. 111 p.

KOCOVÁ, T. (2010): Role vzdělání v procesu rozvoje chudých zemí. Diplomová práce. Katedra sociální geografie a regionálního rozvoje. Přírodovědecká fakulta Univerzity Karlovy v Praze. 76 p.

LESLIE, J. (1988): Women's Work and Child Nutrition in the Third World. World Development, 16(11), 1341–1362. http://dx.doi.org/10.1016/0305-750X(88)90209-4

MACASSA, G., GHILAGABER, G., BERNHARDT, E., DIDERICHSEN, F., BURSTRÖM, B. (2003): Inequalities in child mortality in Mozambique: differentials by parental socio-economic position. Social Science & Medicine, 57(12), 2255–2264. http://dx.doi.org/10.1016/S0277-9536(02)00545-2

McCRARY, J., ROYER, H. (2006): The Effect of Female Education on Fertility and Infant Health: Evidence from School Entry Policies Using Exact Date of Birth. NBER Working Paper, v. W12329.

MURTHI, M. (2002): Fertility Change in Asia and Africa. World Development, 30(10), 1769–1777. http://dx.doi.org/10.1016/S0305-750X(02)00062-1

NAKAVACHARA, V. (2010): Superior female education: Explaining the gender earnings gap trend in Thailand. Journal of Asian Economics, 21, 198–218. http://dx.doi.org/10.1016/j.asieco.2009.09.006

OSILI U. O., LONG, B. T. (2008): Does female schooling reduce fertility? Evidence from Nigeria. Journal of Development Economics, 87, 57–75. http://dx.doi.org/10.1016/j.jdeveco.2007.10.003

OZALP, S., YALCIN, O. T., HASSA, H., ERBAY, B., DALAN, N. (1999): Factors affecting the contraceptive choice in a developing country. International Journal of Gynecology & Obstetrics, 65, 53–57. http://dx.doi.org/10.1016/S0020-7292(99)00010-7

POPULATION REFERENCE BUREAU [online] (2009): 2009 World Population Data Sheet. [cit. 2010-03-27]. http://www.prb.org/pdf09/09wpds_eng.pdf

RANIS, G., STEWART, F., RAMIREZ, A. (2000): Economic Growth and Human Development. World Development, 28(2), 197–219. http://dx.doi.org/10.1016/S0305-750X(99)00131-X

ROTH, E. A., NGUGI, E. N. (2005): Female Education in a Sedentary Ariaal Rendille Community. Paternal Decision-Making and Biosocial Pathways. In: FRATKIN, E., ROTH, E. A.: As Pastoralists Settle. Social, Health, and Economic Consequences of Pastoral Sedentarization in Marsabit District, Kenya. Studies in Human Ecology and Adaptation, 1, 255–269. http://dx.doi.org/10.1007/0-306-48595-8_13

SARMAD, R., AKHTAR, S., MANZOOR, S. (2007): Relationship of female literacy to contraceptive use in urban slums of Khushab (Punjab). Biomedica, 23, 21–23.

SILLES, M. A. (2009): The causal effect of education on health: Evidence from the United Kingdom. Economics of Education Review, 28(1), 122–128. http://dx.doi.org/10.1016/j.econedurev.2008.02.003

TODARO, M. P. (2000): Education and Development. In: Todaro, M. P.: Economic Development (326–361). 7th Edition, Longman.

TULORO, T., DERESSA, W., ALI, A., DAVEY, G. (2006): The role of men in contraceptive use and fertility preference in Hossana town, southern Ethiopia. Ethiopian Journal of Health Development, 20(3), 152–159.

UNDP [online] (2009): Human Development Report 2009: Overcoming barriers: Human mobility and development. UNDP. [cit. 2009-11-29]. http://hdr.undp.org/en/media/HDR_2009_EN_Complete.pdf

VANDEMOORTELE, J., DELAMONICA, E. (2000): The "Education Vaccine" Against HIV. Current Issues in Comparative Education, 3(1), 6–13.

WILLIAMS, N. (2006): Education, Gender and Migration. Paper presented at the Annual Meeting sof the Population Association of America, March 31 – April 1, Los Angeles, CA.

RESUMÉ

Analýza vztahu vzdělání a rozvoje

Ve studii je diskutován vztah vzdělání a rozvoje, který je zde zkoumán na několika úrovních. Od globální, kde ho lze v rámci jednotlivých zemí zcela evidentně doložit, až na úroveň „mikromechanismů", které za „makrovztahem" mezi vzděláním a rozvojem stojí. Na základě rešerše přibližně 100 odborných studií jsou tyto mikromechanismy rozděleny do pěti kategorií – dimenzí lidského rozvoje (ekonomické chování, demografické chování, zdraví, genderová nerovnost a migrace). Kategorizace přitom není snadná – jednotlivé mikromechanismy se prolínají a často lze některé z nich zařadit do více kategorií najednou, což vypovídá o jejich provázanosti. Vzdělání je naprosto zásadním činitelem v procesu rozvoje, nicméně se uskutečňuje s pomocí řady mechanismů, které je třeba považovat za lokálně specifické. V předkládané studii byl doložen nejsilnější vztah mezi vzděláním a změnou kulturních vzorců spojených především s růstem postavení žen. Vzdělání není samo o sobě dostačujícím faktorem, protože bez změn (socioekonomických, kulturních a politických) ve společnosti může být jeho vliv značně snížen.

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DISCLOSURE OF HISTORICAL SPATIAL AND STATISTICAL DATA OF DISTRICTS IN CZECHIA IN A GIS ENVIRONMENT

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ABSTRACT

This article presents a methodology for the creation and reconstruction of historical borders of chosen spatial units, especially political and judicial districts in Czechia for the specific years of population censuses within a GIS environment. Since an ethnic, language, demographic, social and cultural composition of a population is one of the main features of national and regional identity, the main objective of the article is to introduce a new method for the creation of spatial-statistical databases which will make these historical data sources accessible to both experts and the public for general use. For this purpose, district borders from 1921, 1930, (1947), 1950, 1961, 1970, 1991, 2001 and 2011, which represent the years of the population censuses in Czechia, were digitized. Our method is based mainly on historical maps, which correspond with the censuses' statistical datasets. The proposed methodology for the creation of GIS layers (digitalization, geo-referencing, vectorization, accuracy assessment, and spatial identification), their connection with censuses' statistical data (creation of spatial codes), metadata creation, and web publication is described in this article along with examples of some of the difficulties encountered during the process. We also bring attention to several case studies of problematic areas where the reconstruction of borders was particularly complicated. Finally, spatial and statistical data in the format of ESRI shapefile and ESRI Geodatabase offer possibilities for retrospective analyses of quantitative data to current researchers from a range of scientific disciplines. Files in both formats are publicly available at www.historickygis.cz.

Keywords: administrative borders; historical GIS; districts; Czechia; historical cartography

1. Introduction

One of the most important elements involved in the existence of a distinct national and regional identity has been development of demographic, social, and cultural composition of population. A unique source of a wide range of data on this composition was completed primarily due to a long tradition of population censuses, which on our territory spans of over 300 years[1]. Since the mid-19th century, population data have been acquired periodically at regular 10-year intervals through the Population Censuses (censuses)[2]. Since the establishment of Czechoslovakia, the censuses took place in 1921, 1930, (1946/47)[3], 1950, 1961, 1970, 1980, 1991, 2001 and 2011. However, these historically and thematically rich sources of information are currently not being fully utilised, mainly due to a limited accessibility of data, their incompleteness, or damage done to the paper originals over time. Example of such damage were extensive floods in 2002 which destroyed a number of original publications kept at the library of the Czech Statistical Office in Karlín. Valuable historical population data are therefore rarely used for research across the range of scientific disciplines, but instead remain in old statistical repositories of selected institutions[4] and in private collections. In light of the reorientation of the focus of geographic research during the period of transformation (see e.g. Hampl, Dostál and Drbohlav 2007), which now focuses on the investigation of the mechanisms of socio-spatial differentiation, more and more attention is being paid to the development trends and causal mechanisms of social phenomena (see e.g. Semotanová and Chromý 2012; Svoboda, Přidalová and Ouředníček 2014). The inclusion of a large spectrum of spatial and statistical data is therefore becoming not only an appropriate, but often an outright necessary element of such research effort.

The article is one of the outputs of the multidisciplinary project called "Disclosure of Historic Spatial and Statistical Data in GIS Environment". The project has been developed as part of the Program of Applied Research and Development of National and Cultural Identity (NAKI) commenced at the Faculty of Science of the Charles University in Prague (2012–2015). The contribution aims to introduce and to discuss the methodology of disclosure of

[1] Since 1869 in form of regular, nationwide population censuses with relatively stable 10-year periodicity.

[2] Portfolio of surveyed data, as well as the name of censuses itself, have been throughout the history subjects of frequent changes.

[3] Due to the rush period just after the World War II, the census 1946/47 was organized in irregular and incomplete form.

[4] Over the course of the research which prompted this article, the authors have identified a number of valuable publications which are predominantly located (frequently only as a singular exemplar) in repositories and libraries of the Charles University in Prague, the Czech Statistical Office (CZSO), or the Czech Office for Surveying, Mapping and Cadastre (ČÚZK). However, the efforts to locate data sources which would help to provide a complete (as complete as possible, at least) picture were joined by over 20 addressed institutions.

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historical spatial and statistical data in the environment of geographic information systems (GIS). The methodology was proposed in such a way that it should be possible to reproduce, albeit in a perhaps slightly adjusted form, by a range of both domestic and international users in further research concerned with the accessibility of valuable historical spatial and statistical data. We are aware that, for a variety of reasons, it is not currently possible to achieve full digitalization and public availability of all relevant historical data sources. However, we believe that a creation of a unified methodological framework can contribute for it and aid in research efforts interested in the investigation of historical events and processes.

Throughout the attempts at increasing availability of historical sources which provide valuable information on the causal and developmental mechanisms of current processes, several research concepts have proven their particular usefulness. On a theoretical level, we follow research in historical demography and cartography, historical GIS application, and, especially, mapping techniques of the Chicago School (Musil 1991; Gregory and Ell 2007; Ouředníček et al. 2009; Semotanová 2009). The outputs of our research complement the recently published Landscape Atlas of the Czech Republic (Hrnčiarová et al. 2009) offering a complex documentation of the natural and social components of Czech landscape and the Atlas of Socio-spatial Differentiation of the Czech Republic (Ouředníček, Temelová and Pospíšilová 2011), which explores the changes in spatial distribution of selected social and economic phenomena since 1991. A similar emphasis on the accessibility of historical data, retrospective analysis, and acknowledgement of developmental trends during an assessment of the character and intensity of land use changes can be attributed to Bičík et al. (2010) and their Database of Long-term Land Use Changes in Czechia. In regards to methodological approaches to utilization of historical and contemporary population data, this article shares some features with certain international web portals. For example, the internet portal of the US population census (census.gov; see U.S. Census Bureau 2011), which not only provides access to its data, but also allows them to be used interactively for the creation of variously themed online maps, serves as a great inspiration in this case. Domestically, the issue of historical borders and the utility of historical population censuses have recently been explored by Kučera and Kučerová (2009) or Semotanová (2009). However, none of the aforementioned works make use of the GIS software, although modelling of historical spatial data within this framework could make cartographic visualisation and the analysis of historical data significantly more convenient.

The recent rise in interest in the preservation and application of historically valuable data sources is primarily associated with the Program of Applied Research and Development of National and Cultural Identity (NAKI) provided by the Czech Ministry of Culture. Within this program, two similarly oriented research projects have recently been elaborated. One of them aims to propose methodology for discovering and accessibility of old maps, plans, atlases and globes (DF11P01OVV021), while the other deals with technologies which could increase the accessibility of the Czech Republic's official map archives (DF11P01OVV003). Both projects attempt to preserve old maps through a digitalization of their content. However, the digital information is kept in raster format only, and is not converted into a vector format which would enable the creation of new maps with historical data. A shift towards the GIS vector outputs of selected historical borders data is apparent in the recent work of Burda, Janoušek and Chromý (2014). However, the authors were not interested in the reconstruction of historical borders relevant for the individual years for which census data are available. Instead, they produced layers representing years 1930 and 1950, when significant changes in administrative borders occurred. Burda et al. (2014) adjusted the shape and course of the borders to the current GIS cadastral layer (from 2010), from which their creation of the borders went out. For this reason, as the authors mention, "… this is not a reconstruction of an accurate historical border, or of its exact course" (Burda et al. 2014, p. 54). As a point of difference from this approach, we attempted to reconstruct the shape and course of historical borders of administrative units as accurately as possible in respect to the specific census years and available map data sources for both – district units (e.g. political, judicial and post-1960 districts; *okres*) in the case of the entire country and cadastral units (*katastrální* území) and census tracts (*urbanistický obvod*) in the case of Prague.

In the article, we first investigate the changing historical delimitation of spatial administrative units, which significantly affected the development of statistical territorial units used in the population censuses. The central section of the article discusses the methodology of reconstructing the historical borders of these spatial units in GIS and their interaction with population data. Though we used the ArcGIS 10.1 (Esri ©) software the described methodology is applicable in general. We focus on the digitalization of state, regional, and district borders existing on the territory of the Czechia during 1921–2011, as well as corresponding borders of municipal districts, cadastral units, and (later) census tracts on the territory of Prague. We pay particular attention to selection of appropriate map sources in available archives, elaboration of a suitable methodology of converting these data into GIS and their connecting with information obtained through population censuses, and the incorporation of census data into a database. All of these steps improve the accessibility of historical spatial data and enable the creation of historically themed specialised maps, as well as a prospective publication of the Historical Population Atlas of the Czech Lands. These outputs, as well as a new internet map portal (www.historickygis.cz) established over the course of the project, will contribute to an increased usage of these "new" historical spatial and statistical data in public, academic, and educational spheres. Finally, we include three case studies, for which the reconstruction of historical borders involved particular difficulties associated with significant changes of borders throughout the observed period.

2. Development of the Czech districts from 1850 to 2011

Reconstruction of spatial datasets of district borders in Czechia related to the years of the census (in a period of 1921–2011) needs to discuss historical development of the analysed spatial units. The delimitation of districts had its origins in the reform of the spatial administration in 1849, which abolished the feudalism as an administrative system and replaced feudal fiefdoms with political and judicial districts (Růžková et al. 2006; Čáp 2009). Further administrative changes took place during the 20th century, which also impacted on the delimitation of districts for particular census years. We therefore summarize the most important administrative reforms which took place since 1849 and affected the use of districts as statistical units.

The Imperial Edict no. 295/1849 separated political and judicial administration (starting from January 1, 1850). Political districts, made similar in both their area and population size (Janák 1987), became the primary units of state administration below the level of Czech historical lands (Bohemia, Moravia and Silesia) and regions. Total of 79 political districts (not including Prague) were established in Bohemia, 25 in Moravia, and 7 districts were created in Silesia. Judicial administration devolved some of its powers to newly founded regional and district courts (with specifically delimited judicial districts). Consequently, 207 judicial districts were delimited in Bohemia (excluding Prague as a city with special status), 78 in Moravia and 22 in Silesia (Mleziva 2010). These judicial districts also became elementary territorial units (Čáp 2009). The establishment of judicial districts respected historical and geographic borders while maintaining comparable population numbers in individual districts (Jeleček 2000). Alongside judicial districts, the new system also recognized statutory cities which initially comprised only the capital of Prague, but later came to include Brno, Opava, and even later also Liberec (Mleziva 2010). Regions, such as higher spatial units were only established in Bohemia (7 + Prague) and Moravia (2)[5], while the borders of regional authorities corresponded with borders of regions as official territorial units.

The separation of political and judicial administration was temporarily suspended in 1855[6], when every judicial district also assumed the responsibilities of their political counterparts (Jeleček 2000). Then, 208 new administrative units emerged in Bohemia, 76 in Moravia, and 22 in Silesia (Janák 1987; Čáp 2009). The number of regions in Bohemia increased to 13 (excluding Prague), reached 6 in Moravia and 1 region emerged in Silesia (Jeleček 2000). Act no. 44/1868 once again separated judicial and political districts. With minor exceptions, the delimitation of judicial districts followed the set up established in 1850 and over the next few years, their number had risen as a result of further divisions of original districts (Čáp 2009). Political districts were newly delimited (Mleziva 2010) – 89 were established in Bohemia, 30 in Moravia, and 7 in Silesia (Janák 1987; Jeleček 2000). Their numbers also continued to grow along with the population of the country (Růžková et al. 2006). The year 1868 brought about a second significant administrative change – the abolishment of regions as territorial units[7].

A reform of the territorial and administrative system which would create counties (named župa) and discontinue the use of political districts was attempted in 1920 (Mleziva 2010). However, the administrative changes never materialised, since Act no. 126/1920 affected merely territorial units, wherefore counties (župa) never acquired any administrative functions. Czech historical lands were divided into the capital city of Prague, 15 counties (župa), and 330 judicial districts (226 in Bohemia, 81 in Moravia, and 23 in Silesia) (Mleziva 2010). The division into political districts was based on the state before 1918 (Semotanová 2013). Růžičková et al. (2006) account for 159 political districts between years 1921 and 1927. An administrative reform was enacted in 1928 (Mleziva 2010) under Act no. 125/1927 (Růžková et al. 2006). By this act, Czech historical lands regained their position as the highest level administrative units. Silesia had revoked its status of historical land and Czech lands were divided into Bohemia and Moravia-Silesia (Jeleček 2000). The law also completely eliminated counties (župa; see Mleziva 2010). Bohemia became comprised of 103 political and 228 judicial districts, while Moravia-Silesia included 45 political and 106 judicial districts (Dostál and Kára 1992; Jeleček 2000). During the 1921 population census, the spatial organisation of civil administration was not fully established and the 1920 law on the establishment of counties was still in effect. For this reason, the results of the first post-war census were calculated according to these counties (CZSO 2013a). The statistics also operated with political district and judicial districts (CZSO 2013a). At the time of the Population Census (on February 15, 1921) the territory of Czechia was divided

5 From a legal perspective, Silesia was not considered to be a separate region, since it was not administered by a regional president but by a Land governor (see more on the administrative division in Janák 1987).

6 Unlike administrative changes, territorial reorganizations took place already in 1854 (Mleziva 2010).

7 Regional offices had been already disestablished in 1860–1862 (Janák 1987).

into 328 judicial districts (Prague as a single district) and 152 political districts, while 330 judicial and 151 political districts existed in the country during the next census (December 1, 1930) (see Table 1).

The system of judicial and political districts preserved its function until 1949. However, between 1930 and 1949, the numbers of districts of individual types experienced considerable changes as the outcome of the annexation of border regions specified by the Munich Agreement. The period after 1945 and the return of occupied territories to Czechoslovakia saw (with some exceptions) the restoration of the state of affairs valid in September 30th 1938. Czech historical lands were re-parcelled into districts on the basis of a presidential decree from October 27, 1945 (Semotanová 2013) – Bohemia was partitioned into 110 administrative and 223 judicial districts, while Moravia-Silesia featured 44 administrative and 103 judicial districts. In light of significant changes which had occurred during and after the war, the census of 1950 was preceded by a post-war listing of inhabitants which took place in 1947 (May 22) and collected data representing 162 districts.

In 1949, based on Act 280/1948 abandoned historical lands (*země*) as administrative units and re-introduced regions (*kraj*). Czech historical lands were partitioned into 13 regions (8 in Bohemia and 5 in Moravia and Silesia) (Burda 2010). By Decree 3/1949 326 former judicial districts were replaced by 180 new districts which served as territorial units, as well as areas of competence of national district committees (*národní výbor*) and district courts (Mleziva 2010). The first post-war census took place on March 1, 1950, and collected data for 193 units.

While year 1960 did not bring any systemic changes of the administrative set up, it did, however, witness a territorial reform. Act 36/1960 abolished a majority of existing districts and replaced them with 75 new districts (Jeleček 2000), and also reduced the number of regions from 13 to 7 (Burda 2010). Prague became the 76th district and 8th region (Růžková et al. 2006). This division is also considered to be insensitive towards historical and geographic borders of concerned territories (Mleziva 2010). This territorial order of things remained in place for the next 30 years. The Population and Housing Censuses in 1961 (March 1), 1970 (December 1) and 1980 (November 1) all operated with 76 districts.

The administrative system remained unchanged even after 1989, and the Czech Statistical Office used 76 districts when publishing the outputs of the 1991 census. Act 347/1997 on higher territorial self-governing units established territorial units as replacements for the previously existing regions since 2000 (January 1). However, the partition into regions continues to be relevant to this day and some institutions (such as courts) are organized in accordance with it (Pospíšilová and Šimon 2011). District of Jeseník was created in 1996 (through a separation from the larger Šumperk district), wherefore the 2001 census operates with 77 districts. In 2003, in line with Act 320/2002, districts as administrative units were abolished and their responsibilities were mostly taken over by municipalities with extended power (*obec s rozšířenou působností, ORP)*. However, districts continue to be used as territorial and statistical units. For this reason, the 2011 census once again presents its findings as subdivided for 77 districts.

Tab. 1 Number of units recognized in the outputs of Population censuses in Czechia.

Year of the census	Judicial districts	Political districts	Districts
1921	328	152	–
1930	330	151	–
1946/1947	–	–	162
1950	–	–	193
1961	–	–	76
1970	–	–	76
1980	–	–	76
1991	–	–	76
2001	–	–	77
2011	–	–	77

Source: Czech Statistical Office, based on the statistical data

3. Methodology for the creation of historical borders in GIS

3.1 Preparation of map records

A successful reconstruction of administrative borders of selected territorial units used in census publications rests upon a thorough initial research. This research involved the procurement of all map records with vital information on the administrative delimitation and partition of the territory of present-day Czechia in the time periods corresponding with official population censuses (see Table 1). A wide multidisciplinary collaboration joined by over 20 addressed institutions helped to secure approximately 70 valuable maps of the Czechia and an equivalent amount of maps and plans of the city of Prague[8]. This archive work fulfilled the fundamental criteria of usefulness – a depiction of judicial or political districts – or, ideally which feature territorial units of a lower scale level (in this instance primarily cadastral units).

The final selection of maps (Table 2) was guided by two elementary criteria: (i) the year in which the map was published must be as close to the year of the census as possible; (ii) maps include administrative borders which constitute the basis of selected GIS layer. The borders of districts (judicial, political, and administrative) were

[8] A detailed list of maps with their citation references and photographic documentation is available on request in the central data point of the Urban and Regional Laboratory reserach group.

Tab. 2 List of map records used for a transfer of spatial data into GIS.

Name of Map Record	Scale	Format	Provider	Time of Depiction	Author
III. Military Mapping	1 : 75,000	raster	ČÚZK	1927	Ministry of the Interior – Geographic Department
Synoptic map of cadastral areas: Bohemia/Moravia-Silesia	1 : 144,000 / 1 : 115,200	raster	ČÚZK	1936	Ministry of Finance – Reproduction Department
Synoptic map of cadastral areas: Bohemia/ Moravia–Silesia	1 : 200,000	raster	ČÚZK	1947	Ministry of Finance – Reproduction Department
Synoptic map of territorial organization by February 1, 1949	1 : 200,000	raster	ČÚZK	1949	Ministry of Finance – Reproduction Department
Map of administrative subdivision of the ČSR	1 : 200,000	raster	ČÚZK	1960	Central Bureau of Geodesy and Cartography
Map of administrative subdivision of the ČSR	1 : 200,000	raster	ČÚZK	1971–1973	Czech Geodetic and Cartographic Office
Map of administrative subdivision of the ČSR	1 : 200,000	raster	ČÚZK	1980–1982	Czech Geodetic and Cartographic Office
okr96g1s.shp	x	SHP	CZSO (Census 1991)	1991	Czech Statistical Office
okresy_201102.shp	x	SHP	CZSO (Census 2001)	2001	Czech Statistical Office
okres.shp	x	SHP	CZSO (Census 2011)	2011	Czech Statistical Office

Sources: explained in the table itself; adjusted and organised by authors

searched for the case of maps depicting the territory of Czechia. Subsequent geo-referencing and vectorization of these data revealed that a successful utilization of data source (on the level of districts) is dependent on the maps' inclusion of lower scale units' borders – cadastral units (*katastrální* území), in this instance. It is because cadastres are the oldest relatively stable administrative units which allow for a successful delimitation of district borders. Another important criterion for map selection was to keep relatively unified scale throughout the entire time series of maps selected for particular year of censuses. Readability and completeness of administrative borders across the entire map also served as an important criterion for selection, as did the completeness of the coverage of the studied area, while a general clarity and physical condition of the map acted as supporting criteria.

Map records pertinent to the censuses of 1991, 2001, and 2011 were obtained differently from the rest, since their source data were provided by the Czech Statistical office (CZSO). For years 2001 and 2011, complete digital datasets (shp layers) for the level of basic settlement units (*základní sídelní jednotka*) were provided by the CZSO, which can be used for creation of all higher-level administrative or technical units. The administrative borders reflected the scale level of municipalities in 1991 had also been previously determined and adjusted by the URRlab on the basis of vector layers provided by the CZSO. Source data for all censuses had therefore already been digitally recoded into a GIS polygon layer with an associated database of district codes.

Digital vector layers on individual censuses taking place before 1991 had to be created with a comparable level of precision and in similar quality on the basis of above listed contemporary maps (see Table 2). Information from paper maps had to be digitized, geo-referenced, recoded into GIS vector polygon layers and connected with the database of statistical information obtained through individual censuses (see e.g. Robinson et al. 1995; Kolář 1997; Dobrovolný 1998; Tuček 1998; Doubrava 2005; Antoš 2006; Harvey 2008; Kraak and Ormeling 2010; Cajthaml 2007, 2012). Special attention was paid to the process of map scanning, both in terms of the appropriate raster resolution[9] necessary for correct geo-referencing and vectorization, but also in regards to the potentially fragile nature of materials with great historical value.

3.2 Georeferencing and vectorization

The ArcGIS 10.1 software (Esri©) environment was used for georeferencing and vectorization. The scanned map sheets were georeferenced in the GIS environment[10]. The georeferencing was based on a vector layer of census tracts from the 2001 census (supplied by the CZSO) in the .shp format using the JTSK coordinate system. The JTSK coordinate system is used for all final data layers.

9 Scans of source maps were made in the 300 dpi resolution in the tif format. Due to limitations imposed on the borrowing of certain items, we sometimes used the scanning services available at respective institutions. Large-scale scanners had to be used in the case of maps exceeding the A3 format. Therefore, individual map sheets were always scanned as a compact unit in order to avoid distortions potentially caused by splicing. For other technical specifications, see Ouředníček et al. (2014a, b) or webpage www.historickygis.cz.

10 Using ESRI ArcGIS, version 10.1.

Its selection was also inspired by its utilisation in respect to historical maps (e.g. Doubrava 2005; Cajthaml and Krejčí 2008). Unified transformation method – 1st order polynomial (affine) transformation based on a sufficient number of control points was used for all map inputs (e.g. Dobrovolný 1998; Doubrava 2005). Control points were equally distributed across the entire transformed raster and their amount was derived from the spatial deformation of the raster input in order to achieve the highest level of accuracy during the transformation. The Nearest Neighbour calculation method was used for resampling.

The precision of georeferencing (using root mean square error) for map at the scale of 1 : 200,000, which formed the basis of the dataset, was established at 100 metres (0.5 mm at map's scale). In certain cases, it proved impossible to maintain this level of maximum quadratic deviation, especially due to deformations of the source scan. The highest deviation value reached 167 metres.

As has been mentioned earlier, the vectorization was based on a vector polygon layer of basic settlement units from 2001 (further only as zsj_2001) provided by the CZSO in the .shp format. This layer was subsequently manually edited over the georeferenced raster maps from years close to the census years (see Table 2). Where the border lines provided by zsj_2001 vector layer aligned with district borders displayed by the source maps, these were left unchanged. Where they diverged, the zsj_2001 vector layer was edited in accordance with the borders depicted by the source maps. While attempting to identify appropriate catchment areas, it proved expedient to make use of contemporary administrative maps which depict territorial borders of even smaller units than districts (cadastres, in this instance), especially in the case of the earlier censuses. The original polygons were edited using the Editor tool (functions of Topology, Trace, Move Vertex, Input Vertex, Delete Vertex) in order to fit the borders specified in the source maps capturing individual census periods. During this step, we created the .shp layer of "modified areas" (problem areas). This modified zsj_2001 layer was then aggregated into judicial or political districts (or new districts and regions in censuses since 1961). Alongside this aggregation, a database emerged of places with problematic combination of judicial districts into political districts. This difficulty primarily pertains to Moravia and Silesia in the first half of the 20th century (for more information, see e.g. Gawrecká 2004).

Vector layers for the period of 1921–1980 were created independently of each other by a modification of the original zsj_2001 layer in the .shp format. A significant number of district borders (cadastres at district borders) had an identical course over the entire period of 1921–2001. These borders were therefore displayed identically across all layers. However, borders which had undergone change were vectorised independently according to source maps corresponding with the individual census years. This caused divergence in the courses of concerned border lines across different time horizons, which needed to be identified. These layers were topologically revised and edited in order to eliminated gaps or overlaps. This approach ensured the preservation of a unified topology (Kraak and Ormeling 2010; Allen and Coffey 2011) of the entire dataset. Spatial identification of the individual GIS layers and a consistent level of generalisation across the entire set of layers were achieved by the use of a unified vectorization source (which was edited over the raster maps from individual census years), by control of the changes in the shape and course of administrative borders across the specific timeframes, and by final topological adjustment. Subsequently, all layers were assessed for accuracy by a comparison of the location of 24 randomly selected points (scattered across the image in regular intervals) in the original raster and in the resultant vector layer.

The recommended scale for the publication of map outputs is derived from the scales of raster sources used for the vectorization of areas with changed administrative borders and from the level of detail provided by the zsj_2001 vector layer. Recommended scales, as well as the amount of units featured in each layer, and accuracy (deviation) recorded for the individual layers are included in the metadata files, which are integrated into the .shp and .gdb layers. The layers in both forms are freely accessible for download at webpage www.historickygis.cz.

3.3 Spatial identification of individual layers of district borders

Due to a limited availability of suitable map records most of our source maps do not exactly correspond with the specific years of the censuses. Therefore, a perfect link between spatial and statistical data could not be achieved in this form. For this reason, the resulting layers of districts had to be verified through a variety of methods. Discrepancies and disproportionalities found in the vector layers were identified and categorised according to their cause of origin. This categorisation also predetermines the method of their modification.

The first category of discrepancies emerged in the unedited areas of the original zsj_2001 layer. It involved lines (from zsj_2001 layer) whose shape was identical in the case of source maps, but their position was slightly shifted in one direction or another. This deviation was caused by the existing RMS error a verified by a careful measurement of the extent of this displacement (the difference in their location between the source map and the zsj_2001 vector layer). If this distance fulfilled the criteria set by the maximum permissible deviation of the RMS error, the 2001 borders were left in place, because this GIS layer offers greater spatial accuracy than the scanned source maps.

The second type of discrepancy emerged in association with border lines running alongside dynamic physical-geographic elements, such as river meanders. Since the goal of layer creation was to present the most accurate spatial layers corresponding with the shape and extent of territorial units relevant for the censuses years, the original zsj_2001 layer was modified (vectorised) in accordance with the course of river meanders depicted in the source map.

The third kind of spatial discrepancy was brought about by historical changes of state borders. Although the period after 1920s had seen no radical territorial change, several discrepancies which reflected changes to the state borders were identified. These changes were verified in relevant documents (e.g. borders operate; *hraniční operát*) and the resulting layers were adjusted based to these archive documents.

The fourth type of discrepancy was directly caused by the differences between the year portrayed by the source map and the date of the census we assigned it to. The final modifications of the source layers, which mostly streamlined them with the number of units used in the census records, were conducted with the assistance of smaller-scale maps which presented information directly tied to the census in question, or of the legislative documents recording territorial changes in the given period. For example, in the case of the 1980 census, we made use of an atlas which was specifically published to accompany the outputs of the census (Atlas ze sčítání 1980, resp. 1984). Similar publication or their map-based attachments (at various scales) were used in the case of other census years as well.

3.4 Joining the vector layers with the statistical database

In order to join the created shp/gdb layers with the original statistical data provided by the population censuses, it was necessary to create identification codes for individual territorial units across the census years. Due to frequent changes to the numbers of spatial units during the observed period, a desire for a user-friendly (e.g. in terms of adding custom content) interface lead us towards the creation of a dual coding system.

(i) Coding system for district units existing in 1961–2011 is based on the codes of territorial district units used in the 1991 census which are, at least partially available electronically. The coding system features a six-digit unit code, which is composed of first two digits representing the year of the census, followed by numerical designation of a region (second pair of digits), and a third pair of digits specifying the district's designation within the region.

(ii) Coding system for district units existing in 1921–1950 is based on layers of territorial units recognised by the CZSO and derived from the Historical Lexicon of Municipalities (see Růžková et al. 2006) and its attachments in the form of shp layers. These layers were created by a modification of a layer founded on the Register of statistical districts (RSO) from 2001. The JOIN function in the GIS was used to link this data through the use of territorial units' centroids. This system employs numerical codes with 1–3 digits (1–514) adopted from electoral statistics and their numbering of judicial districts[11]. This three digit code was supplemented with a two digit designation of the census year in order to ensure that identically designated territories can be distinguished if more than one spatial layer is used at once (for example during the creation of development maps). The resulting system for the designation of districts therefore includes 5 digits in the case of judicial districts and 6 digits in the case of political districts. The sixth digit represents the number of judicial districts subsumed within the political district in question[12]. The territorial coding systems are included in the attribute tables of all shp/dbf files of individual GIS layers.

The methodological approach described above yielded a Geographic Information System of administrative borders of territorial units which includes 45 polygon layers of judicial districts (or districts since 1961), as well as the political districts (and regions) they combine into, on the territory of Czechia. Furthermore, it also provided the polygon layers of cadastres and census tracts existing during specific census years on the territory of Prague. Data is compiled in the ESRI Shapefile format (.shp) and, for more demanding users, also in the ESRI Geodatabase (.gdb) format. The layers contain basic attributes – names and numerical codes of relevant territorial units. The databases are gradually being filled with statistical data from the historical population censuses.

4. Case studies

During the observed period, certain territories have experienced significant changes of administrative borders. These changes caused by the effects of both, natural and social forces, need to be tackled more specifically on the basis of detailed documentation. Generally known and the most obvious examples would be undoubtedly changes of the national (state) borders. Despite the fact, that 1920s, the changes of state borders have mostly had the character of minor adjustments (or recalculations of the specific course of a given border), exactly these changes tend to receive public attention. However, the most of both, quantitatively and qualitatively taken changes of borderlines occur on lower than the national scale level.

The increased number of these changes in the form of insensitive interventions that ignore historical or natural boundary lines at different scale levels is quite typical for the period of socialism (1948–1989). The most obvious examples of this propensity would be creation of completely new administrative units, establishment of

11 See e.g. (CZSO 2013b): Publication of the Czech Statistical Office: Elections into legislative functions in the Czechoslovak and the Czech Republic 1920–2006.

12 In unclear cases where such aggregation proved problematic, number 9 was assigned instead.

extensive military proving grounds, or changes of administrative borders of large cities (initially associated with gerrymandering, later with large-scale constructions of housing estates). Burda et al. (2014) also draws attention to the massive constructions of dams as the reason for these changes. The aforementioned specific examples of border changes are often very difficult to reconstruct. Case studies of borderlines changes presented below will attempt to shed some light on the matter.

4.1 Boletice military proving ground

Former proving grounds certainly belong among the areas where the reconstruction of the course of historical borders is rather difficult. The delimitation often did not pay attention to historical cadastral borderlines, which otherwise tend to be rather stable and well respected. Moreover, due a certain degree of secrecy, the borders of military proving ground were often portrayed rather vaguely and inconsistently over time.

The northern part of the Boletice proving ground presents one such case. The proving ground was founded in 1950 in the Western section of the district of Český Krumlov, bordering on Prachatice district. The 1950 district border, which had respected the original cadastral partitions, was reconstructed from a Synoptic map of territorial organisation from 1949, produced at a scale of 1 : 200,000. The reform of territorial units in 1960 assigned the entire proving ground to the district of Český Krumlov. The administrative map from 1960 (Figure 1) depicts the district border in a very schematic fashion which does not reflect contemporary cadastral partition. In some places, it does not even reflect the administrative reality of the following years, which could have either been caused by further changes during the 1960s, or more likely by an initially inaccurate map depiction.

The fate of two villages – Dobročkov and Březovík – is particularly interesting. According to the administrative map and the municipal register from 1960, these settlements, located in an immediate vicinity of the military

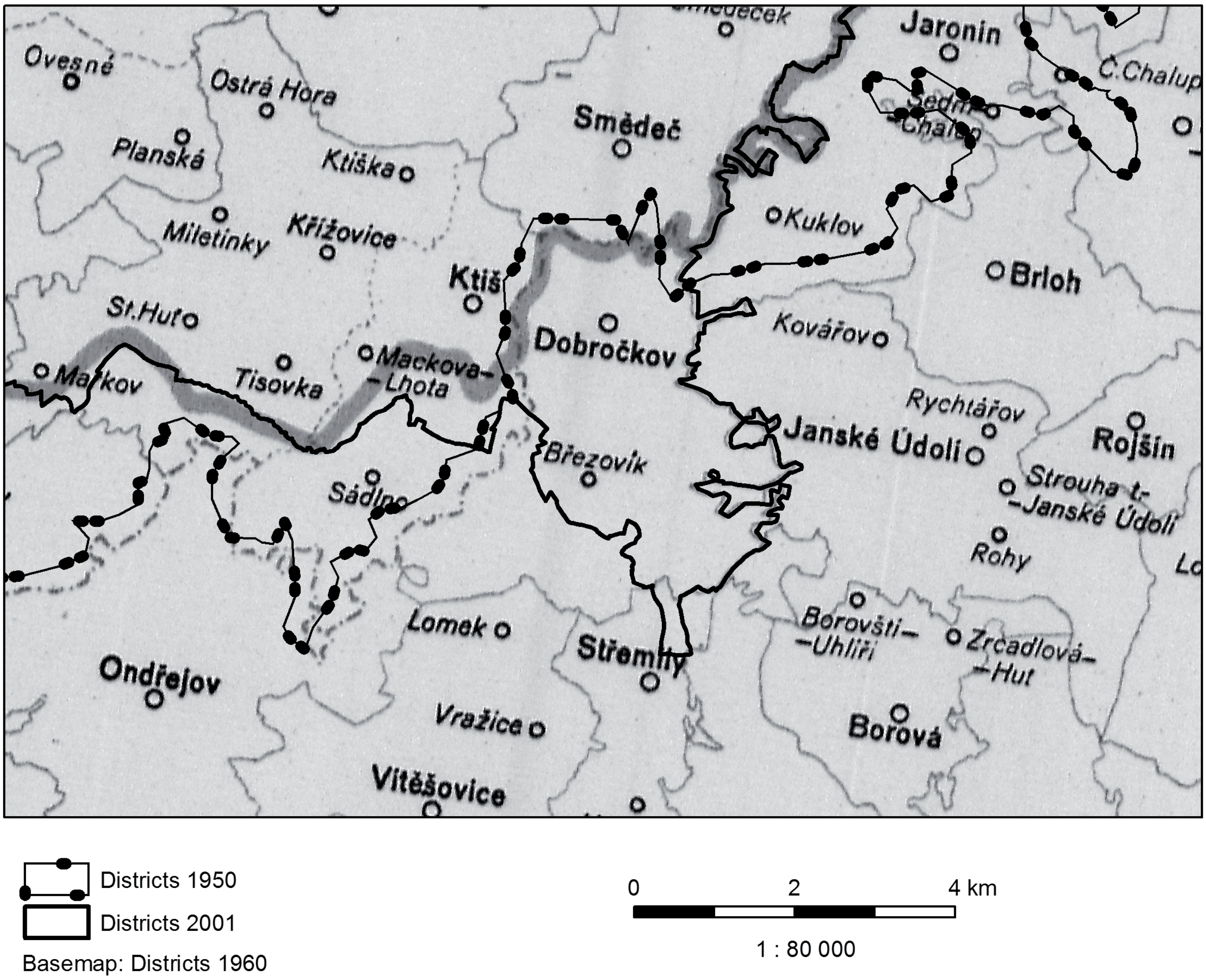

Fig. 1 Changes of district borders caused by the establishment of the Boletice proving ground.
Source: Synoptic map of territorial organisation by February 1, 1949; Polygon district layer from census 2001 (okresy_201102.shp); Map of administrative subdivision of the ČSR 1960; (for reference see Table 2).

proving ground, are both part of the district of Český Krumlov. In the following years, however, the villages are registered as part of the Ktiš municipality within the Prachatice district. Since these villages had been almost abandoned after the war, they joined the geographically closest municipality of Ktiš, which was, however, located in the district of Prachatice. This unification in effect brought about a change of district borders.

4.2 Milovice military proving ground

The Milovice proving ground represents perhaps the most complicated of these cases, because its borders did not respect cadastral units and also frequently changed with the expansion of local military infrastructure (barracks, airstrip). On the available maps, the ground's border tends to be inaccurate and very schematic (Figure 2). In 1950, all parts of the current city of Milovice – Milovice, Mladá, Boží Dar, and Benátecká Vrutice had been parts of the district of Nymburk. Later, Mladá and Boží Dar were registered under the district of Mladá Boleslav. Before 1980, the extent of the Mladá Boleslav district increased even further to encompass the entire proving ground, including the airstrip at Boží Dar. Mladá was part of a different district than Milovice. After 1990, Mladá and Milovice were reunited, which moved the district borders back in the northern direction.

Inaccuracies in the depictions of the borders of military proving grounds on contemporary maps at average of smaller scales reflect a desire to map the course of territorial borders within these sensitive territories in light of the government's emphasis on secrecy. A significant shift in this attitude only came after the revolution, when the border lines of military proving grounds could be precisely delineated with use of the .shp layer provided by the CZSO in 1991.

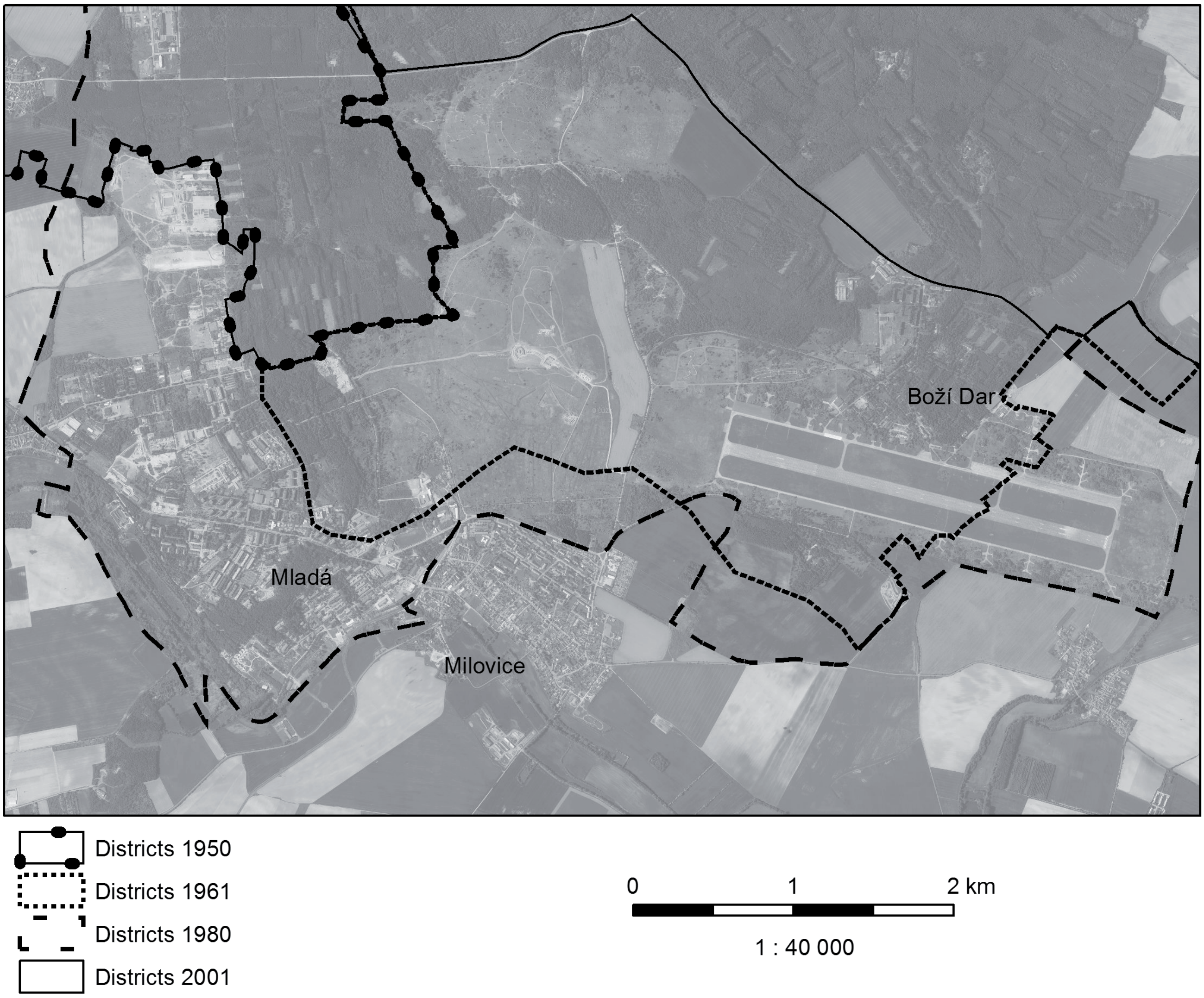

Fig. 2 Changes of the district borders of Mladá Boleslav caused by the establishment of the Milovice proving ground.
Source: Synoptic map of territorial organisation by February 1, 1949; Map of administrative subdivision of the ČSR 1960; Map of administrative subdivision of the ČSSR 1980; Polygon district layer from census 2001 (okresy_201102.shp); Ortophoto of Czechia (ČÚZK 2013); (for reference see Table 2).

4.3 Reconstruction of borders between Ostrava and Opava/Hlučín

Administrative borders led along watercourses experienced changes associated with both natural alterations of river basins and their artificial transformations made by man. Border changes were also commonly triggered by further expansion of large cities. Both factors are involved in the changes of borders between the districts of Ostrava and Opava/Hlučín (Figure 3).

The specialised map of the III. Military mapping (revised in 1927), which was used for the reconstruction of district borders existing in 1921, depicts the border between the two district as following the meandering Odra river. This, of course, does not resemble the extant regulated course of the Odra, nor does such border reflect the current cadastral partition which adapted to the regulation of the watercourse. In 1949, the Petřkovice municipality became part of the district of Ostrava, although it lays on the opposite bank of the Odra. At that point in time, the district border ran between Petřkovice and Ludgeřovice. This state of affairs had lasted until 1960, when the district of Ostrava – city was established. This new district included only the immediate metropolitan area, and Petřkovice were subsumed by the district of Opava. The border therefore returned to the river Odra, although its meandering course (as captured by the administrative map of 1960) now differed from the version depicted by the III. Military mapping. In 1976, the municipality of Petřkovice was added to the city of Ostrava, wherefore the resulting border more or less copied the district border from 1950.

The regulation of the Odra river basin performed in the following years lasts till today. Since no currently available vector layers depict the meandering flow of the Odra prior to its artificial regulation, this natural border

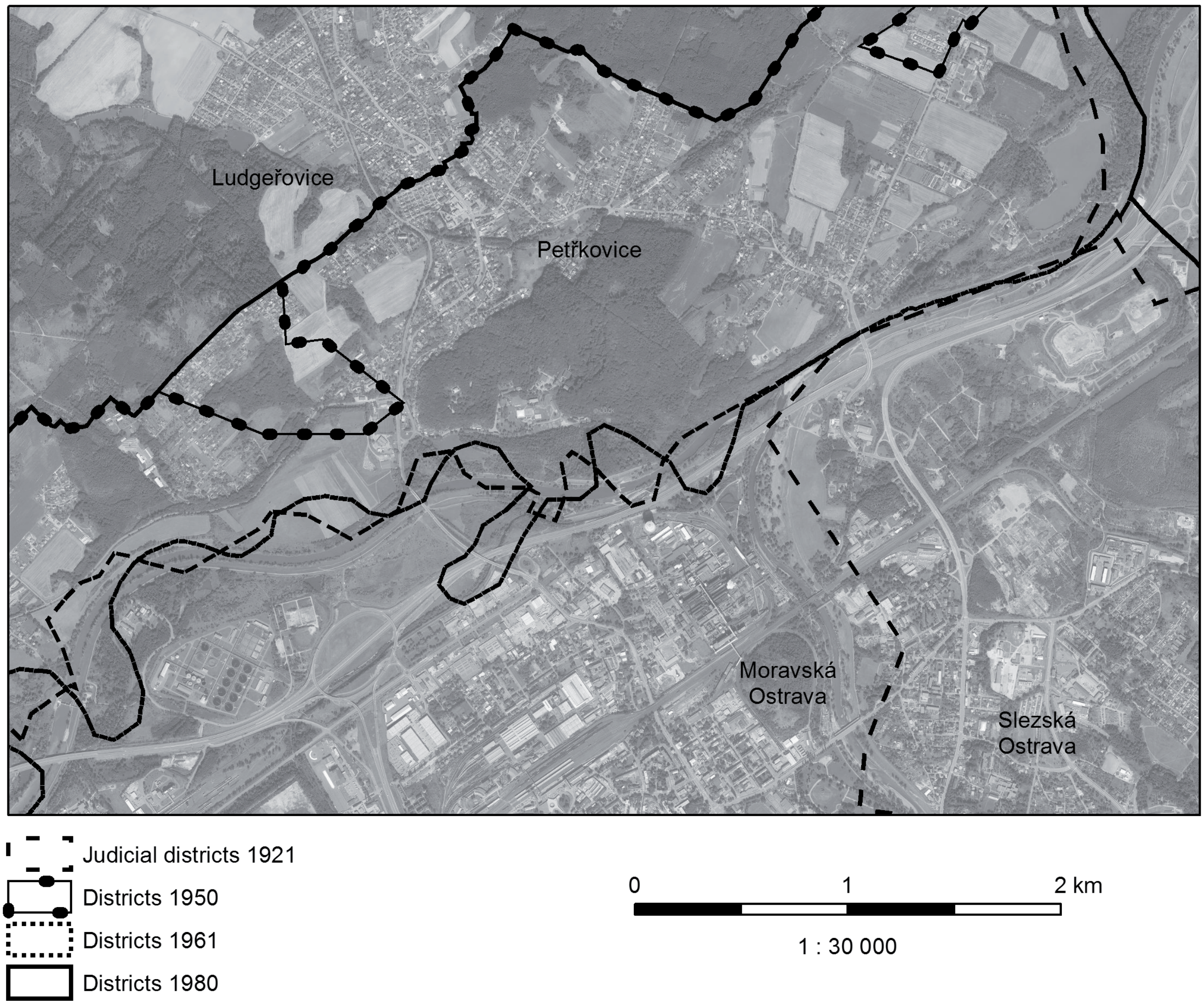

Fig. 3 Changes in the course of a border between the districts of Ostrava (Ostrava-město) and Hlučín/Opava.
Source: III. Military Mapping revised in 1927; Synoptic map of territorial organisation by February 1, 1949; Map of administrative subdivision of the ČSR 1960; Map of administrative subdivision of the ČSSR 1980; Polygon district layer from census 2001 (okresy_201102.shp); Ortophoto of Czechia (ČÚZK 2013); (for reference see Table 2).

had to be reconstructed with the assistance of contemporary source maps. However, each of the relevant maps portrays a somewhat different course for the meandering river. For an earlier period (until 1949), we used the river course captured by the map of the III. Military mapping, which is the most accurate of the available maps in terms of the reconstruction of historical borders. For the later time horizons (1961, 1970), we used the administrative maps pertaining to the specific years.

We are aware that it is impossible to cover all problems and challenges, let alone all cases for which the reconstruction of historical borders appeared to be problematic, over the course of one publication. Therefore, we tried to use these case studies to illustrate some of the typical difficulties which we encountered and which others are likely to encounter during a reconstruction of historical borders.

5. Discussion and conclusions

Although the creation of specific GIS layers always requires a certain degree of individualism (which would reflect the source data it builds upon, its purpose, its audience, etc.), it is necessary to maintain a unity of the system. This means using unified inputs for the vectorization and georeferencing, employing a unified coordinates system and proceeding according to a unified methodology. It is essential to preserve a unified topology across the entire dataset and to secure the production of relevant metadata. However, specific GIS elements which were subject to change over time demanded a specific way of processing – such as a coding system or the use of additional sources which could help with the reconstruction of border lines in areas with significant changes.

Cartographic visualization of historical statistical data have mostly only been possible within rather inaccurate borders and outside of the framework of GIS. Even partial outputs produced through the GIS have yet to fully make use of layers modified according to contemporary historical maps. This project is the first to introduce a reconstruction of the course of selected administrative borders in Czechia during the years of individual population censuses.

The aim was not only to propose a methodology for the processing of historical spatial and statistical data in the GIS, but primarily to provide the outputs of our applied research – authentic map layers and selected sorted statistical data, which form an interconnected spatial database. This database can be utilised by experts, students, or members of the public who wish to operate within the GIS environment and the outputs can be used in further basic or applied geographic research, as well as for teaching at both universities and high schools. One of their primary advantages is the nearly unlimited option to create custom "historical maps" within the GIS framework.

The discussed methodology for the application of historical spatial data within the GIS environment offers a detailed description of the approach from the selection of source map records, through the digitalisation of acquired data, georeferencing, all the way to the creation of shp layers and their joining with population censuses data. It places emphasis on the possibility of a replication of this approach in case of further, more detailed research carried out at the scale level of Czech municipalities, or of a reconstruction of a specific territory with changing administrative borders. Our broadly defined goal is to make historical spatial and statistical data produced during the past century accessible in the GIS framework. In light of this, we are open to collaboration with a range of organisations and institutions, as well as to constructive criticisms and suggestions for the improvement of the approaches presented in this article, in order to improve the access of both experts and members of the public to valuable sources of information on our national history.

The product of our research – the Geographic Information System of selected administrative units' borders in Czechia – includes 45 polygon layers of judicial districts (or districts since 1961), as well as the political districts (and regions) they combine into, on the territory of Czechia. It also provides the polygon layers of cadastres and census tracts existing during specific census years on the territory of Prague. All data is compiled in the ESRI Shapefile format (.shp) and the ESRI Geodatabase (.gdb) format, with names and numerical codes of relevant territorial units included in the attribute tables of these layers. We provide our outputs in two formats due to their distinct advantages. The advantage of the shapefile format consists in its unproblematic transferability between software types, its simplicity and accessibility (ability to easy access to the attributes), and its widespread use. The ESRI Geodatabase format then is designated to more advanced users, it compiles data into a single file and offers options to work with topologies, domains, subtypes, or spatially dependent attributes (Kartografie, e-learning portal 2013). Upon user registration, the elaborated files are freely available to the wider public for download, or comments, at www.historickygis.cz. The web portal also stores metadata files for the individual layers.

The project's principal output – the Geographic Information System of selected administrative units' borders in Czechia – will be further used for the creation of specialised large-scale maps and the Historical Population Atlas of the Czech Lands. These outputs will further contribute to a greater understanding of national and cultural identity and will open avenues for further research. However, we hope for a much more widespread utilisation of the produced outputs through research analysing the causal and developmental mechanisms of spatial polarisation, changes of sociocultural patterns, or socio-economic differentiations in Czechia. Proposals on further practical applications of the produced outputs are also gradually being published in other publications (Ouředníček and Pospíšilová 2013; Semotanová 2013; Přidalová and Ouředníček 2014; Svoboda, Přidalová and Ouředníček 2014).

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REFERENCES

ALLEN, D. W., COFFEY, J. M. (2011): GIS Tutorial 3: Advanced Workbook. ESRI Press.

ANTOŠ, F. (2006): Problematika skenování historických map a jejich následné prezentace na internetu. Master thesis, ČVUT, Praha.

BIČÍK, I. et al. (2010): Vývoj využití ploch v Česku. Česká geografická společnost, Praha.

BURDA, T. (2010): Kraje a jejich hranice: 1850–2000. In: Geografie pro život ve 21. století: Sborník příspěvků z XXII. sjezdu České geografické společnosti pořádaného Ostravskou univerzitou v Ostravě 31. srpna – 3. září 2010. Ostravská univerzita v Ostravě, p. 771–777.

BURDA, T., JANOUŠEK, Z., CHROMÝ, P. (2014): Historické hranice v prostředí GIS: Správní regiony v Česku 1920–2012. Historická geografie 40(1), 41–72.

CAJTHAML, J. (2007): Nové technologie pro zpracování a zpřístupnění starých map. Dissertation thesis, ČVUT, Praha.

CAJTHAML, J. (2012): Analýza starých map v digitálním prostředí na příkladu Müllerových map Čech a Moravy. 1st ed. ČVUT, Praha.

CAJTHAML, J., KREJČÍ, J. (2008): Využití starých map pro výzkum krajiny. Sborník z 15. ročníku mezinárodního sympozia GIS Ostrava. [Online] http://gis.vsb.cz/GIS_Ostrava/GIS_Ova_2008/sbornik/ [cit. 1. 6. 2013].

ČÁP, J. (2009): Okresní soudy – správní vývoj, vnitřní organizace a agenda. Státní okresní archiv, Náchod.

DOBROVOLNÝ, P. (1998): Dálkový průzkum Země. Digitální zpracování obrazu. Masarykova Univerzita, Brno.

DOUBRAVA, P. (2005): Zpracování rastrových mapových podkladů pro využití v oblasti aplikací GIS a katastru nemovitostí. Doktorská dizertační práce, ČVUT, Praha.

DOSTÁL, P., KÁRA, J. (1992): Territorial administration in Czechoslovakia: an overview. In: Dostál, P., Illner, M., Kára, J., Barlow, M. (eds.): Changing Territorial Administration in Czechoslovakia: International Viewpoints. Instituut voor Sociale Geografie, Universiteit van Amsterdam, Amsterdam, p. 17–32.

GAWRECKÁ, M. (2004): Československé Slezsko mezi světovými válkami 1918–1938. Filozoficko-přírodovědecká fakulta, Slezská univerzita v Opavě, Opava.

GREGORY, I. N., ELL, P. S. (2007): Historical GIS. Technologies, Methodologies and Scholarship. Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CBO9780511493645

HAMPL, M., DOSTÁL, P., DRBOHLAV, D. (2007): Social and cultural geography in the Czech Republic: under pressures of globalization and post-totalitarian transformation. Social & Cultural Geography 8(3), 475–493. http://dx.doi.org/10.1080/14649360701489029

HARVEY, F. (2008): A Primer of GIS: Fundamental Geographic and Cartographic Concepts. The Guilford Press, New York.

HRNČIAROVÁ, T., MACKOVČIN, P., ZVARA, I. et al. (2009): Atlas krajiny České republiky. Ministerstvo životního prostředí ČR a Výzkumný ústav Silva Taroucy, Praha-Průhonice.

JANÁK, J. (1987): Dějiny správy v českých zemích v letech 1848–1918 se soupisy pramenů a literatury. Státní pedagogické nakladatelství, Praha.

JELEČEK, L. (2000): Územněsprávní reformy v Česku v letech 1848–2000. Geografické rozhledy 9(5), 136–137.

KOLÁŘ, J. (1997): Geografické informační systémy. ČVUT, Praha.

KRAAK, M. J., ORMELING, F. (2010): Cartography: Vizualization of Spatial data. The Guilford Press, New York.

KUČERA, Z., KUČEROVÁ, S. (2009): Národnostní struktura obyvatelstva (1930, 1950). In: Hrnčiarová, T., Mackovčin, P., Zvara, I. et al.: Atlas krajiny České republiky. Ministerstvo životního prostředí ČR a Výzkumný ústav Silva Taroucy, Praha-Průhonice, p. 85.

MLEZIVA, Š. (2010): Retrospektivní přehled územních jednotek a územních celků od roku 1850 do současnosti. Academia, Praha.

MUSIL, J. (1991): Nové vymezení sociální ekologie. Sociologický časopis 27(1), 69–89.

OUŘEDNÍČEK, M. (2012): Sociálně prostorová struktura industriální Prahy. In: Chodějovská, E., Šimůnek, R. (eds.): Krajina jako historické jeviště, Historický ústav AV ČR, v. v. i., Praha, p. 263–283.

OUŘEDNÍČEK, M., KUPKOVÁ, L., POSPÍŠILOVÁ, L., ŠIMON, M., RIŠKA, M., SVOBODA, P., SOUKUP, M., MARVANOVÁ, P. et al. (2014a): Metodika vytvoření a využití historických prostorových dat v prostředí GIS: Administrativní hranice katastrálních území a urbanistických obvodů Prahy. [Online] http://www.historickygis.cz, [cit. 2014-07-20].

OUŘEDNÍČEK, M., KUPKOVÁ, L., POSPÍŠILOVÁ, L., ŠIMON, M., SVOBODA, P., KŘIVKA, M., MARVANOVÁ, P. et al. (2014b): Metodika vytvoření a využití historických prostorových dat v prostředí GIS: Administrativní hranice okresů v České republice. [Online] http://www.historickygis.cz, [cit. 2014-07-20].

OUŘEDNÍČEK, M., NOVÁK, J., TEMELOVÁ, J., PULDOVÁ, P. (2009): Metody geografického výzkumu města. In: FERENČUHOVÁ, S., HLEDÍKOVÁ, M., GALČANOVÁ, L., VACKOVÁ, B. (EDS.): Město: Proměnlivá ne/samozřejmost. Pavel Mervart/Masarykova univerzita, Brno, p. 93–128.

OUŘEDNÍČEK, M., POSPÍŠILOVÁ, L. (2013): Nové historické mapy. Geografické rozhledy 22(3), 15.

OUŘEDNÍČEK, M., TEMELOVÁ, J., POSPÍŠILOVÁ, L. eds. (2011): Atlas sociálně prostorové diferenciace České republiky. Karolinum, Praha.

POSPÍŠILOVÁ, L., ŠIMON, M. (2011): Administrativní členění. In: Ouředníček, M., Temelová, J., Pospíšilová, L. (eds.): Atlas sociálně prostorové diferenciace České republiky. Nakladatelství Karolinum, Praha, p. 13–14.
PŘIDALOVÁ, I., OUŘEDNÍČEK, M. (2014): Proměna národnostní struktury Prahy mezi lety 1921 a 2011. Geografické rozhledy 23(4), 24–25.
ROBINSON, A. H., MORRISON, J. L., MUEHRCKE, P. C., KIMERLING, A. J., GUPTILL, S. C. (1995): Elements of cartography. John Wiley and Sons, New York.
RŮŽKOVÁ, J., ŠKRABAL, J., BALCAR, V., HAVEL, R., KŘÍDLO, J., PAVLÍKOVÁ, M., ŠANDA, R. (2006): Historický lexikon obcí České republiky 1869–2005, I. díl. Český statistický úřad, Praha.
SEMOTANOVÁ, E. (2009): Republika Československá; Československo a vznik České republiky (1993). In: Hrnčiarová, T., Mackovčin, P., Zvara, I. et al.: Atlas krajiny České republiky. Ministerstvo životního prostředí ČR a Výzkumný ústav Silva Taroucy, Praha-Průhonice, p. 76.
SEMOTANOVÁ, E. (2013): Historické regiony Česka – součást regionální identity v evropském prostoru. Geografické rozhledy 22(5), 24–27.
SEMOTANOVÁ, E., CHROMÝ, P. (2012): Development and current trends of the Czech historical geography. Historická geografie 38(1), 9–34.
SVOBODA, P., PŘIDALOVÁ, I., OUŘEDNÍČEK, M., (2014): Ukazatele ekonomické struktury a mobility obyvatelstva ve sčítáních lidu. Historická geografie 40(2), 285–306.
TUČEK, J. (1998): Geografické informační systémy. Computer-Press, Praha.

Other sources

ACT No 121/1945: Dekret prezidenta republiky o územní organisaci správy, vykonávané národními výbory, předpis č. 121/1945 Sb.
ACT No 126/1920: Zákon ze dne 29. 2. 1920 o zřízení župních a okresních úřadů v republice Československé, 126/1920 Sb.
ATLAS ZE SČÍTÁNÍ LIDU, DOMŮ A BYTŮ 1980 (1984): Česká socialistická republika 1 : 500 000. Geografický ústav ČSAV, Brno.
CZSO (2013a): Území a jeho administrativní rozdělení při sčítáních v roce 1921 a 1930. ČSÚ, Praha. [Online] http://www.czso.cz [cit. 7. 8. 2013].
CZSO (2013b): Volby do zákonodárných orgánů Československé a České republiky 1920–2006. ČSÚ, Praha. [Online] http://notes3.czso.cz/sldb/sldb.nsf/i/uzemi_a_jeho_administrativni_rozdeleni_pri_scitanich_1921_a_1930 [cit. 7. 8. 2013].
ČÚZK (2013): Ortofoto České republiky. [Online] http://geoportal.cuzk.cz/(S(ouj0jkwwekvmri4rrm4vjzcg))/Default.aspx?mode=TextMeta&metadataID=CZ-CUZK-ORTOFOTO-R&metadataXSL=full&side=ortofoto [cit. 17. 5. 2014].
KARTOGRAFIE, E-LEARNING PORTAL (2013): Datový model. [Online] http://kartografie.fsv.cvut.cz/2-1-0-datovy-model.php [cit. 3. 6. 2013].
U.S. CENSUS BUREAU (2011). Geography Division, Cartographic Products Management Branch. [Online] http://www.census.gov [cit. 16. 1. 2014].
WWW.HISTORICKYGIS.CZ (2014): Web portal for the project "Disclosure of Historic Spatial and Statistical Data in GIS environment" [Online] http://www.historickygis.cz [cit. 20. 6. 2014].

RESUMÉ

Zpřístupnění historických prostorových a statistických dat okresů Česka v prostředí GIS

Článek je výstupem širokého výzkumného týmu sociálních geografů, kartografů, historiků, statistiků a archivářů, jejichž spolupráce byla nutná pro vytvoření doposud unikátních datových podkladů vztahujících se k historickým hranicím v prostředí geografických informačních systémů. Cílem článku je popis a vysvětlení jednotlivých kroků při přípravě prostorových vrstev (administrativních hranic) navázaných na rozhodné okamžiky sčítání lidu na území dnešního Česka v letech 1921–2011 a jejich zpřístupnění v prostředí GIS. Hlavním výsledkem práce je 45 datových sad ve formátech .shp a .gdb, které obsahují historické hranice soudních, politických a současných okresů pro celé území Česka a dále hranice městských obvodů, katastrálních území a urbanistických obvodů pro území hlavního města Prahy. Článek popisuje práci při získávání podkladových administrativních map, jejich zpracování, vektorizaci, georeferencování, přizpůsobení administrativním hranicím v rozhodné okamžiky sčítání a následné propojení s populačními daty obsaženými v jednotlivých sčítáních lidu mezi lety 1921–2011. Na případových studiích jsou detailně vykresleny hlavní problémy řešené při zpracování prostorových dat na příkladu vojenských újezdů nebo hranic vedoucích po měnících se vodních tocích. Metodika tvorby datových podkladů i všechny výstupy jsou k dispozici odborné i širší veřejnosti na specializovaném internetovém portálu www.historickyGIS.cz.

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A NEURAL NETS URBAN LAND COVER CLASSIFICATION: A CASE STUDY OF BRNO (CZECHIA)

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ABSTRACT

Accurate and updated land cover maps provide crucial basic information in a number of important enterprises, with sustainable development and regional planning far from the least of them. Remote sensing is probably the most efficient approach to obtaining a land cover map. However, certain intrinsic limitations limit the accuracy of automatic approaches to image classification. Classifications within highly heterogeneous urban areas are especially challenging. This study makes a presentation of multilayer perceptron (MLP), an artificial neural network (ANN), as an applicable approach to image classification. Optimal MLP architecture parameters were established by means of a training set. The resulting network was used to classify a sub-scene within ASTER imagery. The results were evaluated against a test dataset. The overall accuracy of classification was 94.8%. This is comparable to classification results from a maximum likelihood classifier (MLC) used for the same image. In built-up areas, MLP did not exaggerate built-up areas at the expense of other classes to the same extent as MLC.

Keywords: image classification, multilayer perceptron, urban land cover, ASTER

1. Introduction

Urbanization has an enormous impact on the environment at every scale – local, regional and global (Lu et al. 2008). Anthropogenic land use changes, such as various forms of cultivation, livestock grazing, settlement and construction, reserves and protected lands, and timber extraction, have made cumulative transformations to global land cover (Turner et al. 1994). This in turn influences the environment: climate, biodiversity, soils, water and sediment flow are all in continuous states of change. The urbanization process is very often driven by other interests: nevertheless, efficient urban planning should be based on chronologically and spatially accurate land cover maps (Novack et al. 2011).

Remote sensing provides data and tools which enable the most efficient mapping of urban land cover (Novack et al. 2011). Image classification, the assignation of pixels to selected classes, is one of the basic methods used to generate thematic maps from remote sensing (Vatsavai et al. 2011). Approaches to automatic classification still face certain limitations. Improving the accuracy of land cover classification has attracted a great deal of recent interest in remote sensing studies. Detailed and accurate classification of built-up areas is one of the basic problems, arising out of the enormous spatial and spectral heterogeneity of urban areas, in which built-up structures (buildings, transportation areas), various types of vegetation cover (e.g. parks, gardens, agricultural areas), bare soil zones and bodies of water exist in close proximity (Herold et al. 2002). Definition within built-up areas depends heavily upon the spatial resolution of whatever input images are available. With very high-resolution imagery, every building, road or pavement can be identified and built-up areas are represented as a union of these objects. At a coarser resolution, it is impossible to identify individual objects and individual pixels consist of several types of real-world item (building, road, pavement, garden, forest, soil, etc.). In this case, built-up areas are defined as pixels with prevailing areas of impervious surfaces (including roofs, roads, pavements, car parks, etc.). Spatially and spectrally high and very high-resolution images are not enough to map urban land cover precisely. Improved image classification techniques are of equal importance (Herold et al. 2002).

Recently, several approaches have been suggested that may overcome or suppress some of the features that make it difficult to classify urban land use/land cover correctly using traditional approaches. Thus, for example, subpixel classification reduces the effect of heterogeneity in built-up areas by estimating the composition of a single pixel area (Wu and Murray 2003; Adams and Gillespie 2006; Lu and Weng 2006, 2009; Powell et al. 2007). An object-based approach enables consideration of matters other than spectral characteristics and is particularly useful for classification of very high resolution imagery (Kux and De Pinho 2006; Chen et al. 2007; Cleve et al. 2008; Zhou et al. 2009; Myint et al. 2011; Pu et al. 2011; Dingle Robertson and King 2011). Machine learning methods do not assume any specific theoretical data distribution (Bagan et al. 2008; Yuan et al. 2009; Mountrakis et al. 2011; Sowmya et al. 2011; Rodriguez-Galiano et al. 2012; Jin 2012; Tehrany et al. 2013).

Our study is motivated by the fact that different surfaces (land cover categories) in urban areas significantly influence spatial distribution of air temperature and they

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contribute directly e.g. to urban heat island formation. Thus land cover maps of urban areas are needed with relatively high precision and in time. This contribution presents artificial neural nets as a non-traditional method of urban land cover classification. In the following section we briefly review recent classification approaches to urban remote sensing. The study area is described in Section 3, together with the classification scheme employed. The available data and a detailed description of the multilayer perceptron algorithm are presented in Section 4. The classification results appear in Section 5, with an evaluation of them and comparison with a statistical classifier in Section 6. Section 7 consists of discussion and our main conclusions appear in Section 8.

2. Review of methods

Remote sensing image analysis acquires the results of a wide range of approaches to land cover mapping that have already been used – with varying degrees of success – in the urban environment. Some of these appear below.

Traditional parametric statistical approaches to supervised classification depend on an assumption of normal data distribution, which may be one of the reasons that they often fail to classify heterogeneous urban areas correctly. Among them, maximum likelihood classifier (MLC) often serves for the evaluation of results arising out of other classification methods, because MLC provides the most accurate results compared to other classifiers (Bishof et al. 1992; Paola and Schowengerdt 1995; Zha et al. 2003; Seto and Liu 2003; Vyorálková 2003; Setiawan et al. 2006).

Methods of spectral enhancement, including the construction of spectral indices (Xu 2007) may be used to extract built-up areas. Spectral indices are usually defined as a simple or normalized ratio of image channels. Normalized difference built-up index (NDBI) has been used for direct extraction of built-up areas (Zha et al. 2003). This is a combination of the short-wavelength infrared (SWIR) and near-infrared (NIR) channels. It is based on the significant increment from NIR to SWIR in the reflectance of built-up areas and barren lands in comparison with only slightly larger or smaller digital number values representing vegetation in the SWIR band than in the NIR band (Zha et al. 2003). NDBI results are often worked up together with other spectral indices, such as the normalized difference vegetation index NDVI (Zha et al. 2003; He et al. 2010), normalized difference water index NDWI, and others (Xu 2007; Uddin et al. 2010). The most serious practical difficulty associated with spectral indices is establishment of the most suitable threshold for extracting built-up areas (He et al. 2010).

Subpixel classification may also be employed when urban land cover is mapped by means of remote sensing. The original specific three-dimensional "vegetation – impervious surface – soil" (V-I-S) model was presented by Ridd (1995), in which classes of urban land cover may be modelled as fractions of vegetation, impervious surface and soil (Wu and Murray 2003). Setiawan et al. (2006) made a comparison between V-I-S and MLC. The overall accuracy achieved by the subpixel approach was 80%, as against 53% for MLC. For estimating impervious surfaces, spectral mixture analysis is the technique most frequently used (Roberts et al. 1998; Wu and Murray 2003; Adams and Gillespie 2006; Lu and Weng 2006, 2009; Powell et al. 2007). This is based on the "un-mixing" of individual land cover fractions, and thus utilizes the same concept as the V-I-S model.

Object-oriented classification is based on segmentation of the original image, dividing the image into groups of neighbouring pixels (objects). These objects are homogenous according to previously-defined criteria. Subsequently, these objects may be classified according to their spectral properties, as well as textural and spatial characteristics. The object-oriented approach allows images of various spatial resolutions to be classified. It is often used in conjunction with very high-resolution sensors (Herold et al. 2002; Kux and De Pinho 2006; Myint et al. 2011; Pu et al. 2011), and for aerial data (Cleve et al. 2008; Zhou et al. 2009). Object-based classification of urban land cover has been tested with high-resolution Landsat data (Dingle Robertson and King 2011) and ASTER data (Chen et al. 2007).

Recently, machine learning algorithms, such as Random Forest (Rodriguez-Galiano et al. 2012; Jin 2012), Support Vector Machine (Mountrakis et al. 2011; Tehrany et al. 2013) and Artificial Neural Networks (ANNs – Bagan et al. 2008; Yuan et al. 2009; Sowmya et al. 2011), have been applied to urban land cover classification (Vatsavai et al. 2011). These approaches can perform at both per-pixel and subpixel levels (Walton 2008) and be used in object-based classification (Smith 2010). One of their advantages for urban land cover classification is independence from theoretical data distribution.

This contribution presents an example of classification employing the multilayer perceptron (MLP) algorithm with application of the back-propagation learning rule. MLP is one of the ANNs based on (presumed) human brain processing; its basic principles appear in section 4.2. As previous studies have shown (Paola and Schowengerdt 1995; Mustapha et al. 2010), the MLP algorithm can achieve higher classification accuracy than the maximum likelihood method. Recently, certain authors (among them Hu and Weng 2009; Sun et al. 2011; Da Silva Brum et al. 2013) have combined or compared the MLP approach with other machine learning algorithms.

3. Study area and classification scheme

Brno is the second largest city in the Czech Republic and the administrative centre of the South Moravian Region [*Jihomaravský kraj*]. In 2002, when the data used in this study were acquired, Brno had a population of over

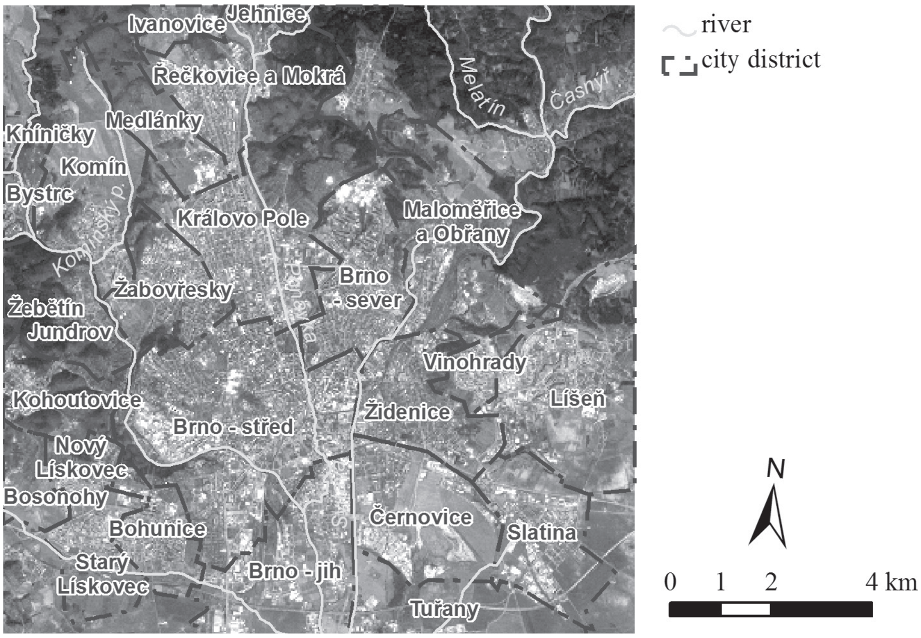

Fig. 1 The city of Brno in ASTER imagery, acquired on 2 April 2002; band VNIR 1.

370,000. Figure 1 shows the extent of its built-up area and a distribution of main land cover types as they appear in the ASTER imagery that was used for analysis in this paper.

The city is situated in complex terrain at the confluence of two rivers. Natural and anthropogenic surfaces create a rich mosaic, highly influenced by local topography. The historically earlier built-up areas are concentrated in the river valleys. The city has progressively expanded onto its surrounding slopes and also into the lower hills, where the most of housing estates are located (Figure 1). The complexity of terrain has always prevented the creation of a compact city. About 28% of the city administrative area is covered by forests, located mainly at higher altitudes to the north and west of the city. Agricultural fields and large industrial areas occupy the lowland southerly part of the study area, with a number of arterial highways.

Five main land cover types were defined in the study area: built-up areas, agricultural areas, bare soils, forest areas and bodies of water. Built-up areas, the extraction of which is the aim of this classification, include densely built-up areas in the old city centre and housing estates at the edge of the town, suburban built-up areas, and contiguous industrial areas. Other land-cover types were selected in a general way to refine the built-up area extraction. Agricultural areas take the form of fields surrounding the city boundary, especially to the south. Fields differ mainly in volume of vegetation and water content; the category of bare soils is largely represented by quarries. Forest areas include deciduous and coniferous forests located mainly in the northern part of the study area, as well as city parks characterized by a lower density of trees. Bodies of water include larger rivers and several small ponds.

4. Data and methodology

4.1 ASTER Data

The advanced space-borne thermal emission and reflection radiometer (ASTER) imagery used in this study was acquired on the 24th of June 2005. Original VNIR and SWIR images were rectified using a second-order polynomial transformation. All bands of VNIR and SWIR images at 30-m spatial resolution were merged into a single file.

The original image of nine bands (three VNIR and six SWIR) was cropped to the study area. VNIR bands represent the intensity of green, red and near-infrared radiation (wavelength range 0.5–0.9 μm) detected by the VNIR subsystem. The SWIR subsystem acquired six bands at near-infrared wavelengths (1.6–2.43 μm). The next step involved calculation of the divergence statistic that is used as a measure of inter-band correlation (Narendra and Fukunaga 1977) and which may also be used to reduce the number of bands required for a classification. This approach selects bands of the highest discrimination between the categories classified. This is important for the ANN-based method, because reduction of the number of bands determines the size and architecture of the neural net and may significantly reduce its learning time. However, in this study, the net designed for different band subsets according to divergence statistics did not achieve better results compared to the original set of nine bands. All nine VNIR and SWIR bands were therefore employed.

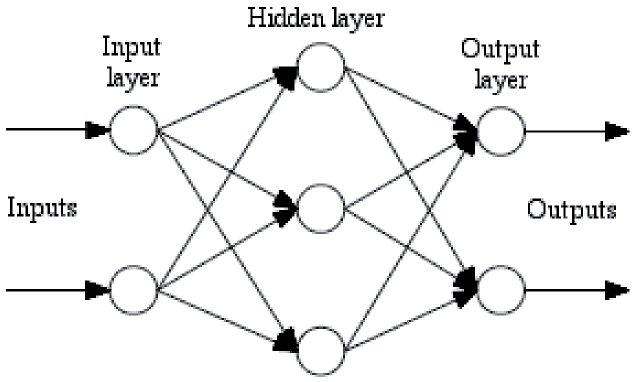

Fig. 2 An example of MLP architecture.

4.2 Multilayer perceptron

The MLP algorithm was applied for land-cover classification. MLP consists of a number of interconnected processing units, arranged in three layers – input layer, one or more hidden layers, and output layer. This arrangement of units is known as the network architecture (Figure 2).

The network architecture was designed in terms of four main parameters: the number of input units, the number of hidden layers, the number of units in each of them and the number of output units. Input units present the bands selected, and possibly other parameters of the image (such as a texture). Each feature may be represented by one or more input units. If more units are used to present a single feature, the range of feature values is divided uniformly; such division can provide enough differences to separate similar values (Bischof et al. 1992).

The numbers of hidden layers and the numbers of their units also affect overall classification accuracy (Foody and Arora 1997). It is recommended to use one or two hidden layers (Šíma and Neruda 1996). An increase in the number of hidden layers enables the network to deal with more complex problems, but is associated with reduction of the ability to generalize and an increase in training time (Foody 1995). According to Lippmann (1987), if two hidden layers are used, the number of units in the second hidden layer should not exceed three times the number of units in the first hidden layer.

The number of output units is usually equal to the number of categories in the classification (Atkinson and Tatnall 1997). Some researchers suggest the use of a greater number of output units to enhance classification accuracy (Benediktsson et al. 1993).

The main principle of ANN is what has become known as the "feed-forward" concept. An input pattern is presented to the network via the input layer and the signals are passed to the neurons of the next layer. The signal is modified along its path through the network by weights associated with neuronal connections. Each receiving neuron sums up weighted signals from all neurons in the preceding layer to which it is connected. The output of a given neuron is computed as a function (usually a non-linear sigmoid function) of the sum of its inputs. When the signal reaches the output layer it becomes network output. In established hard classification the output of one neuron in the output layer (representing one chosen class) is set to one, and the outputs of all other neurons are set to zero.

A network of selected architecture was trained by means of a training set of pixels to set the weights associated with neuronal interconnections. The aim of training is to build a model that can predict outputs from inputs it has never seen before. This property is known as generalization. The back-propagation learning algorithm, described originally by Rumelhart et al. (1986), was used to train the network. A training pattern is presented to the network and the signals are forward-fed via weighted interconnections. The weights are initially set to a random value. The input net_j of a single neuron of the network is computed as a weighted sum of all the inputs it receives and a numerical value, bias b_j (representing a usually-negative threshold value for the unit activation), is added to the sum. Formally, this can be stated as:

$$net_j = \sum_{i=1}^{n} w_{ji} o_i + b_j$$

where n is the number of units in the preceding layer, w_{ji} is the weight associated with the connection between the receiving unit j and the unit i of the preceding layer, while o_i is the output signal of the unit i. The output o_j of a given unit j is computed as a function of the sum according to:

$$o_j = f(net_j) = \frac{1}{1 + e^{-net_j}}$$

The network output is then compared to the desired output and the net partial error E_i is calculated as:

$$E_i = \frac{1}{2} \sum_{j=1}^{k} \left(o_{ij} - t_{ij}\right)^2$$

where k is the number of categories (number of units in the output layer), o_{ij} is the current output of an output unit j and t_{ij} is the proper output of this unit. The sum of net partial errors for the whole training set provides the total error E of the net. The error is then back-propagated and weights are altered to minimize it. This process is repeated until the computed error drops below a predetermined value or the number of iterations exceeds a predefined maximum.

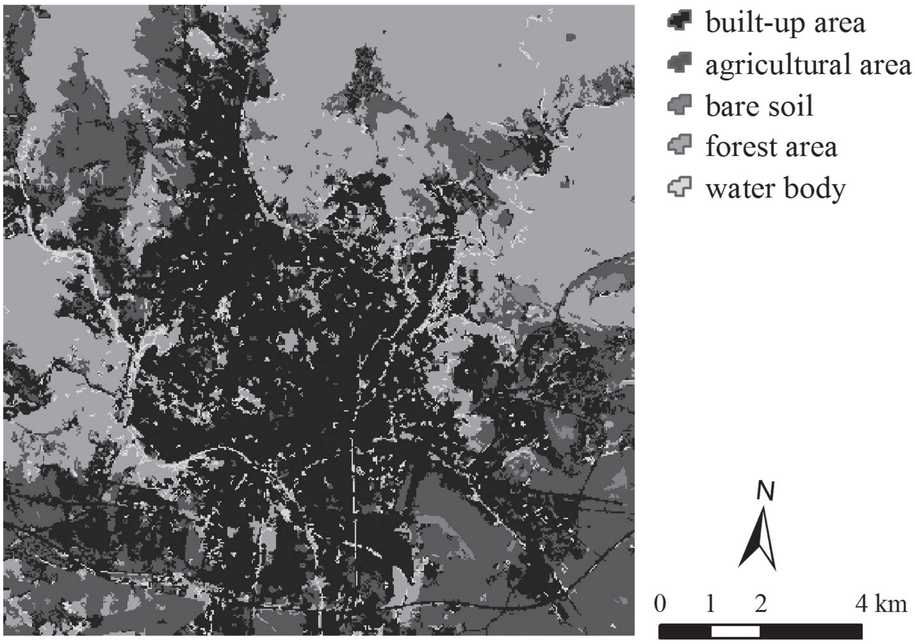

Fig. 3 Land cover of the Brno area as classified from ASTER imagery using MLP.

5. Results

Several ANN architectures, with different numbers of input units, of hidden layers and their units and different numbers of output units, were tested minimize total error and ensure maximal classification accuracy. The best results were obtained using three units per input channel, when the value range is divided into thirds. It follows that the input layer consists of 27 units. Networks tested with only one hidden layer failed to reduce total error to the desired degree. The use of more than two hidden layers mean that networks lose the ability to generalize – the value for total error decreased successfully during the training phase, but the classification accuracy did not achieve a satisfactory value. This trend is known as overfitting. Optimal results were achieved using two hidden layers. The first hidden layer contained 27 units and the second 11 units. The output layer of the optimal network architecture contained the five units that correspond to the individual land cover classes (see Section 4.2). The results of ANN classification appear in Figure 3.

Comparison of classification results (Figure 3) and the original data (Figure 1) indicates that the outer boundaries of built-up areas were identified satisfactorily. Roads were correctly assigned to the built-up area class. Continuous internal parts of the city are disrupted by discrete pixels of agricultural areas, bare soils and bodies of water. Pixels that were incorrectly classified as agricultural areas and bare soils tended to be those of large areas covered by impervious surfaces without vegetation. Pixels incorrectly assigned to bodies of water were often shaded areas.

The classification results were first inspected by simple visual comparison. Figures 4, 5 and 6 compare the built-up areas extracted using MLP with those delimited from very high-resolution aerial photography in three different environments. Figure 4 shows built-up area extraction in the densely built-up city centre. Parks and other larger vegetated areas (site 1 in Figure 4 on the right) are clearly delineated in a continuous street network. In contrast, small or linear parks (site 2) were not all recognised due to the coarser resolution of the image analysed. In Figure 5, a housing estate on the outskirts is presented for

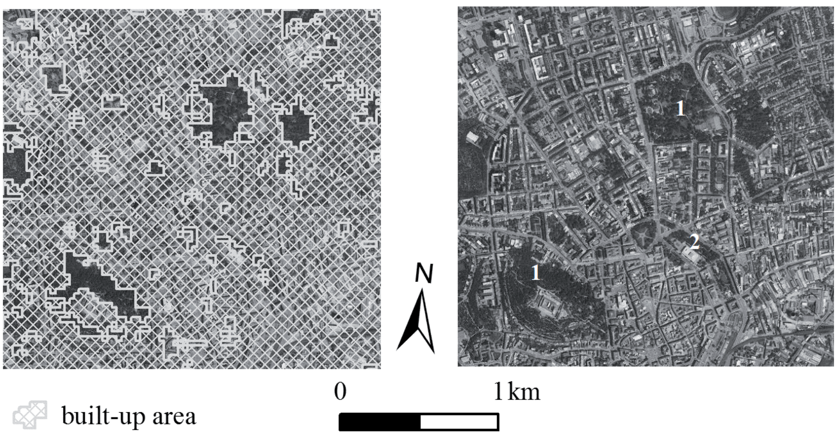

Fig. 4 Built-up areas extracted by classification (a) compared with aerial photography (b: source: WMS geoportal.cuzk.cz) of the city centre; see text for site numbers explanation.

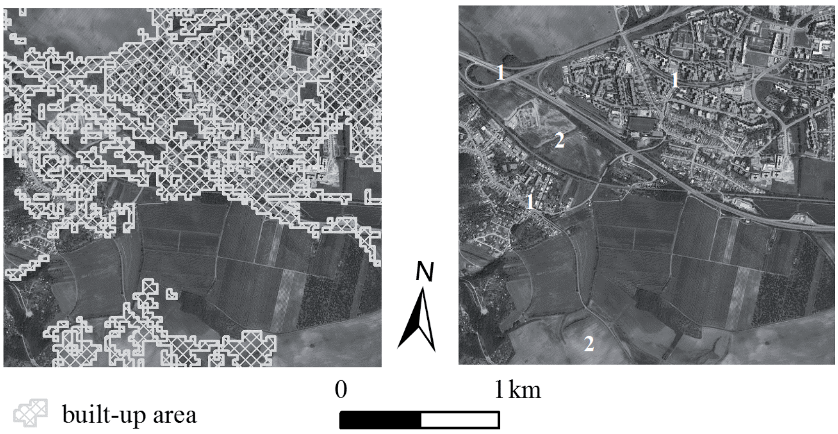

Fig. 5 Built-up areas extracted by classification (a) compared with aerial photography (b: source: WMS geoportal.cuzk.cz) of a housing estate on the outskirts; see text for site numbers explanation.

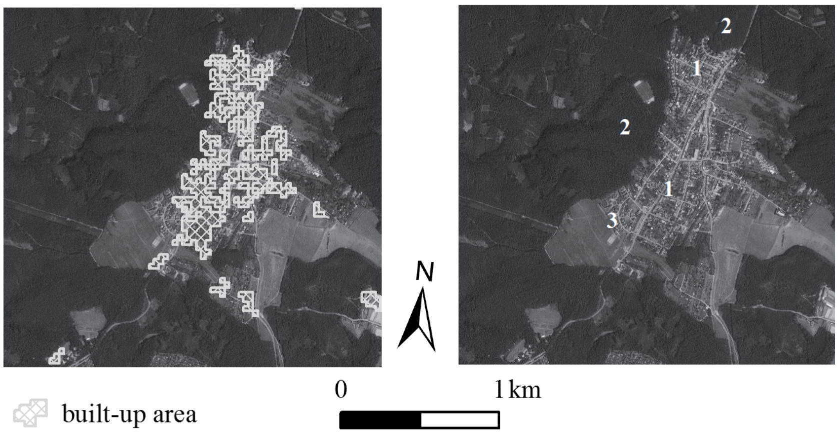

Fig. 6 Built-up areas extracted by classification (a) compared with aerial photography (b: source: WMS geoportal.cuzk.cz) of the city suburbs; see text for site numbers explanation.

comparison. Buildings and roads are correctly assigned to built-up areas (site 1 in Figure 5 on the right). However, certain parts that are in fact fields are inaccurately classified as built-up areas as well (site 2). Finally, Figure 6 shows the extraction of built-up areas in the suburban part of the city. Impervious surfaces representing built-up areas are identified with considerable success (site 1 in Figure 6 on the right). Gardens are correctly assigned to agricultural areas. A sharp boundary between built-up areas and forests is also visible in Figure 6 (site 2). A few buildings in the south-east are not assigned to built-up areas (site 3). These sites were under construction at the time of imagery acquisition and this construction zone was assigned to "bare soils".

Tab. 1 Confusion matrix of a test dataset, comparing class assigned to pixel by the MLP classification and an appropriate class (abbreviations explained in text).

Class		**Test dataset**					**Sum**	UA [%]
		1	2	3	4	5		
Classified data	1	**786**	6	4	0	1	797	**98.62**
	2	33	**732**	1	2	0	768	95.31
	3	8	2	**185**	0	0	195	94.87
	4	5	15	0	**1041**	10	1071	97.20
	5	24	0	1	42	**66**	133	49.62
Sum		856	755	191	1085	77	**2964**	–
EO [%]		8.18	3.50	3.14	4.60	14.29	–	–
EC [%]		1.29	4.77	5.24	2.76	87.01	–	–
PA [%]		**91.82**	96.95	96.86	95.94	85.71	–	–

Classes: 1 – built-up area, 2 – agricultural area, 3 – bare soil, 4 – forest area, 5 – body of water.

6. Verification of results

The classification results were verified more formally and objectively in two ways. First, using an independent test dataset and confusion matrix. For an independent test, ground-truth data were divided into two parts. The first one was used for ANN training while the second one was used for validation of results (Section 6.1). Second, the same image was classified in terms of MLC and the results compared to MLP classification results (Section 6.2).

6.1 Evaluation of results

For the MLP classification results, a confusion matrix was computed according to an independent test dataset (Table 1). Five different measures of accuracy were derived – an error of omission (EO), an error of commission (EC), user accuracy (UA), producer accuracy (PA) and overall accuracy: definitions for these appear in, for example, Foody (2002).

An error of omission consists of the percentage of single-class pixels assigned to incorrect classes by classification. In the extraction of built-up areas, about 8% of the pixels were assigned to other classes, mainly to the agricultural area group. The highest error value (nearly 15%) occurred in the class containing bodies of water, as 10 pixels of a total of 77 test pixels in this class were classified as forests. The level of error of commission, specifying the number of pixels incorrectly assigned to a specific class, is very high (nearly 90%) for the water body class, to which 42 pixels of forest area and 24 pixels of built-up area were assigned. Such confusion between bodies of water and forested area arises largely out of the deep shadow thrown in forests. User accuracy defines the ratio of correctly-classified pixels to all pixels as assigned to specific classes. The highest value was derived for built-up areas; nearly 99% of pixels assigned to them truly belong to built-up areas. Except in the class covering bodies of water, user accuracy was around or over 95% for every class. Only one in two pixels assigned to water bodies represented an actual body of water. Producer accuracy describes the numbers of pixels in each class classified correctly. More than 95% of pixels for agricultural and forest areas and bare soils were assigned to the corresponding, correct class. The overall accuracy of the MLP classification was almost 95%.

6.2 Comparison with MLC

For maximum likelihood classification, the original five classes (Section 3) were divided into 11 sub-classes based on differences within categories. The built-up class was divided into three sub-classes. The first consisted of industrial and commercial areas characterized by large, continuous areas of impervious surface, such as concrete, asphalt, etc. The second corresponded to areas with a high density of buildings in the city centre and the third covered suburban areas of houses with gardens. The same set of training pixels as that employed for the MLP classification was used. Training pixels were assigned to sub-classes.

The sub-classes were aggregated into the original five categories and the results evaluated by means of the same independent test dataset as the MLP classification. The overall accuracy was similar (94.5%) to the MLP classification. The error of omission was lower (4.3%) in built-up areas in the MLC classification. However, the error of commission was higher (4.7%). The user accuracy of MLC was 95.3%, in comparison with 98.6% in MLP classification. Altogether, this means that almost 5% of the pixels assigned to built-up areas actually belonged to different classes. In producer accuracy, MLC gave a higher percentage (95.7%) than MLP. A greater difference occurred in error of commission and producer accuracy for bodies of water. In MLC, the error of commission was 5% higher than in MLP and producer accuracy was 4% lower. The producer and user accuracies for most of the classes in MLP (Figure 7) were slightly higher than those in MLC.

A comparison of the overall area assigned to each class by MLC and MLP showed that MLC exaggerated built-up areas at the expense of other classes. MLP classified 36.5% of the image as built-up area, while MLC assigned 43.6% of all pixels to this class.

7. Discussion

The neural network of MLP used in this study to extract built-up areas performed slightly better than statistical MLC. The MLC approach aims to define the subspaces in feature space corresponding to classified categories using parameters of normal distribution computed from a training set. Hence it fails correctly to classify highly heterogeneous built-up areas, which often deviate

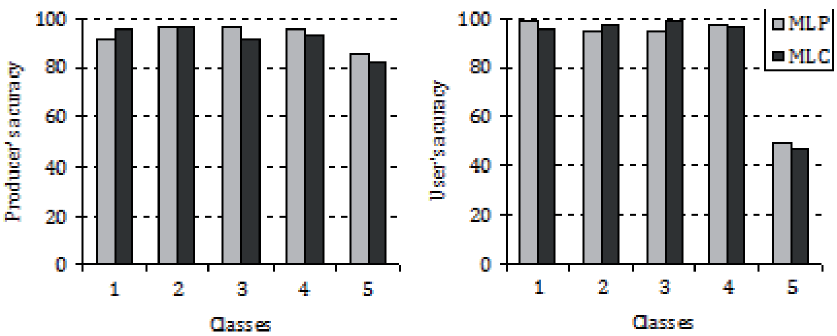

Fig. 7 Comparison of producer and user accuracy of MLP and MLC classification computed for all classes. 1 – built-up area, 2 – agricultural area, 3 – bare soil, 4 – forest area, 5 – body of water.

from "normality". In contrast, MLP does not assume any specific theoretical distribution. Moreover, MLP training attempts to define boundaries between classes in feature space. Boundaries can best be established using atypical representatives of class pixels, independent of value distribution. In this study, the same training set of typical representatives was used for both classifications. This may have partly biased the result of comparison and may be behind the fact that differences in classification accuracy are only slightly significant.

Our analysis related to the design of ANN demonstrated that the accuracy of MLP classification results is influenced to a large extent by ANN architecture. If a network has more than one input neuron for each input channel, it may capture slight differences between the inputs. As presented in Section 5, a topology with three input neurons per channel was used in this study. However, the use of more is far from uncommon, e.g. Benediktsson et al. (1990) used eight neurons and Bischof et al. (1992) used 13 neurons for each input channel. The number of hidden layers also influences network classification performance. A training phase for a smaller network can lead to a deadlock in the local minimum of total error function and the desired error value will not be achieved. Networks with a large number of neurons and hidden layers generally converge rapidly during the training phase, but there is considerable risk of overfitting. An overfitted network is capable of correct classification of a training set but cannot correctly assign pixels it has never seen before. It is therefore necessary to seek the network architecture most appropriate to the particular problem.

In general, MLP classification can be improved by objective selection of the bands required for classification (Kavzoglu and Mathers 2003; Sotoca et al. 2007). Reduction of the number of input bands may serve to emphasize important information in the image. Further, it entails a reduction of units in the neural net and subsequently a reduction in the time required for net training. Transformation of original bands with, for example, principal components, may also enhance important information and suppress noise in the image classified. Band selection based on divergence statistics was used in this contribution, but it did not improve classification accuracy (Section 4.1). ANNs enable the inclusion into classification of data from various sources. In the case of urban land-cover classification, texture information derived from the original image may also help distinguish highly heterogeneous built-up areas from other land cover types (Berberoglu et al. 2007).

Despite its successful classification results, the use of ANNs is still comparatively limited. Empirical rules (e.g. Atkinson and Tatnall 1997; Mather 1999) for determining the number of layers and their neurons are usually overestimated and generate over-large networks prone to overfitting. A large topology can usually be pruned. However, definition of the optimal fitting architecture is still a trial-and-error process (Wilamowski 2009). The time required to train a net may be shortened using more effective computers, through parallel computing, or with faster learning algorithms (Yu and Wilamowski 2009).

8. Conclusion

The need for accurate and up-to-date land cover information has become pressing (Feranec et al. 2007). Spatially and spectrally improved images and sophisticated classification approaches provide tools that eliminate the drawbacks of commonly-used statistical classifiers. Classification results can be further improved by enhancement of specific information in an image with spectral indices and image transformations (Deng et al. 2008; Uddin et al. 2010).

In agreement with several previous studies (e.g. Paola and Schowengerdt 1995; Mustapha et al. 2010), we demonstrated that ANN can address the problem of urban land use/land cover classification as well as, or even better than, statistical approaches and that it does not exaggerate built-up areas as much as a statistical classifier. Thus ANN may be a powerful tool for image classification, but it is still limited by the complex process of finding the best-fitting net architecture (Vatsavai et al. 2011) and a time-consuming and non-deterministic training phase.

The ANN method of land cover classification applied in this case study and our main findings concerning the classification accuracy are related to long-term activities dealing with urban climate of Brno. As different land cover categories contribute differently to air temperature variability and to UHI intensity (Hart and Sailor 2009; Dobrovolný 2013), a compilation of more precise land cover maps is very important. The classification accuracy of the land cover maps directly influences precision of air temperature mapping and subsequently our abilities to mitigate negative consequences of UHI formation. Land cover mapping is important not only in empirically based studies (Dobrovolný and Krahula 2012), but may significantly contribute to urban climate modeling (Hidalgo et al. 2008). Both the land cover map compiled in this case study and the design of the ANN will be further used not only for estimation of UHI intensity but will be also provided to decision maker as a support for sustainable development and for regional planning in Brno area.

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REFERENCES

ADAMS, J. B., GILLESPIE, A. R. (2006): Remote sensing of landscapes with spectral images: A physical modeling approach. Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511617195

ATKINSON, P. M., TATNALL, A. R. L. (1997): Introduction Neural networks in remote sensing. International Journal of Remote Sensing 18(4), 699–709. http://dx.doi.org/10.1080/014311697218700

BAGAN, H., WANG, Q., WATANABE, M., KAMEYAMA, S., BAO, Y. (2008): Land-cover classification using ASTER multi-band combinations based on wavelet fusion and SOM Neural Network. Photogrammetric Engineering and Remote Sensing 74(3), 333–342. http://dx.doi.org/10.14358/PERS.74.3.333

BENEDIKTSSON, J. A., SWAIN, P. H., ERSOY, O. K. (1990): Neural network approaches versus statistical methods in classification of multisource remote sensing data. IEEE Transactions on geoscience and remote sensing 28(4), 540–552. http://dx.doi.org/10.1109/TGRS.1990.572944

BENEDIKTSSON, J. A., SWAIN, P. H., ERSOY, O. K. (1993): Conjugate-gradient neural networks in classification of multisource and very-high-dimensional remote sensing data. International Journal of Remote Sensing 14(15), 2883–2903. http://dx.doi.org/10.1080/01431169308904316

BERBEROGLU, S., CURRAN, P. J., LLOYD, C. D., ATKINSON, P. M. (2007): Texture classification of Mediterranean land cover. International Journal of Applied Earth Observation and Geoinformation 9(3), 322–334. http://dx.doi.org/10.1016/j.jag.2006.11.004

BISCHOF, H., SCHNEIDER, W., PINZ, A. J. (1992): Multi-spectral classification of Landsat images using neural network. IEEE Transactions on Geoscience and Remote Sensing 30(3), 482–490. http://dx.doi.org/10.1109/36.142926

CHEN, X. L., ZHAO, H. M., LI, P. X., YIN, Z. Y. (2006): Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. Remote sensing of environment 104(2), 133–146. http://dx.doi.org/10.1016/j.rse.2005.11.016

CHEN, Y., SHI, P., FUNG, T., WANG, J., LI, X. (2007): Object-oriented classification for urban land cover mapping with ASTER imagery. International Journal of Remote Sensing 28(20): 4645–4651. http://dx.doi.org/10.1080/01431160500444731

CLEVE, C., KELLY, M., KEARNS, F. R., MORITZ, M. (2008): Classification of the wildland–urban interface: A comparison of pixel- and object-based classifications using high-resolution aerial photography. Computers, Environment and Urban Systems 32(4), 317–326. http://dx.doi.org/10.1016/j.compenvurbsys.2007.10.001

DA SILVA BRUM, V., GARCIA, L. M., KORTING, T. S., DUQUE, C. M. (2013): Intraurban land cover classification using IKONOS II images and data mining techniques: a comparative analysis. In: Urban Remote Sensing Event (JURSE), 2013 Joint. IEEE, 214–217. http://dx.doi.org/10.1109/JURSE.2013.6550703

DENG, J. S., WANG, K., DENG, Y. H., QI, G. J. (2008): PCA-based land-use change detection and analysis using multitemporal and multisensor satellite data. International Journal of Remote Sensing 29(16), 4823–4838. http://dx.doi.org/10.1080/01431160801950162

DINGLE ROBERTSON, L., KING, D. J. (2011): Comparison of pixel- and object-based classification in land cover change mapping. International Journal of Remote Sensing 32(6), 1505–1529. http://dx.doi.org/10.1080/01431160903571791

DOBROVOLNÝ, P. (2013): The surface urban heat island in the city of Brno (Czech Republic) derived from land surface temperatures and selected reasons for its spatial variability. Theoretical and Applied Climatology 112(1–2), 89–98. http://dx.doi.org/10.1007/s00704-012-0717-8

DOBROVOLNÝ, P., KRAHULA, L. (2012): Vliv geometrie zástavby na pole teploty vzduchu a intenzitu tepelného ostrova města na příkladu Brna. Meteorologické zprávy, Praha: Český hydrometeorologický ústav 65(2), 51–57.

EFTHYMIADIS, D. A., JONES, P. D. (2010): Assessment of maximum possible urbanization influences on land temperature data by comparison of land and marine data around coasts. Atmosphere 1(1), 51–61. http://dx.doi.org/10.3390/atmos1010051

FERANEC, J., HAZEU, G., CHRISTENSEN, S., JAFFRAIN, G. (2007): Corine land cover change detection in Europe (case studies of the Netherlands and Slovakia). Land Use Policy 24(1), 234–247. http://dx.doi.org/10.1016/j.landusepol.2006.02.002

FOODY, G. M. (1995): Land cover classification by an artificial neural network with ancillary information. International Journal of Geographical Information Systems 9(5), 527–542. http://dx.doi.org/10.1080/02693799508902054

FOODY, G. M. (2002): Status of land cover classification accuracy assessment. Remote sensing of environment 80(1), 185–201. http://dx.doi.org/10.1016/S0034-4257(01)00295-4

FOODY, G. M., ARORA, M. K. (1997): An evaluation of some factors affecting the accuracy of classification by an artificial neural network. International Journal of Remote Sensing 18(4), 799–810. http://dx.doi.org/10.1080/014311697218764

HART, M. A., SAILOR, D. J. (2009): Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island. Theoretical and Applied Climatology 95(3–4), 397–406. http://dx.doi.org/10.1007/s00704-008-0017-5

HE, C., SHI, P., XIE, D., ZHAO, Y. (2010): Improving the normalized difference built-up index to map urban built-up areas using a semiautomatic segmentation approach. Remote Sensing Letters 1(4), 213–221. http://dx.doi.org/10.1080/01431161.2010.481681

HEROLD, M., SCEPAN, J., MÜLLER, A., GÜNTHER, S. (2002): Object-oriented mapping and analysis of urban land use/cover using IKONOS data. In: 22nd Earsel Symposium Geoinformation for European-Wide Integration.

HIDALGO, J., MASSON, V., BAKLANOV, A., PIGEON, G., GIMENO, L. (2008): Advances in urban climate modeling. Trends and Directions in Climate Research, Annals of the New York Academy of Sciences, 1146(1), 354–374. http://dx.doi.org/10.1196/annals.1446.015

HU, X., WENG, Q. (2009): Estimating impervious surfaces from medium spatial resolution imagery using the self-organizing map and multi-layer perceptron neural networks. Remote Sensing of Environment 113(10), 2089–2102. http://dx.doi.org/10.1016/j.rse.2009.05.014

JIANG, J., TIAN, G. (2010): Analysis of the impact of land use/land cover change on land surface temperature with remote sensing. Procedia environmental sciences 2, 571–575. http://dx.doi.org/10.1016/j.proenv.2010.10.062

JIN, J. (2012): A Random Forest Based Method for Urban Land Cover Classification using LiDAR Data and Aerial Imagery, M.A. thesis, Geography Department, University of Waterloo.

KAVZOGLU, T., MATHER, P. M. (2003): The use of backpropagating artificial neural networks in land cover classification. International Journal of Remote Sensing, 24(23), 4907–4938. http://dx.doi.org/10.1080/0143116031000114851

KUX, H. J. H., DE PINHO, C. M. D. (2006): Object-oriented analysis of high-resolution satellite images for intra-urban land cover

classification: Case study in São José Dos Campos, São Paulo State, Brazil. In: Proceedings of 1st International Conference on Obgect-based Image Analysis (OBIA 2006), 4–5.
LIPPMANN, R. (1987): An introduction to computing with neural nets. ASSP Magazine, IEEE 4(2), 4–22. http://dx.doi.org/10.1109/MASSP.1987.1165576
LU, D., SONG, K., ZENG, L., LIU, D., KHAN, S., ZHANG, B., ZONGMING, W., JIN, C. (2008): Estimating impervious surface for the urban area expansion: Examples from Changchun, northeast China. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 37, 385–391.
LU, D., WENG, Q. (2006): Use of impervious surface in urban land-use classification. Remote Sensing of Environment 102(1), 146–160. http://dx.doi.org/10.1016/j.rse.2006.02.010
LU, D., WENG, Q. (2009): Extraction of urban impervious surfaces from an IKONOS image. International Journal of Remote Sensing 30(5), 1297–1311. http://dx.doi.org/10.1080/01431160802508985
MATHER, P. M. (1999): Computer Processing of Remotely-Sensed Images – An Introduction. 2nd ed., John Wiley and Sons, Hoboken, N. J.
MOUNTRAKIS, G., IM, J., OGOLE, C. (2011): Support vector machines in remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing 66(3), 247–259. http://dx.doi.org/10.1016/j.isprsjprs.2010.11.001
MUSTAPHA, M. R., LIM, H. S., MAT JAFRI, M. Z. (2010): Comparison of neural network and maximum likelihood approaches in image classification. Journal of Applied Sciences(Faisalabad) 10(22), 2847–2854.
MYINT, S. W., GOBER, P., BRAZEL, A., GROSSMAN-CLARKE, S., WENG, Q. (2011): Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. Remote Sensing of Environment 115(5), 1145–1161. http://dx.doi.org/10.1016/j.rse.2010.12.017
NARENDRA, P. M., FUKUNAGA, K. (1977): A branch and bound algorithm for feature subset selection. Computers, IEEE Transactions on 100(9), 917–922.
NOVACK, T., ESCH, T., KUX, H., STILLA, U. (2011): Machine learning comparison between WorldView-2 and QuickBird-2-simulated imagery regarding object-based urban land cover classification. Remote Sensing 3(10), 2263–2282. http://dx.doi.org/10.3390/rs3102263
PAOLA, J. D., SCHOWENGERDT, R. A. (1995): A detailed comparison of back-propagation neural network and maximum-likelihood classifiers for urban and land use classification. IEEE Transactions on Geoscience and Remote Sensing 33(4), 981–996. http://dx.doi.org/10.1109/36.406684
POWELL, R. L., ROBERTS, D. A., DENNISON, P. E., HESS, L. L. (2007): Sub-pixel mapping of urban land cover using multiple endmember spectral mixture analysis: Manaus, Brazil. Remote Sensing of Environment 106(2), 253–267. http://dx.doi.org/10.1016/j.rse.2006.09.005
PU, R., LANDRY, S., YU, Q. (2011): Object-based urban detailed land cover classification with high spatial resolution IKONOS imagery. International Journal of Remote Sensing 32(12), 3285–3308. http://dx.doi.org/10.1080/01431161003745657
RIDD, M. K. (1995): Exploring a VIS (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. International Journal of Remote Sensing 16(12), 2165–2185. http://dx.doi.org/10.1080/01431169508954549
ROBERTS, D. A., Gardner, M., Church, R., Ustin, S., Scheer, G., Green, R. O. (1998): Mapping chaparral in the Santa Monica Mountains using multiple endmember spectral mixture models. Remote Sensing of Environment 65(3), 267–279. http://dx.doi.org/10.1016/S0034-4257(98)00037-6
RODRIGUEZ-GALIANO, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., Rigol-Sanchez, J. P. (2012): An assessment of the effectiveness of a random forest classifier for land-cover classification. ISPRS Journal of Photogrammetry and Remote Sensing 67, 93–104. http://dx.doi.org/10.1016/j.isprsjprs.2011.11.002
RUMELHART, D. E., HINTONT, G. E., WILLIAMS, R. J. (1986): Learning representations by back-propagating errors. Nature 323, 533–536. http://dx.doi.org/10.1038/323533a0
SETIAWAN, H., MATHIEU, R., THOMPSON-FAWCETT, M. (2006): Assessing the applicability of the V–I–S model to map urban land use in the developing world: Case study of Yogyakarta, Indonesia. Computers, Environment and Urban Systems 30, 503–522. http://dx.doi.org/10.1016/j.compenvurbsys.2005.04.003
SETO, K. C., LIU, W (2003): Comparing ARTMAP neural network with the maximum-likelihood classifier for detecting urban change. Photogrammetric Engineering and Remote Sensing 69 (9), 981–990. http://dx.doi.org/10.14358/PERS.69.9.981
SMITH, A. (2010): Image segmentation scale parameter optimization and land cover classification using the Random Forest algorithm. Journal of Spatial Science 55(1), 69–79. http://dx.doi.org/10.1080/14498596.2010.487851
SOWMYA, B., Thirumaran, A., Aravindh, R., Prasad, A. A. (2011): Land cover classification using Adaptive Resonance Theory-2. In: Electronics, Communication and Computing Technologies (ICECCT), 2011 International Conference on. IEEE, 78-82.
SUN, Z., GUO, H., LI, X., LU, L., DU, X. (2011): Estimating urban impervious surfaces from Landsat-5 TM imagery using multilayer perceptron neural network and support vector machine. Journal of Applied Remote Sensing 5(1). http://dx.doi.org/10.1117/1.3539767
ŠÍMA, J., NERUDA, R. (1996): Teoretické otázky neuronových sítí. 1st ed., MATFYZPRESS, Praha.
TEHRANY, M. S., PRADHAN, B., JEBU, M. N. (2013): A comparative assessment between object and pixel-based classification approaches for land use/land cover mapping using SPOT 5 imagery. Geocarto International, ahead-of-print: 1–19.
TURNER, B. L., MEYER, W. B., SKOLE, D. L. (1994): Global land-use/land-cover change: towards an integrated study. AMBIO-STOCKHOLM 23, 91–91.
UDDIN, S., AL GHADBAN, A. N., AL DOUSARI, A., AL MURAD, M., AL SHAMROUKH, D. (2010): A remote sensing classification for land-cover changes and micro-climate in Kuwait. International Journal of Sustainable Development and Planning 5, 367–377. http://dx.doi.org/10.2495/SDP-V5-N4-367-377
SOTOCA, J. M., PLA, F., SÁNCHEZ, J. S. (2007): Band selection in multispectral images by minimization of dependent information. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 37(2), 258–267.
VATSAVAI, R. R., BRIGHT, E., VARUN, C., BUDHENDRA, B., CHERIYADAT, A., GRASSER, J. (2011): Machine learning approaches for high-resolution urban land cover classification: a comparative study. In: Proceedings of the 2nd International Conference on Computing for Geospatial Research and Applications. ACM.
VYORÁLKOVÁ, I. (2003): Zpracování satelitních snímků neuronovými sítěmi. Automatizace 46(11), 742–745.
WALTON, J. T. (2008): Subpixel urban land cover estimation: comparing cubist, random forests, and support vector regression. Photogrammetric Engineering and Remote Sensing 74(10), 1213–1222. http://dx.doi.org/10.14358/PERS.74.10.1213

WILAMOWSKI, B. M. (2009): Neural network architectures and learning algorithms. Industrial Electronics Magazine, IEEE 3(4), 56–63. http://dx.doi.org/10.1109/MIE.2009.934790
WU, C., MURRAY, A. T. (2003): Estimating impervious surface distribution by spectral mixture analysis. Remote sensing of Environment 84(4), 493–505. http://dx.doi.org/10.1016/S0034-4257(02)00136-0
XU, H. (2007): Extraction of urban built-up land features from Landsat imagery using a thematic-oriented index combination technique. Photogrammetric Engineering and Remote Sensing 73(12), 1381–1391. http://dx.doi.org/10.14358/PERS.73.12.1381
YU, H., WILAMOWSKI, B. M. (2009): Efficient and reliable training of neural networks. In: Human System Interactions, 2009. HSI'09. 2nd Conference on. IEEE, 109–115.
YUAN, H., VAN DER WIELE, C. F., KHORRAM, S. (2009): An automated artificial neural network system for land use/land cover classification from Landsat TM imagery. Remote Sensing 1(3), 243–265. http://dx.doi.org/10.3390/rs1030243
ZHA, Y., GAO, J., NI, S. (2003): Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. International Journal of Remote Sensing 24(3), 583–594. http://dx.doi.org/10.1080/01431160304987
ZHOU, W., HUANG, G., TROY, A., CADENASSO, M. L. (2009): Object-based land cover classification of shaded areas in high spatial resolution imagery of urban areas: A comparison study. Remote Sensing of Environment 113(8), 1769–1777. http://dx.doi.org/10.1016/j.rse.2009.04.007

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RESUMÉ

Role neuronových sítí při klasifikaci druhů povrchu v zastavěných oblastech: vícevrstvá neuronová síť

Aktuální a přesné mapy druhů povrchů poskytují zásadní informace pro řadu odvětví, mezi jinými pro územní plánování a trvale udržitelný rozvoj. Dálkový průzkum Země nabízí zřejmě nejefektivnější přístup pro tvorbu těchto map. Přesnost metod automatické klasifikace obrazu je nicméně stále limitována, zvláště ve vysoce heterogenních zastavěných oblastech. Tato studie prezentuje vícevrstvou neuronovou síť (multilayer perceptron) jako příklad jednoho z možných přístupů ke klasifikaci obrazu. Optimálního nastavení parametrů architektury použité neuronové sítě bylo dosaženo pomocí trénovací množiny vzorů. Výsledná síť se dvěma skrytými vrstvami byla použita pro klasifikaci satelitního snímku pořízeného senzorem ASTER. Výsledek klasifikace byl následně zhodnocen pomocí testovací množiny dat. Celková přesnost klasifikace vůči testovacím datům dosahovala 94,8 %, což je srovnatelné s klasifikací získanou využitím klasifikátoru maximální pravděpodobnosti (maximum likelihood) pro totožný snímek. Výraznějšího rozdílu v klasifikaci si lze povšimnout především ve výsledné rozloze zastavěných ploch, kdy klasifikátor maximální pravděpodobnosti značně nadhodnotil zastoupení zastavěných ploch v obraze (43,6 %) oproti ostatním klasifikovaným třídám. Klasifikací vícevrstvou neuronovou sítí byla zastavěná plocha vymezena na 36,5 % klasifikovaného území.

THE IMPORTANCE OF PROTECTED AREAS AS NATURAL LANDSLIDE LABORATORIES

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ABSTRACT

Geological hazards such as landslides pose potential threats to people and infrastructure, and, accordingly, are a high priority for scientific study. However, the very presence of that infrastructure in developed areas can potentially influence landslide behavior, complicating efforts to assess the natural triggering and displacement mechanics of landslide events. Protected areas – such as natural reserves, conservation areas, and national parks – are particularly valuable as laboratories for landslide studies because they typically exhibit only those natural factors important for understanding landslide behavior. In this paper we examine the importance of protected areas as natural landslide laboratories, consider the benefits of long-term landslide investigation, discuss how protected areas may be used to monitor different landslide types, and present some of the key investigational and operational characteristics of suitable natural landslide laboratories.

Keywords: landslides, natural laboratories, long-term investigation, protected areas

1. Introduction

Geoscientists conduct much of their research outside the controlled laboratory setting familiar to chemists and physicists. Observations and samples are often collected in physically challenging locations and hypotheses must be validated in settings with many unconstrained variables. Some geologic phenomena, landslides prominently among them, have the potential to be hazardous to people and the built environment upon which people depend. The scientific study of landslides is therefore the first of many important steps in ensuring public safety (De Graff 2012). In order to derive quantitative data on landslide triggering mechanisms and deformational mechanics, natural laboratories for landslide research are desirable.

Geoscientists investigating landslides and landslide processes often must determine how both natural and anthropogenic factors have influenced a particular landslide occurrence. Deconvolving these factors can be a difficult task in landscapes with considerable human development or other alterations (Griffiths 1999; Burns 2010). Anthropogenic activities in the past, as well as ones contemporaneous with a landslide occurrence, can cause, magnify, or mask the natural factors influencing a particular event. Distinguishing between natural and anthropogenic factors is critical for understanding what triggered a landslide and influenced its movement in order to successfully mitigate the hazard and risk posed by present and future landslides.

In this paper we discuss the importance of protected areas, such as natural reserves or conservation areas, which are for the most part undeveloped and, therefore free of direct anthropogenic influences, as laboratories for landslide research. We herein use the term "landslide" in a general sense to encompass movements of masses of rock, sediments, or soil under the influence of gravity (Clague 2013). Where a specific type of landslide is referred to, the terminology follows Varnes (1978) and Cruden and Varnes (1996). From our own monitoring experience and familiarity with other efforts in the United States, we suggest what investigational and operational characteristics may make a protected area especially suitable for the long-term study of landslide phenomena. Some landslide types appear to be more often used as natural laboratories based on our review of the literature. We discuss how protected or other undeveloped areas may be used to monitor the natural factors influencing rock fall which is one of the landslide types less frequently the subject of this type of monitoring effort.

1.1 Landslide Study in Developed Versus Protected Areas

The 1979 Abbotsford landslide in Dunedin, New Zealand illustrates the difficulty in ascribing the relative importance of natural and anthropogenic factors of a landslide occurring in a developed area (Hancox 2008). This large and catastrophic landslide was intensely studied and yielded several conclusions about the relative influence of site characteristics and triggering factors. First, increased pore water pressure caused by a rising ground water level was deemed to be a very significant factor (Hancox 2008). This rising of a water level was related to both infiltration of higher rainfall amounts during the preceding 10 years and to leakage from a water pipeline within the upper area of the landslide (Hancox 2008). Removal of natural vegetation due to development

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AUC Geographica, 50, No. 2, pp. 165–172

activities was also considered a possible contributing anthropogenic factor causing changes to infiltration and the water level, but its significance could not be determined for lack of data (Hancox 2008). Second, landslide development was found to have been enhanced by the natural progressive downcutting of an adjacent creek (Hancox 2008). However, quarrying of a large volume of sand from the toe of the slope 10 years prior to the landslide event was also determined to be a significant slope-destabilizing factor (Hancox 2008). An unquantifiable, but deemed significant, factor influencing the landslide was urban development, which added weight to the slope, modified storm water infiltration, and allowed water from local waterline breaks to enter the slope (Hancox 2008). The uncertainty in fully distinguishing the extent to which the Abbotsford landslide was influenced by both natural and anthropogenic factors influenced the selection of suitable mitigation measures. This uncertainty also complicated identifying strategies for avoiding or mitigating future landslides in similar terrain in this part of New Zealand.

In order to develop sufficient data to validate hypotheses and determine relationships between natural factors and landslide responses, study must take place over an extended period of time. It often requires carrying out what can be termed investigative monitoring (DeGraff 2011). Landslides in highly developed areas are problematic for use in long-term studies due to the more immediate need to mitigate the landslide's actual or threatened impact to surrounding residences, businesses, and infrastructure; the affected population is unlikely to support the idea of withholding mitigation actions during many years of investigative monitoring. Accordingly, landslides suitable for extended study of natural factors influencing landslide formation and movement are more likely to be found in natural environments. Some landslides suitable for extended study may be within the vicinity of homes, roads, pipelines, power lines and similar human infrastructure; landslides in the areas where these anthropogenic influences are minor could still serve as suitable sites for the study of natural factors. Some areas where the land use is restricted to low-impact activities such as hiking, biking, or grazing might also serve as protected areas for landslide study. However, landslides found in protected areas such as land managed by private or governmental entities to preserve natural landscapes, protect wildlife habitat or watersheds, or promote scientific investigation are the most desirable for long-term study. In such settings, landslides can serve as laboratories where the variables important to landslide triggering and development are limited to natural factors.

The explicit recognition of a landslide in an undeveloped area serving as a natural laboratory was made in a U.S. Geological Survey (USGS) publication describing multi-year research findings for the Slumgullion earth flow (Varnes and Savage 1996). The Slumgullion earth flow in southwestern Colorado (Figure 1A) is an outstanding example of a landslide in a protected area that provides significant insight into natural factors influencing landslide triggering and morphological development. While roads and some seasonal residences are located in the vicinity of the earth flow, their location does not affect the natural processes influencing on the earth flow. The earth flow and surrounding area are located on public land managed by the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service (USFS). Consequently, the location has remained in natural conditions. Since 1996, continuing study of the Slumgullion earth flow by the USGS and other geologists have yielded valuable insights on such factors as its rate of movement, internal deformation, and the seismic signature generated by movement on the basal slip surface and side-boundary faults (Messerich and Coe 2003; Baum et al. 2003; Coe et al. 2003; Parise 2003; Parise et al. 2003; Coe et al. 2009; Schultz et al. 2009a; Gomberg et al. 2011; Walter et al. 2013).

1.2 Benefits of Long-term Landslide Investigation

Investigating the formation, kinematics, morphology, and response to triggering events of landslides in a natural setting has numerous benefits. Systematic landslide studies within a geographic region, of a particular landslide type, or of landslide triggering mechanisms offer valuable information for understanding the formative landslide processes, establishing hazard and risk relationships, and identifying important design constraints for mitigating measures (Keefer 1994; De Graff 1994; Wieczorek and Snyder 2009; Cannon et al. 2010). The depth of understanding produced by detailed long-term study of a particular landslide feature or landslide type can potentially reveal previously unrecognized aspects of these phenomena. The measurements carried out at the Slumgullion earth flow, which enabled researchers to detect atmospheric tides as a component of movement, is but one example (Schulz et al. 2009b).

Water is one of the most significant factors associated with initiation and movement of landslides. However, water content, saturation ratio and pore-water pressure at the time a landslide occurs, or the landslide responses to water infiltration from rainfall or snowmelt, are not easily determined after the landslide occurrence. Long-term investigations such as those at Minor Creek (northern California) and Johnson Creek (western Oregon) have yielded important insights into the influence of water on landslide movement (Iverson and Major 1987; Priest et al. 2008; 2011). At the complex landslide feature in Minor Creek, the motion of the landslide was found to be controlled by both the near-surface hydraulic gradient and pore-water pressure waves initiated by intermittent rainfall (Iverson and Major 1987). The translational landslide in local bedrock at Johnson Creek provided data demonstrating how movement was initiated and accelerated by rainfall-induced pore-pressure waves (Priest et al. 2008; 2011).

Another benefit from long-term detailed studies of landslides in undeveloped areas is providing data that are useful for modeling landside phenomena and validating new methods of numerical analyses (Iverson and Major 1987; Guzzetti et al. 2003; Gomberg et al. 2011; Brückl et al. 2013). The use of landslides as natural laboratories can also serve to test and refine study techniques and technology, which generally validates and improves their widespread application (Squarzoni et al. 2003; Coe et al. 2003; Casson et al. 2005; Jomard et al. 2010; Berger et al. 2010; Stock et al. 2012; Zimmer et al. 2012; Booth et al. 2013). Examples of recent techniques and technology include the application of SAR interferometry, the utility of high-resolution 3D imagery, and new designs for channel bed erosion sensors.

2. Characteristics of a suitable natural laboratory for landslides

A crucial suitability factor for a potential natural landslide laboratory is being able to protect that area from human activity that might alter natural factors affecting the landslide. Table 1 provides a sampling of landslides in undeveloped locations in North America and Europe currently or recently used as natural laboratories (Figure 1). The landslides listed in Table 1 are only representative of natural laboratories in undeveloped locations, rather than a comprehensive listing. All listed landslide study sites in the United States except for Minor Creek and Johnson Creek are on public land managed by governmental agencies such as the USFS, BLM, and National Park Service (NPS); these agencies have the authority and responsibility for controlling land use activities where the study areas are found. Minor Creek is on land owned and managed by a single timber company. At Johnson Creek, protection is achieved by an Oregon Department of Transportation right-of-way agreement.

Collaboration between governmental entities, universities, and research institutes provides the protection for the landslide study sites listed in Austria, France and Switzerland (Table 1). Illgraben, the Swiss study site (Figure 1B), illustrates how such collaborations can be carried out (B. McArdell, Swiss Federal Institute WSL, Written Comm., Oct. 2014). Most of the land outside the city limits of Susten, on the alluvial fan, is under the control of that municipality. Regulation guided by federally mandated, hazard-intensity maps provide protection of the channel where debris flows pass and are deposited. Most of the land within the Illgraben catchment is simply too hazardous for any activities other than seasonal grazing or use as a nature preserve. Consequently, researchers from entities like the Swiss Federal Institute for Forest, Snow, and Landscape Research are able to carry out long-term debris flow monitoring there (B. McArdell, Swiss Federal Institute WSL, Written Comm., Oct. 2014). Review of published findings and associated Internet sites suggests similar collaborations ensure the protection of the listed landslide study sites found in Austria and France (Table 1).

Tab. 1 Examples of landslide monitoring in protected areas within the United States and Europe.

Name	Landslide Type	Location	Main Study Period
Chalk Cliffs[1]	Debris flows	Rocky Mountains, CO, USA	2008–Ongoing
Cleveland Corral[1]	Earth flow	Sierra Nevada, CA, USA	1997–Ongoing
Doren[2]	Complex slide	Eastern Alps, Austria	2000–Ongoing
Ferguson[3]	Rock slide	Sierra Nevada, CA, USA	2006–2012
Gradenbach[4,5]	Deep-seated gravitational slope deformation	Eastern Alps, Austria	1999–Ongoing
Illgraben[6]	Debris flows	Valais Alps, Switzerland	2001–Ongoing
Johnson Creek[1]	Rock slide	SW coast OR, USA	2004–Ongoing
La Clapière[7]	Rock slide	Southern Alps, France	1987–Ongoing
La Valette[8]	Complex slide	Southern Alps, France	1988–Ongoing
Minor Creek[9]	Complex slide	Coast Range, CA, USA	1973–Ongoing
Slumgullion[10]	Earth flow	Rocky Mountains, CO, USA	1990–Ongoing
Yosemite[11]	Rock falls, rock slides	Sierra Nevada, CA, USA	1980–Ongoing

[1] http://landslides.usgs.gov/monitoring/, [2] Roncat et al. 2013, [3] Harp et al. 2008, [4] Brückl et al. 2013, [5] http://gbonline.tugraz.at/gb_welcome_en.php, [6] McArdell et al. 2003, [7] http://gravitaire.oca.eu/spip.php?rubrique15, [8] Squarzoni et al. 2003, [9] Iverson and Major 1987, [10] Varnes and Savage 1996, [11] Stock et al. 2013

In general, initial identification of landslides suitable for use as natural landslide laboratories result from studies initiated in response to some actual or threatened impact. A number of landslides listed in Table 1 came to the attention of researchers because of adverse effects to roads or the potential for altering river flow. For example, the Ferguson rock slide in central California (Figure 1C) completely blocked a major highway used to access a local community and Yosemite National Park, and threatened to dam a major river (Harp et al. 2008). Other landslides were identified due to the effects of much earlier movement. For example, movement of the Slumgullion earth flow nearly 700 years ago was responsible for forming Lake San Cristobal (Figure 1A; Varnes and Savage 1996), and the persistence of this natural dam stimulated interest in the earth flow that had created it.

There are both investigational and operational characteristics that make a landslide in an undeveloped area

Fig. 1 Examples of protected areas in North America and Europe used as natural landslide laboratories. (a) The Slumgullion earth flow in the Rocky Mountains of Colorado, USA, photograph courtesy of the U.S. Geological Survey; (b) The Illgraben debris flow study area in the Valais Alps, Switzerland, photograph by Franz Iseli; (c) The Ferguson Rock Slide in the Sierra Nevada mountains of California, USA.

suitable for use as a natural laboratory. Investigational characteristics include: 1) the availability of existing data such as maps of the local geology and landslide features, 2) identification of movement type and amount, and 3) the likelihood that additional movement will occur. Operational characteristics include: 1) being present within an undeveloped area, 2) a low likelihood of intentional or inadvertent human interference with study efforts, and 3) sufficient access for repetitive measurements and to install and maintain instrumentation.

2.1 Investigational Characteristics

Initial investigation of a landslide produces data on the triggering mechanism, mode of movement, and internal deformation. This data provides a starting point for further study. The initial understanding of the landslide serves as the basis for designing specific long-term monitoring to address particular study objectives. Whether this happens or not is largely dependent on the mission or research interest of organizations initially involved with the landslide, or the interests of individual researchers within reasonable geographic proximity of the landslide.

Landslide monitoring and investigation is a significant component of the geologic hazards mission of the USGS (see http://landslides.usgs.gov/monitoring/). Thus, it is not surprising that USGS geologists contributed to research for all the United States landslides noted in Table 1. As one example, the real-time monitoring of the Cleveland Corral landslide was undertaken by the USGS in cooperation with the USFS to provide timely emergency response for any significant movement, which would threaten U.S. Highway 50 (Reid and LaHusen 1998). Blockage of Highway 50 and temporary damming of the South Fork of the American River by the nearby Mill Creek landslide in 1997 had heightened concern about future movement by the Cleveland Corral landslide.

Another important investigational characteristic is the amount of movement occurring within a landslide being considered for long-term monitoring. All or a significant part of the landslide must be sufficiently active to further the research undertaken. This can be slow but measureable deformation such as that measured at the Slumgullion earth flow, or brief episodic events such as those occurring at Illgraben (Table 1). Given the expenditure of time and funds for investigative monitoring, landslide movement needs to occur at a frequency sufficient to warrant continued study. The Ferguson rock slide is no longer monitored partly because the movement nearly ceased thus reducing its hazard, and, in turn, its risk (Table 1). Significant reactivation of movement took place beginning in 2006 on this pre-existing rock slide (Harp et al. 2008). Real-time monitoring of the Ferguson rock slide during the next few years showed that movement consistently accelerated within days following major rainfall (De Graff et al. 2014). Subsequently, total cumulative movement decreased during several years of lower-than-normal total rainfall to the point that only detectable, small movement was recorded even during significant storm events.

2.2 Operational Characteristics

As noted previously, the availability of a landslide for long-term study is a characteristic more likely to be found for a landslide in a protected area or relatively undeveloped area rather than in a densely developed area. The generally lower likelihood that a landslide poses a risk to the smaller population of an undeveloped area in the landslide's vicinity reduces the need for immediate mitigation of further movement. Also, the land values in undeveloped areas do not typically support the cost-benefit ratio of many mitigation measures commonly applied to urban landslides. Before committing to using a particular landslide as a natural laboratory, it would be important to determine the current and planned land management of adjacent areas. Timber harvest, access road construction, or similar land uses could alter groundwater patterns influencing landslides. The Ferguson rock slide (Figure 1C) was wholly within a part of a national forest managed as a scenic river corridor and for wildlife habitat. This ensured that no land use activity occurred that might alter the natural processes involved with this landslide.

The smaller human population present in the vicinity of a landslide in an undeveloped area limits the likelihood of intentional or inadvertent interference with monuments and instruments installed as part of long-term studies. However, study design should consider how to limit the effect of such interference. Depending on the arrangements with the land owner or whoever has control over the likely access points to the landslide, there may be ways to further reduce vulnerability to human interference. A closure order to public entry was issued by the USFS for the Ferguson rock slide and surrounding national forest land. Later, fencing and traffic control associated with installation of a road detour further limited the ability of individuals to reach the landslide.

Accessibility is another operational characteristic important in selection of a landslide for long-term study. Seasonal changes may render access more difficult and, thereby, affect the timing of certain repetitive measurements or justify the costs for remote recording or transmitting capability. Some instrumentation may be unsuitable because it is too heavy, requires emplacement using equipment that cannot reach the landslide, or does not justify the expense of helicopter delivery. Access is also a consideration for operating instrumentation dependent on maintenance including scheduled battery replacement or seasonal effects on solar panels efficiency. At the Ferguson rock slide (Figure 1C), instrumentation capable of transmitting movement data in real-time via radio and dedicated phone line was installed (De Graff et al. 2014). The urgency of receiving this information during the impending rainy season justified using a helicopter for emplacing the instruments. This approach was facilitated by the availability of a USFS helicopter and a nearby heli-spot operated by Yosemite National Park. While the instrumentation could operate for a year on batteries, it required an annual trek by a crew to carrying replacements up a long, steep trail. A companion system monitoring the water level of the river upstream and downstream from the Ferguson rock slide reported through a battery-powered satellite transmission system (De Graff 2011). The battery was recharged by solar panels. Positioned in the bottom of a steep-sided canyon, the solar panels were incapable of fully charging the battery during the winter when the low sun angle placed the monitoring station in shadows for much of the day. Batteries recharged off-site needed to be brought to the site every ten days during the winter months to ensure data were reported via the satellite system.

Another operational characteristic that may be important is that some protected areas such as national parks or wilderness areas may have rules limiting the extent, duration, or visibility of scientific instrumentation on landslides. In these cases, the deployment of instrumentation may be of short duration, or may have to be concealed or camouflaged to reduce the visual impact to visitors. There may also be rules limiting the type of equipment that can be used for transporting or installing instruments. Such rules may constrain the instrumentation suitable for long-term study in these protected areas.

3. Investigating an individual landslide versus areas with multiple landslides

Table 1 is not a comprehensive list of landslides in protected areas presently or recently used as natural laboratories. However, it is representative of some well-known examples and illustrates the predominance of individual, large landslides being used for this purpose. This listing also demonstrates that all landslide types (Varnes 1978; Hungr et al. 2014) are not equally represented in these long-term study efforts. The potential for destructive effects is not limited to large, individual landslides similar to the ones noted in Table 1. Two landslide types, debris flows and rock falls, are also notable for their destructive capability because they move rapidly and can travel some distance from their initiation point.

Debris flows and rock falls range from small to large discrete events often affecting the same general area. It can be difficult to identify undeveloped areas where debris flows will occur frequently enough to permit the kind of studies comparable to those applied to large individual landslides. Illgraben (Figure 1B) and Chalk Cliffs are two exceptions where watersheds are subject to repeated debris flow occurrence on a time scale consistent with long-term study (Table 1). Both of these study areas utilize the tendency of debris flows to flow down existing channels. In contrast to debris flows, rock fall will often be concentrated along a linear area defined by escarpments composed of susceptible bedrock where long-term study can be carried out.

Yosemite Valley in Yosemite National Park represents a somewhat unique case illustrating the importance of protected area status for long-term studies of rock falls. The ~1 km-tall, glacially steepened cliffs of Yosemite Valley experience many rock falls each year, ranging from small events on the order of 1 cubic meter in volume to larger events involving hundreds of cubic meters (Figure 2; Stock et al. 2013); the largest historical rock falls are hundreds of thousands of cubic meters in volume. The cliffs of Yosemite Valley are within a designated wilderness area within a national park, and are thus essentially free of anthropogenic influences. Conversely, the floor of Yosemite Valley, where rock fall talus is deposited, is relatively densely developed with campgrounds, cabins, restaurants, and other amenities serving approximately four million visitors a year. The combination of natural rock falls occurring in wilderness settings along with the substantial hazard and risk posed by these rock falls has led to detailed and long-term study and documentation of rock falls and rock-fall hazard in Yosemite Valley (e.g., Guzzetti et al. 2003; Stock et al. 2011, 2012, 2013; Wieczorek and Jäger 1996; Wieczorek and Snyder 1999; Wieczorek et al. 2000, 2008; Zimmer et al. 2012). Documentation of rock fall events, of which there are approximately 40–60 per year, extends back to 1857; the database of rock falls in Yosemite (Stock et al. 2013) now contains more than 1,000 events. This database can be used to identify the most active cliffs and lithologies for rock falls, the common environmental conditions that trigger rock falls, and the most frequent types of rock-fall impacts to human infrastructure.

The NPS, USGS, and academic researchers recently completed a comprehensive study of rock-fall hazard and risk in Yosemite Valley (Stock et al. 2014). This work focused on the evidence of past rock-fall activity in the form of boulders at and beyond the edge of the active talus slope. Yosemite's status as a protected area was vitally important in this regard, as these boulders were mapped with reasonable certainty that they had not be removed or relocated following their deposition. The undisturbed nature of rock fall deposits on the valley floor also allowed for accurate dating of their deposition (Stock and Uhrhammer 2010; Cordes et al. 2013; Stock et al. 2014). Based on this research, the NPS, which solely manages the park, was able to take aggressive steps to reduce risk by removing or relocating buildings and campsites from hazardous areas (Stock and Collins 2014).

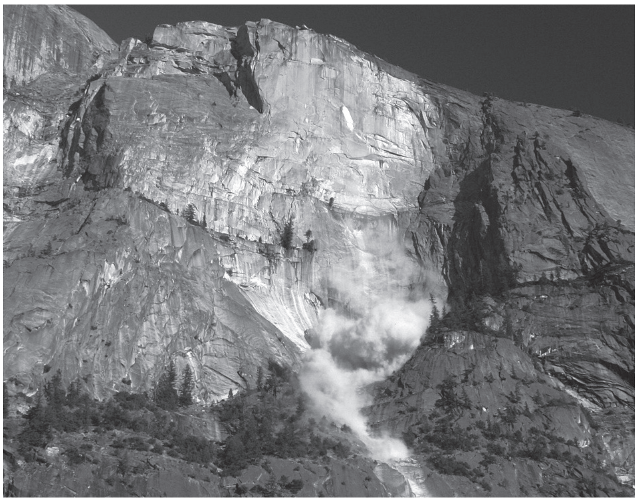

Fig. 2 A rock fall with a volume of approximately 150 cubic meters that fell on 24 July 2010 from a cliff west of Half Dome in Yosemite Valley, Yosemite National Park, California. The cliffs of Yosemite Valley are in a designated wilderness area within a national park, and thus represent an important natural laboratory for investigating rock falls and other landslide phenomena. Photograph courtesy of Ludovina Fernandez.

4. Conclusions

Landslides in protected or other undeveloped areas offer an opportunity to study in isolation the natural factors responsible for their formation, kinematics, morphology, and response to triggering events. The smaller human population, or even lack of population, in protected areas makes long-term study of landslides possible while limiting or avoiding introduction of anthropogenic factors. The suitability of protected areas to serve as natural landslide laboratories is facilitated by studying landslides that take advantage of both investigational characteristics, such as activity level, and operational characteristics, such as accessibility. Although a number of these natural laboratories exist, most study large individual landslides. There is a need for more natural laboratories devoted to the study of landslide types, such as debris flows and rock falls, involving multiple events rather than movements by the same landslide. The addition of any new landslides as natural laboratories will likely follow the pattern of existing ones; a significant landslide will take place in a suitable area resulting in an initial study. The initial study will stimulate an agency or research collaborative to seek funding for subjecting the landslides to long-term study. The investigational and operational characteristics previously described should be considered in determining whether a particular landslides is suitable for study in this manner.

Landslide study in protected areas can yield multiple benefits. These natural laboratories provide an ideal situation for testing instrumentation and investigative techniques that can then be applied to other landslide investigations with greater confidence in their validity and accuracy. Similarly, the long-term studies carried out in protected areas generate data that constrain models being developed to demonstrate landslide initiation, movement rates, kinematics, and provide reliable criteria for designing mitigation measures at locations with similar characteristics. In this regards, long-term study of landslides in protected areas is favorable for producing data useful for forensic investigations of landslides in developed areas to aid distinguishing the extent to which natural and anthropogenic factors are responsible for a particular landslide. This is especially important when considering the effect of water on triggering landslide movement, controlling the rate of movement, and its relationship to rainfall and snowmelt sources. The findings established in this manner could provide insight by defining how natural factors influence certain movement or deformation responses, identifying characteristic surface features and subsurface morphology, or determining stress-strain or pore-pressure constraints.

Scientific knowledge is advanced by these studies when new principles and understandings are determined from these long-term data. Whether stated explicitly, as in the case of Johnson Creek landslide in the United States, or implied for long-term study at other landslides, such as LaClapière in France, research results are expected to be applicable to other landslides similar to the one under long-term study. The degree to which such findings are truly widely applicable is enhanced by achieving similar results at more than one long-term landslide study site, or by undertaking focused studies at a number of similar landslides to specifically test a finding. Ultimately, detailed studies of landslides in natural settings provide context for understanding landslides occurring in developed areas and may clarify the nature of human influence on landslide occurrence in urban settings.

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REFERENCES

BAUM, R. L., SAVAGE, W., WASOWSKI, J. (2003): Mechanics of earth flows. In Proceedings of the International Conference FLOWS, Sorrento, Italy.

BERGER, C., MCARDELL, B. W., FRITSCHI, B., SCHLUNEGGER, F. (2010): A novel method for measuring the timing of bed erosion during debris flows and floods. Water Resources Research, 46(2), W02502. http://dx.doi.org/10.1029/2009WR007993

BOOTH, A. M., LAMB, M. P., AVOUAC, J. P., DELACOURT, C. (2013): Landslide velocity, thickness, and rheology from remote sensing: La Clapière landslide, France. Geophysical Research Letters, 40(16), 4299–4304. http://dx.doi.org/10.1002/grl.50828

BRÜCKL, E., BRUNNER, F. K., LANG, E., MERTL, S., MÜLLER, M., STARY, U. (2013): The Gradenbach Observatory – monitoring deep-seated gravitational slope deformation by geodetic, hydrological, and seismological methods. Landslides, 10(6), 815–829. http://dx.doi.org/10.1007/s10346-013-0417-1

BURNS, S. F. (2015): Urban Landslides: Challenges for Forensic Engineering Geologists and Engineers. In Engineering Geology for Society and Territory-Volume 5. Springer International Publishing, 3–9. http://dx.doi.org/10.1007/978-3-319-09048-1_1

CANNON, S. H., GARTNER, J. E., RUPERT, M. G., MICHAEL, J. A., REA, A. H., PARRETT, C. (2010): Predicting the probability and volume of postwildfire debris flows in the intermountain western United States. Geological Society of America Bulletin, 122(1–2), 127–144. http://dx.doi.org/10.1130/B26459.1

CASSON, B., DELACOURT, CH., ALLEMAND, P. (2005). Contribution of multi-temporal remote sensing images to characterize landslide slip surface? Application to the La Clapière landslide (France). Natural Hazards and Earth System Science 5(3), 425–437. http://dx.doi.org/10.5194/nhess-5-425-2005

CLAGUE, J. J. (2013): Landslides, In BOBROWSKY, P. T., ed., Encyclopedia of Natural Hazards: Springer, Heidleberg, 594–602. http://dx.doi.org/10.1007/978-1-4020-4399-4_212

COE, J. A., ELLIS, W. L., GODT, J. W., SAVAGE, W. Z., SAVAGE, J. E., MICHAEL, J. A., KIBLER, J. D., POWERS, P. S., LIDKE, D. J., DEBRAY, S. (2003): Seasonal movement of the Slumgullion landslide determined from Global Positioning System surveys and field instrumentation, July 1998 – March 2002. Engineering Geology, 68(1), 67–101. http://dx.doi.org/10.1016/S0013-7952(02)00199-0

COE, J. A., MCKENNA, J. P., GODT, J. W., BAUM, R. L. (2009): Basal-topographic control of stationary ponds on a continuously moving landslide. Earth Surface Processes and Landforms, 34(2), 264–279. http://dx.doi.org/10.1002/esp.1721

CORDES, S. E., STOCK, G. M., SCHWAB, B. E., GLAZNER, A. F. (2013): Supporting evidence for a 9.6 ± 1 ka rock fall originating from Glacier Point in Yosemite Valley, California. Environmental and Engineering Geoscience XIX, 345–361. http://dx.doi.org/10.2113/gseegeosci.19.4.345

CRUDEN, D. M., VARNES, D. J. (1996): Landslide Types and Processes, in TURNER, A. K., AND SCHUSTER, R. L., eds., Landslides: Investigations and Mitigation: Transportation Research Board, Special Report 247, Chapter 3, 36–75.

DE GRAFF, J. V. (1994): The geomorphology of some debris flows in the southern Sierra Nevada, California. Geomorphology, 10(1), 231-252. http://dx.doi.org/10.1016/0169-555X(94)90019-1

DE GRAFF, J. V. (2011): Perspectives for Systematic Landslide Monitoring. Environmental & Engineering Geoscience, 17(1), 67–76. http://dx.doi.org/10.2113/gseegeosci.17.1.67

DE GRAFF, J. V. (2012): Solving the dilemma of transforming landslide hazard maps into effective policy and regulations. Natural Hazards and Earth System Science, 12(1), 53–60. http://dx.doi.org/10.5194/nhess-12-53-2012

DE GRAFF, J. V., GALLEGOS, A. J., REID, M. E., LAHUSEN, R. G., DENLINGER, R. P. (2014): Using monitoring and simulation to define the hazard posed by the reactivated Ferguson Rockslide, Merced Canyon, California. Natural Hazards, 76(2), 769–789. http://dx.doi.org/10.1007/s11069-014-1518-4

GOMBERG, J., SCHULZ, W., BODIN, P., KEAN, J. (2011): Seismic and geodetic signatures of fault slip at the Slumgullion Landslide Natural Laboratory, Journal of Geophysical Research, 116, B09404. http://dx.doi.org/10.1029/2011JB008304

GRIFFITHS, J. S. (1999): Proving the occurrence and cause of a landslide in a legal context. Bulletin of Engineering Geology and the Environment, 58(1), 75–85. http://dx.doi.org/10.1007/s100640050070

GUZZETTI, F., REICHENBACH, P., WIECZOREK, G. F. (2003): Rockfall hazard and risk assessment in the Yosemite Valley, California, USA. Natural Hazards and Earth System Sciences, 3, 491–503. http://dx.doi.org/10.5194/nhess-3-491-2003

HANCOX, G. T. (2008), The 1979 Abbotsford Landslide, Dunedin, New Zealand: a retrospective look at its nature and causes. Landslides, 5(2), 177–188. http://dx.doi.org/10.1007/s10346-007-0097-9

HARP, E. L., REID, M. E., GODT, J. W., DEGRAFF, J. V., GALLEGOS, A. J. (2008). Ferguson rock slide buries California State Highway near Yosemite National Park. Landslides, 5(3), 331–337. http://dx.doi.org/10.1007/s10346-008-0120-9

HUNGR, O., LEROUEIL, S., PICARELLI, L. (2014): The Varnes classification of landslide types, an update. Landslides, 11(2), 167–194. http://dx.doi.org/10.1007/s10346-013-0436-y

IVERSON, R. M., MAJOR, J. J. (1987): Rainfall, ground-water flow, and seasonal movement at Minor Creek landslide, northwestern California: Physical interpretation of empirical relations. Geological Society of America Bulletin, 99(4), 579–594. http://dx.doi.org/10.1130/0016-7606(1987)99<579:RGFASM>2.0.CO;2

JOMARD, H., LEBOURG, T., GUGLIELMI, Y., TRIC, E. (2010): Electrical imaging of sliding geometry and fluids associated with a deep seated landslide (La Clapière, France). Earth Surface Processes and Landforms, 35(5), 588–599. http://dx.doi.org/10.1002/esp.1941

KEEFER, D. K. (1994): The importance of earthquake-induced landslides to long-term slope erosion and slope-failure hazards in seismically active regions. Geomorphology, 10(1), 265–284. http://dx.doi.org/10.1016/0169-555X(94)90021-3

MCARDELL, B. W., ZANUTTIGH, B., LAMBERTI, A., RICKENMANN, D. (2003): Systematic comparison of debris flow laws at the Illgraben torrent, Switzerland. In Debris flow Mechanics and Mitigation Conference, Mills Press, Davos, 647–657.

MESSERICH, J. A., COE, J. A. (2003): Topographic map of the active part of the Slumgullion landslide on July 31, 2000, Hinsdale County, Colorado. US Geological Survey.

PARISE, M. (2003): Observation of surface features on an active landslide, and implications for understanding its history of movement. Natural Hazards and Earth System Science, 3(6), 569–580. http://dx.doi.org/10.5194/nhess-3-569-2003

PARISE, M., COE, J. A., SAVAGE, W. Z., VARNES, D. J. (2003): The Slumgullion landslide (southwestern Colorado, USA): investigation and monitoring. In Proceedings of the International Conference FLOWS, Sorrento, Italy.

PRIEST, G. R., ALLAN, J. C., NIEM, A. R., NIEM, W. A., DICKENSON, S. E. (2008): Johnson Creek Landslide Research Project, Lincoln County, Oregon: Final Report to the Oregon Department of Transportation. Oregon Department of Geology and Mineral Industries Special Paper 40, 227 pp.

PRIEST, G. R., SCHULZ, W. H., ELLIS, W. L., ALLAN, J. A., NIEM, A. R., NIEM, W. A. (2011): Landslide stability: role of rainfall-induced, laterally propagating, pore-pressure waves. Environmental & Engineering Geoscience, 17(4), 315–335. http://dx.doi.org/10.2113/gseegeosci.17.4.315

REID, M. E., LAHUSEN, R. G. (1998): Real-time Monitoring of Active Landslides Along Highway 50, El Dorado County. California Geology, 51(3), 17–20.

RONCAT, A., GHUFFAR, S., SZÉKELY, B., DORNINGER, P., RASZTOVITS, S., MITTELBERGER, M., KOMA, Z., KWARCZYK, D., PFEIFER, N. (2013): A natural laboratory – Terrestrial laser scanning and auxiliary measurements for studying an active landslide: 2nd Joint International Symposium on Deformation Monitoring.

SCHULZ, W. H., MCKENNA, J. P., KIBLER, J. D., BIAVATI, G. (2009a): Relations between hydrology and velocity of a continuously moving landslide – evidence of pore-pressure feedback regulating landslide motion? Landslides, 6(3), 181–190. http://dx.doi.org/10.1007/s10346-009-0157-4

SCHULZ, W. H., KEAN, J. W., WANG, G. (2009b): Landslide movement in southwest Colorado triggered by atmospheric tides. Nature Geoscience, 2(12), 863–866. http://dx.doi.org/10.1038/ngeo659

STOCK, G. M., AND UHRHAMMER, R. A. (2010): Catastrophic rock avalanche 3600 years BP from El Capitan, Yosemite Valley, California. Earth Surface Processes and Landforms, 35, 941–951. http://dx.doi.org/10.1002/esp.1982

STOCK, G. M., COLLINS, B. D. (2014): Reducing rockfall risk in Yosemite National Park. Eos, 95(29), 261–263. http://dx.doi.org/10.1002/2014EO290002

STOCK, G. M., BAWDEN, G. W., GREEN, J. K., HANSON, E., DOWNING, G., COLLINS, B. D., BOND, S., LESLAR, M. (2011): High-resolution three-dimensional imaging and analysis of rock falls in Yosemite Valley, California. Geosphere, 7(2), 573–581. http://dx.doi.org/10.1130/GES00617.1

STOCK, G. M., MARTEL, S. J., COLLINS, B. D., HARP, E. L. (2012): Progressive failure of sheeted rock slopes: the 2009–2012 Rhombus Wall rock falls in Yosemite Valley, California, USA. Earth Surface Processes and Landforms, 37, 546–561. http://dx.doi.org/10.1002/esp.3192

STOCK, G. M., COLLINS, B. D., SANTANIELLO, D. J., ZIMMER, V. L., WIECZOREK, G. F., SNYDER, J. B. (2013): Historical rock falls in Yosemite National Park, California (1857–2011). U.S. Geological Survey Data Series 746. www.pubs.usgs.gov/ds/746/

STOCK, G. M., LUCO, N., COLLINS, B. D., HARP, E. L., REICHENBACH, P., FRANKEL, K. L. (2014): Quantitative rock-fall hazard and risk assessment for Yosemite Valley, Yosemite National Park, California. U.S. Geological Survey Scientific Investigations Report 2014-5129. www.pubs.usgs.gov/sir/2014/5129/

SQUARZONI, C., DELACOURT, C., ALLEMAND, P. (2003): Nine years of spatial and temporal evolution of the La Valette landslide observed by SAR interferometry. Engineering Geology, 68(1), 53–66. http://dx.doi.org/10.1016/S0013-7952(02)00198-9

VARNES, D. J. (1978): Landslide types and processes, In SCHUSTER, R. L., KIRZEK, R. J. (Eds.), Landslide Analysis and Control: Washington, D. C., National Academy Press, Transportation Research Board, National Academy of Sciences, Special Report 176, 12–33.

VARNES, D. J., SAVAGE, W. Z. (Eds.). (1996): The Slumgullion earth flow: a large-scale natural laboratory. U.S. Geological Survey Bulletin 2130, 1–4.

WALTER, M., GOMBERG, J., SCHULZ, W., BODIN, P., JOSWIG, M. (2013): Slidequake generation versus viscous creep at softrock-landslides: synopsis of three different scenarios at Slumgullion landslide, Heumoes slope, and Super-Sauze mudslide. Journal of Environmental and Engineering Geophysics, 18(4), 269–280. http://dx.doi.org/10.2113/JEEG18.4.269

WIECZOREK, G. F., JÄGER, S. (1996): Triggering mechanisms and depositional rates of postglacial slope-movement processes in the Yosemite Valley, California. Geomorphology, 15, 17–31. http://dx.doi.org/10.1016/0169-555X(95)00112-I

WIECZOREK, G. F., SNYDER, J. B. (1999): Rock falls from Glacier Point above Camp Curry, Yosemite National Park, California. U.S. Geological Survey Open-File Report 99-385.

WIECZOREK, G. F., SNYDER, J. B. (2009): Monitoring slope movements, in Young, R., and Norby, L, Geological Monitoring: Boulder, Colorado, Geological Society of America, 245–271.

WIECZOREK, G. F., SNYDER, J. B., WAITT, R. B., MORRISSEY, M. M., UHRHAMMER, R. A., HARP, E. L., NORRIS, R. D., BURSIK, M. I., FINEWOOD, L. G. (2000): Unusual July 10, 1996, rock fall at Happy Isles, Yosemite National Park, California. Geological Society of America Bulletin, 112 (1), 75–85. http://dx.doi.org/10.1130/0016-7606(2000)112<75:UJRFAH>2.0.CO;2

WIECZOREK, G. F., STOCK, G. M., REICHENBACH, P., SNYDER, J. B., BORCHERS, J. W., GODT, J. W. (2008): Investigation and hazard assessment of the 2003 and 2007 Staircase Falls rock falls, Yosemite National Park, California, USA. Natural Hazards and Earth System Sciences, 8, 421–432. http://dx.doi.org/10.5194/nhess-8-421-2008

ZIMMER, V. L., COLLINS, B. D., STOCK, G. M., SITAR, N. (2012): Rock fall dynamics and deposition: an integrated analysis of the 2009 Ahwiyah Point rock fall, Yosemite National Park, USA. Earth Surface Processes and Landforms, 37, 680–691. http://dx.doi.org/10.1002/esp.3206

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LANDSLIDE AND GLACIAL LAKE OUTBURST FLOOD HAZARD IN THE CHUCCHÚN RIVER BASIN, CORDILLERA BLANCA, PERU

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ABSTRACT

The Chucchún River basin was hit by glacial lake outburst flood (GLOF) triggered by ice/rock avalanche which caused spill over from the Lake 513 (April 11, 2010). The whole region is also highly susceptible for landslide occurrences, therefore the GLOF and landslide multi-hazard map were prepared for the watershed. Definition of the GLOF hazard zones was done using 1D mathematical model HEC-RAS for modeling of flooded areas. Landslide hazard zonation was based on landslide inventory mapping and historical records of the landslide occurrences. Resulting multi-hazard map shows that 26% of the studied river basin is under some degree of hazard from landslides or GLOFs. It clearly shows the most endangered inhabited areas as well as places, where floods and landslides may adversely affect each other increasing intensity of the hazardous event.

Keywords: landslide hazard, GLOFs, flood hazard, Cordillera Blanca, Peru

1. Introduction

Landslides and glacial lake outburst floods (GLOFs) represent high danger especially in glaciated mountain regions recently experiencing adverse effects of climate change, to which Cordillera Blanca belongs (Rabatel et al. 2013). Both of these processes may be interrelated in complex process chain increasing possible damage to affected communities. Landslides may often initiate the process chain by falling/sliding into the glacial lake (Hubbart et al. 2005; Vilímek et al. 2005; Klimeš et al. 2014; Schneider et al. 2014; Emmer et al. 2014) and causing impact wave, which overtops the lake dam and transforms into GLOF or debris flow moving downstream and causing the main damage. Resulting GLOF may be also responsible for triggering landslides on the river banks, which in turn may at least partly block the river causing local and temporal water level increase, which along with subsequent breaches may be responsible for further damages.

Recent works suggest that climate warming causing permafrost degradation may be main factor governing occurrence of slope movements in permafrost regions above glacial lakes (Huggel 2009; Haeberli 2013). Nevertheless, there are some other works suggesting that deglaciation and permafrost degradation effects on slope stability is less straight forward with diverse slope responses depending on geological and hydrological properties (Holm et al. 2004) or may be over-ride by other landslide triggers, among which an extreme precipitation and earthquakes are the most common ones. The latter proved to be the main landslide trigger in the Cordillera Blanca as documented by landslide inventory done by Plafker et al. (1971) after May 1970 earthquake. During that event hundreds of landslides occurred including two catastrophic ice/rock avalanches (Evans et al. 2009) from the Huascárn Norte Mt. Along with the main ice- and rock avalanche which destroyed the city of Yungay (in the Santa River valley) a smaller event happened in the Llanganuco Valley destroying base camp of mountain climbers. Despite the frequent natural hazards and long lasting experience with their catastrophic effects also in the Cordillera Blanca (Carey et al. 2012), the Andean societies increase their exposure and vulnerability by rapid urban development and population growth (Hermanns et al. 2012). Historical catastrophic GLOFs, which claimed thousands of lives in the Santa River basin below Cordillera Blanca Mts. caused high sensitivity of the local as well as national population to these events (Carey et al. 2012). It was proved by strong media and political response to even small magnitude events during last decade. In April 2003 NASA's false warning about possible fall of ice avalanche into the Palcacocha Lake caused economical problems for the local capital of Huaraz with high economic looses from decreased tourism during Eastern Holidays (Vilímek et al. 2005). Minor flood on the Quilcay River running from the Palcacocha Lake through regional capital city of Huaraz occurred the following month (March 2003). It rise again large attention of the local population and urged rapid response of Peruvian scientists and authorities. Also the GLOF from April 2010 from the Lake 513, which damaged property in the city of Carhuaz – Acopampa (Carey et al. 2012; Klimeš et al. 2014), rise national wide attention and the affected river basin is now subject of international development project (Schneider et al. 2014).

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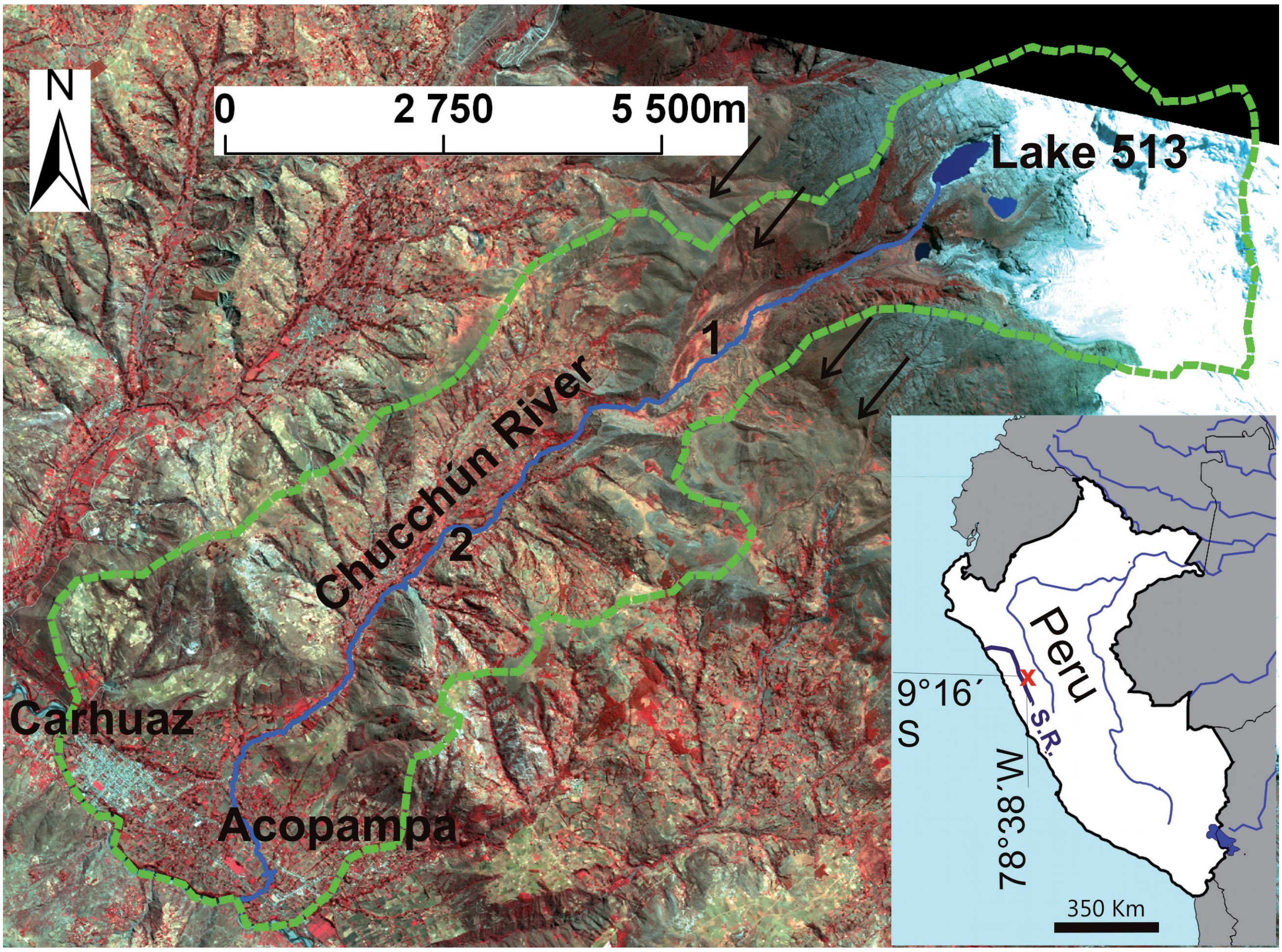

Fig. 1 Chucchún River basin is shown by dashed line, arrows point to the Cordillera Blanca normal fault scarp, 1 – Pampa Schonquil, 2 – Pariacaca Village, background image is 2010 SPOT View image.

The first GLOF model for the Chucchún basin (Figure 1) was done by Valderrama and Vilca (2010) before the 2010 GLOF event which unfortunately had no effects on flood hazard mitigation in the basin. It presents a scenario-based debris flow model in Flow2D. Their calculations showed that transitions between hyper-concentrated flood and debris flow will occur during the course of the GLOF. It was later confirmed by geomorphological research (Vilímek et al. 2014) and also reflected in debris flow simulations performed in RAMMS software as part of process chain modelling (Schneider et al. 2014). The RAMMS model was done using 8 m resolution digital elevation model (DEM) derived from 2012 WorldView satellite images (Schneider et al. 2014). It calculated peak discharge at the lake dam of 9,000 m^3 for the 2010 event. The debris flow models made using Flow2D were also prepared for other sites within the Peruvian Andes (Castillo et al. 2006; Valderrama et al. 2007).

Landslides have been causing serious damage in Peru for a long time (Kojan and Hutchinson 1978; Plafker et al. 1971; Vilímek et al. 2000), and recently, large attention has been broad to national wide landslide inventory and susceptibility assessment. The most general one covers south part of Peru (not including the study area) displaying landslide inventory and susceptibility maps at scale 1 : 750,000 (e.g. Fídel et al. 2006). The small map scale is determined by extend and remoteness of the mountainous terrain of the Peruvian territory. More detailed landslide and susceptibility mapping was performed for the Ancash Region covering the study area (Zavala et al. 2009). It contains series of 1 : 250,000 landslide susceptibility maps based on heuristic approach. Site specific landslide studies in the Ancash region focused mainly on sites affected by rock avalanche from the Huascarán Mt. (Evans et al. 2009; Klimeš et al. 2009) or catastrophic landslide at the Rampac Grande village, Cordillera Negra (Klimeš and Vilímek 2011). In most cases, the landslide susceptibility maps are very general with respect to used input thematic information (e.g. geological map, topographic data) to be applicable on local level. Due to the overview scale of the maps, they also can not contain all landslides which may be important for the local hazard assessment. Therefore we decided to perform the first detail landslide inventory mapping for the Chucchún basin producing susceptibility and hazard maps. This information is combined with results of flood models based on in field measured topographic profiles using 1D hydrological simulation in HEC-RAS software. Resulting flood characteristics (e.g. flooded areas and maximum flood depths) are combined with landslide hazard assessment identifying areas where floods and landslides may combine to possibly increase hazard during specified GLOF scenarios.

2. Study area

Head part of the Chucchún River basin is in the granitic rocks of the Cordillera Blanca batholit, which is limited by normal fault forming prominent scarp (indicated by arrows on Figure 1) of the graben type valley of the Santa River. It is filled with Mesozoic and Tertiary sedimentary and volcanic rocks which are partly covered by glaciofluvial sediments. Water level of the Lake 513 is fixed by tunnel carved in the bed rock at 4,431 m asl. The Chucchún stream starts here and runs for 14.4 km to its mouth with the Santa River at 2,650 m asl. Upper part of the stream runs across very steep slope formed mostly by bed rock below which it reaches wide area of paleolake in site called Pampa Schonquil (no. 1 on Figure 1). Middle reach of the valley is mostly narrow in some parts forming narrow canyons, whereas the lowest part flows across wide alluvial fan. Detailed description of the valley morphology is in Vilímek et al. (2014). The highest up-stream located village is Pariacaca (no. 2 on Fig. 1) whereas Carhuaz and Acopampa are located on the alluvial fan, where houses are often placed very close to the river. According to the 2007 national census data (INEI), there are 650 inhabitants living in Acopampa and 3,596 in Carhuaz districts located on the cone.

3. Methods

3.1 Landslide hazard assessment

Landslides were mapped using recent GoogleEarth images (2012 and 2013) and classified as debris flows and landslides which were further subdivided into shallow and deep-seated landslides. The later contains features with estimated shear plane depth exceeding 15 m. The landslide bodies were first identified and mapped and then, more generalized polygons were drawn reflecting their possible extend during potential future reactivations. The polygons were defined based on landslide morphology, estimated depth and expert knowledge of landslide run-out distances in the study area. In cases when several smaller landslides occurred on one slope or within local drainage basin, they were grouped and entire slope was mapped as single landslide prone area. This approach defines landslide prone areas based on previous occurrences but it is clear that the landslide susceptibility outside the mapped landslides and debris flows is not zero and needs to be assessed. Therefore we used the slope dip as simple criterion to distinguish more landslide prone regions on slopes where no evidences about previous landslide occurrence where found. This approach proved to be relevant for different types of landslides including shallow landslides and debris flows (Klimeš 2008). We analyzed the mapped landslides against the digital elevation model and assigned the slope interval of 15°–35° as more landslide prone than slopes below 15° or above 35°. Resulting map represents spatial prognostic landslide susceptibility map.

To evaluate landslide temporal occurrence probabilities we used long-term annual occurrence frequencies based on historical records for large part of the Santa River valley (Vilímek et al. 2012). The historical landslide occurrence data cover period 1971–2009 and thus do not reflect the effect of major earthquake in 1970. During the evaluated period (39 years) seven debris flows, three landslides and one major snow avalanche or rockfall occurred on average every year. Thus we assigned the high occurrence probability to debris flows and medium probability to landslides and deep-seated landslides.

Then we combined the spatial and temporal information into the hazard classes. The "very high" class was assigned to the debris flows, "high" to landslides and "medium" hazard class to the deep-seated landslides which are unlikely to reactivate as a whole, but represent highly favorable conditions for development of secondary landslides (Klimeš and Blahůt 2012). "Low" landslide hazard class was assigned to slopes with dip 15°–35°. This class represents parts of the study area where no evidences of past sliding were found, but due to the favorable morphological conditions its future occurrence cannot be excluded. The rest of the study area (e.g. 0°–15° and > 35°) was assigned as "very low" landslide hazard class where only landslide accumulation may occur.

3.2 GLOF hazard assessment

We assume that the majority of floods which have occurred in the Chucchún basin have originated from the glacial lakes. Among different causes of GLOFs, ice or ice/rock avalanches triggering overtopping wave in the Lake 513 is the most probable one. The flood mapping was based on modeling in one-dimensional mathematical model HEC-RAS v. 4.1.0. The stream and floodplain geometry was characterized by topographic cross-sections measured in a field for particular intervals (reach lengths) selected based on character of valley morphology. Therefore the flow conditions, e.g. cross-section shape, surface roughness, and slope vary from one section to the next. A mix flow regime was used for the steady flow analysis with a supercritical flow regime modelled mostly in the steep upper part of the river and a subcritical regime modelled in its shallower lower part. For more details regarding the input data and calculations please refer to Klimeš et al. (2014), which also includes online supplement with the necessary input data for flood model calculation.

Magnitude frequency relationship of the ice/rock avalanches is unknown for the study site as well as the Cordillera Blanca Mts., therefore we defined the flood hazard classes based on documented historical event and geomorphological evidences. Only two hazard classes were defined. The “very high” hazard class was based on the results of the April 11, 2010 GLOF model (Klimeš et al. 2014). To reflect uncertainty in the flood model results and magnitude estimation of possible future GLOFs, we set the down-stream boundary condition in the model as water level 1 m above the maximum flood height calculated for the 2010 event. We assume that this flood scenario has the highest occurrence probability. Low hazard class was defined by mapping the lowest fluvial terraces of the Chucchún River which are not regularly flooded during recent times, but were formed by repeating floods of different magnitudes during the evolution of the valley. Therefore we cannot exclude that these regions could be flooded in a future as well. Such a flood would require significantly larger flow than the 2010 event and therefore we assume its relatively low occurrence probability.

The resulting multi-hazard map was prepared by overlaying the GLOF hazard map with “very high and low” classes over landslide hazard map containing “very high, high, medium, low and very low” classes. The glaciated part of the Chucchún watershed was excluded from the analysis and its hazard is not shown on the resulting map. It is because the landslide initiation conditions in this part of the study area are largely unknown and differ significantly from the non-glaciated terrain.

4. Results

4.1 Landslide hazard assessment

The landslide inventory map of the Chucchún basin contains 61 landslides with area of 5.4 km^2 (54% of the total landslide area), 39 debris flows covering 1.2 km^2 (13% of the total landslide area) and only 5 deep-seated landslides, which though cover in total 3.2 km^2 (33% of the total landslide area). In the case of the debris flows, potential transport areas from each source zone are also included on the map, despite there were no recent signs of debris flows travelling through majority of the gullies.

The landslide hazard map (Figure 2) shows that the majority of landslides and debris flows occur in the middle and lower part of the watershed, whereas the head of the valley is almost free of them. The only exceptions are deep-seated landslides which develop in the area near the Cordillera Blanca fault, suggesting that they may be predisposed by tectonic activity of the fault. Debris flows occur either on steep slopes (over 35°) or in the head parts of the right tributaries of the Chucchún River. Their activity in some of the tributary valleys is evidenced by freshly looking debris accumulations on the valley floors. Landslides are represented either by rather small features which developed on the river banks or occur within several large areas along the lower reach of the Chucchún River.

4.2 Flood modeling and hazard map

The GLOF scenario defining the “very high” hazard class resulted into the peak flow of 965 m^3 s^{-1}. The maximum flood depths increased significantly in many of the river reaches (Figure 3) compared with the 2010 event flood model. The most significant flood depth increase occurred in the middle, most narrow part of the valley (Figure 4), where the flooded area remained almost identical compare to the 2010 event. “Low” hazard class covers majority of the Carhuaz-Acopampa alluvial fan and flat part of the Pampa Schonquil. Two minor low hazard areas were also mapped on the middle reach of the river (A, B on Figure 3).

Combining the two described hazard maps into a single map gives the multi-hazard landslide/flood map (Figure 5).

5. Discussion and conclusions

Key issue when producing hazard maps is assessment of their reliability and possible uncertainties involved in their preparation which may limit their use (Klimeš 2013). In the study area, absence or short period of historical records on the past dangerous events is the main limiting factor in hazard assessment. It is especially true in the case of the GLOFs which return period is impossible to define using scarce historical records. Moreover, climate change may adversely change environmental conditions contributing toward higher occurrence of ice/rock avalanches, which are among the most dangerous GLOF triggering mechanisms. Also estimation of the basic characteristics of the possible future ice/rock avalanches (e.g. volumes, velocities) are very subjective, although are critical in assessment of the resulting GLOF volumes (Schneider et al. 2014). To avoid these uncertainties, we adopted conservative approach to define future flood scenario which defines the “very high” GLOF hazard class. Its definition is based on the only well-known historical GLOF event from April 2010 in the Chucchún River basin. The resulting zonation is probably rather optimistic, e.g. assigning relatively small portion of the study area into the “very high” hazard class. On the other hand, the “low” flood hazard class defined by field mapping of alluvial terraces and alluvial fan represents conservative scenario – it assigns relatively large part of the study area to this hazard zone. It is mainly true for the alluvial fan where only part of it may be affected during a single GLOF event. Its magnitude depends mainly on water volume stored in the Lake 513 which remains the same due to the already existing drainage system.

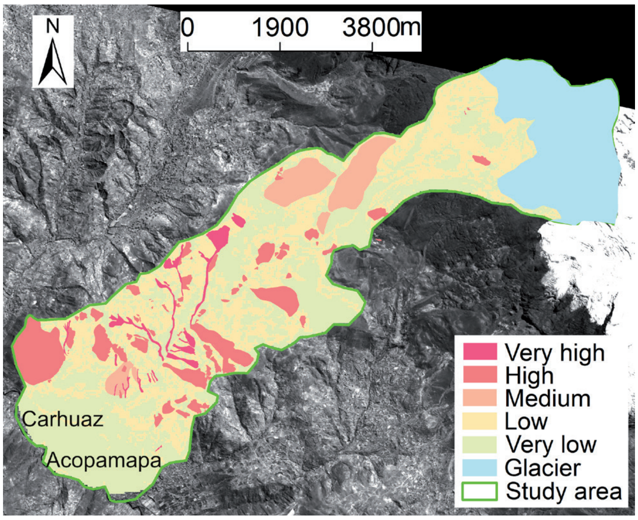

Fig. 2 Landslide hazard map with mask covering the glaciated part of the watershed as shown on 2010 SPOT View image.

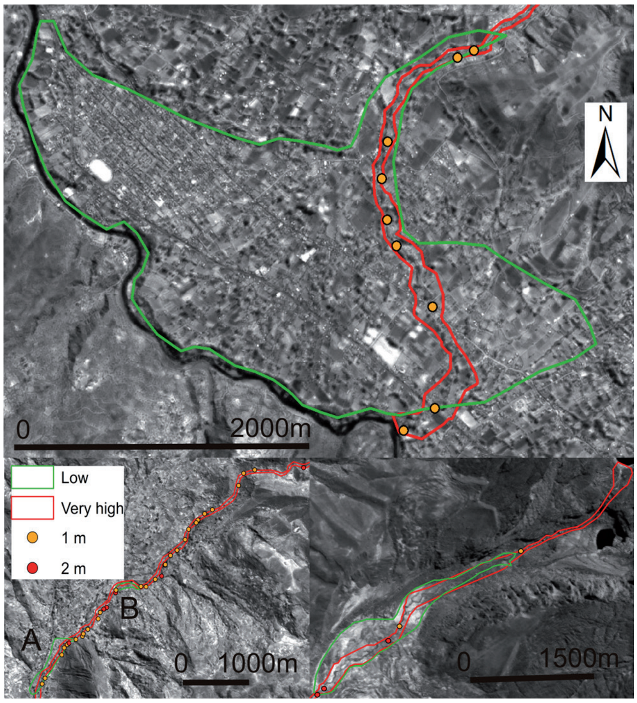

Fig. 3 GLOF hazard map, red line – "very high" hazard and green line – "low" hazard classes, background image is 2010 SPOT View image. Dots show increase of the maximum flow depths (orange – 1 m, red – 2 m) comparing the 2010 GLOF event model and the flood model used to define the "very high" hazard class.

Fig. 4 Deeply incised and narrow riverbed in the middle part of the Chucchún River valley, view to the north-east.

Possible source of uncertainties in the landslide hazard mapping is identification of previous, already denudated landslide forms, which in the study area may be in addition masked by intensive agricultural use of the region. It is well recognized that landslides tend to occur on places affected by slope movements in the past. Thus failing to identify such recently non-active and masked landslide forms may lead to underestimation of the hazard. Expert based aggregation of smaller individual landslides into larger landslide hazard zones probably leads to the more pessimistic landslide hazard zoning, e.g. larger areas were included into higher hazard class. This may compensate the possible underestimation of the landslide occurrence as described above. We also think that the more pessimistic hazard zoning is appropriate considering the possible seismic events, which may trigger much more abundant landslides compare to "regular" climatically governed triggering conditions which were probably responsible for occurrence of the majority of the studied landslides.

The expert based landslide hazard zonation approach was selected due to the lack of detailed and reliable preparatory factor maps covering the entire study region. The available geological information is based on the relatively large scale (1 : 100,000) maps. Lithological or structural information gained during the field works is available in great detail only for limited portion of the study area situated along the stream and thus is not suitable for regional landslide hazard zonation. On the other hand, the basic input information for the GLOF modeling was obtained from detailed field topographic surveys providing high resolution and reliable input information. Therefore combining results of GLOF model based on detailed field data with landslide hazard zonation prepared using large scale input maps would result in high spatial uncertainties. To avoid these additional drawbacks of the hazard assessment, we decided to perform subjective hazard zonation based on landslide inventory mapping done over equally distributed and high resolution satellite images available on GoogleEarth.

Note the similarities between the presented GLOF hazard assessment and results of Schneider et al. (2014) based on RAMMS and IBER models of the complex chain of processes leading to the GLOFs. The "very high" hazard zones defined in both studies are almost identical.

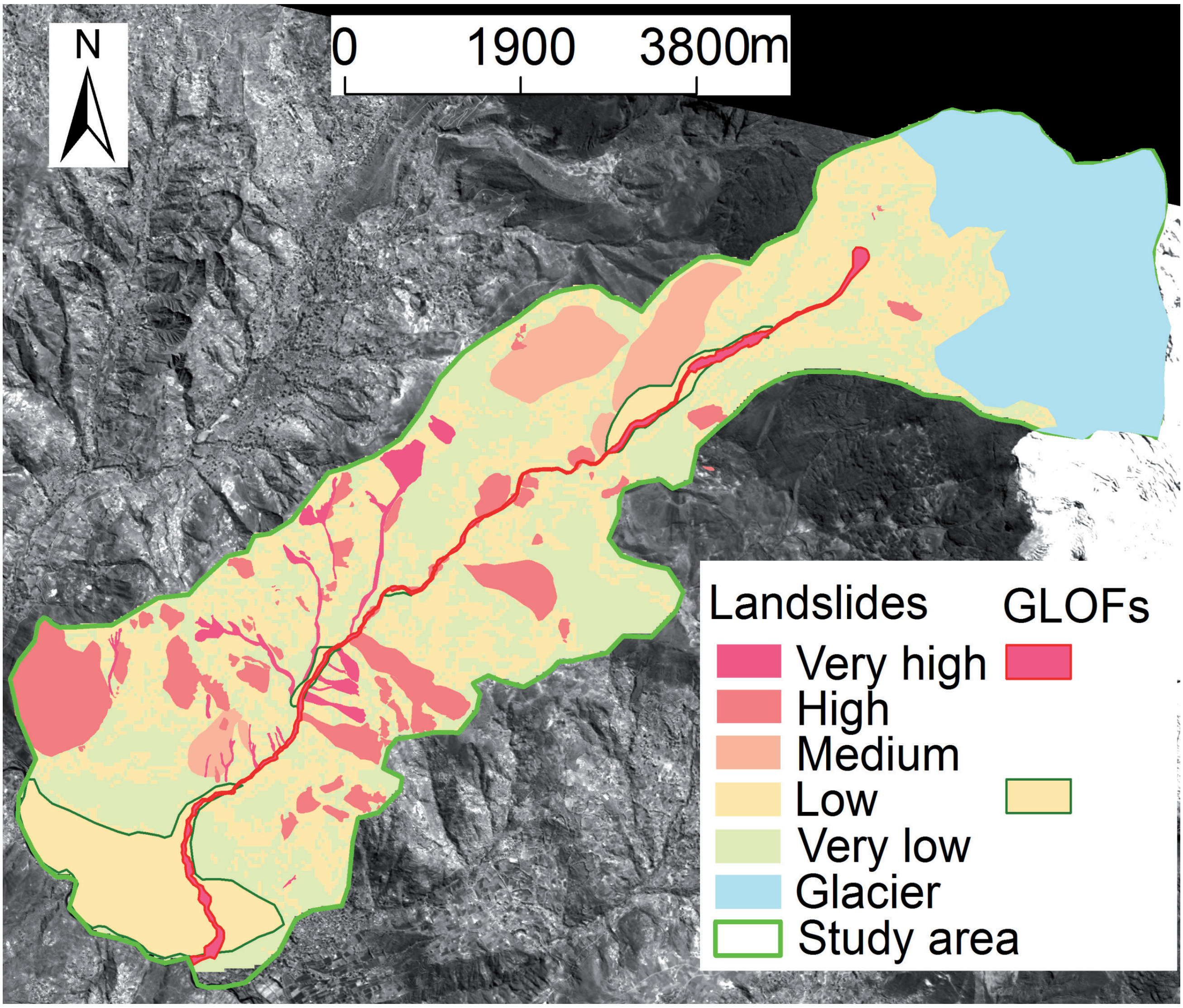

Fig. 5 Multi-hazard map for the Chucchún basin, background image is 2010 SPOT View image.

Also the "low" GLOF hazard class on Fig. 4 is almost identical with "residual" and "low" hazard class in Schneider et al. (2014) with the only significant difference on the steep rock slope just below the Lake 513. The similarities between GLOF hazard zonation could be consider as validation of the results encouraging their practical applications in GLOF risk management at the local level. This is very difficult and sensitive process, but in the case of the Chucchún basin the ongoing development project "Proyecto Glaciares" funded by Swiss Agency for Development and Cooperation provides all necessary conditions for successful application of the scientific results into the practical use.

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REFERENCES

CAREY, M., HUGGEL, C., BURY, J., PORTOCARRERO, C., HAEBERLI, W. (2012): An integrated socio-environmental framework for climate change adaptation and glacier hazard management: Lessons from Lake 513, Cordillera Blanca, Peru, Climatic Change 112, 733–767. http://dx.doi.org/10.1007/s10584-011-0249-8

CASTILLO, L. N., FÍDEL, S. L., JACKSON, L. E. (2006): Modelado de flujos de lodo usando Flow-2D en la quebrada Paihua: impacto en la ciudad de Matucana, Lima. XIII Congreso Peruano de Geología, 17-20.10.2006, Resúmenes Extendidos, Sociedad Geológica del Perú, 92–95.

EMMER, A., VILÍMEK, V., KLIMEŠ, J., COCHACHIN, A. (2014): Glacier retreat, lakes delevolment and associated natural hazards in Cordilera Blanca, Peru. In: Shan W, Guo Y, Wang F, Marui H, Strom A (eds.): Landslides in Cold

Regions in the Context of Climate Change. http://dx.doi.org/10.1007/978-3-319-00867-7_17
EVANS, S. G., BISHOP, N. F., SMOLL, L. F., MURILLO, P. V., DELANEY, K. B., AND OLIVER-SMITH, A. (2009): A re-examination of the mechanism and human impact of catastrophic mass flows originating on Nevado Huascarán, Cordillera Blanca, Peru in 1962 and 1970. Eng Geol 108, 96–118. http://dx.doi.org/10.1016/j.enggeo.2009.06.020
FIDEL, L., ZAVALA, B., NÚŇEZ, S., VALENZUELA, G. (2006): Estudio de Riesgos Geológicos del Perú. Franja 4. INGEMMET, Serie C. Geodinámica e Ingeniería Geológica 29, 386 pp.
HAEBERLI, W. (2013): Mountain permafrost – research frontiers and a special long-term change. Cold Region Science and Technology 96, 71–76. http://dx.doi.org/10.1016/j.coldregions.2013.02.004.
HERMANNS, R. L., DEHLS, J. F., GUZMÁNN, M. A., ROBERTS, N., CLAGUE, J. J., CAZAS SAAVEDRA, A., QUENTQ QUISPE, G. (2012): Relation of recent megalandslides to prehistoric events in the city of La Paz, Bolivia. In: EBERHARDT, E., FROESE, C., TURNER, A. K., LEROUEIL, S. (Eds.) Landslides and engineered slopes: Protecting society through improved understanding, Taylor and Francis Group, London, 265–271.
HOLM, K., BOVIS, M., JAKOB, M. (2004): The landslide response of alpine basins to post-Little Ice Age glacial thinning and retreat in southwestern British Columbia. Geomorphology 57, 201–216. http://dx.doi.org/10.1016/S0169-555X(03)00103-X
HUBBARD, B., HEALD, A., REYNOLDS, J. M., QUINCEY, D., RICHARDSON, S. D., ZAPATA-LUYO, M., SANTILLAN-PORTILLA, N., HAMBREY, M. J. (2005): Impact of a rock avalanche on a moraine-dammed proglacial lake: Laguna Safuna Alta, Cordillera Blanca, Peru. Earth Surf Process Landf 30, 1251–1264. http://dx.doi.org/10.1002/esp.1198
HUGGEL, C. (2009): Recent extreme slope failures in glacial environments: effects of thermal perturbation. Quaternary Sci Rev 28, 1119–1130. http://dx.doi.org/10.1016/j.quascirev.2008.06.007
KLIMEŠ, J. (2008): Use of the deterministic approach for the landslide susceptibility mapping, vsetínské vrchy highland, Czechia (in Czech). Geografie – sborník ČGS 113, 48–60.
KLIMEŠ, J., VILÍMEK, V., OMELKA, M. (2009): Implications of geomorphological research for recent and prehistoric avalanches and related hazards at Huascaran, Peru. Nat Hazards 50, 193–209. http://dx.doi.org/10.1007/s11069-008-9330-7
KLIMEŠ, J., VILÍMEK, V. (2011): A catastrophic landslide near Rampac Grande in the Cordillera Negra, northern Peru. Landslides 8, 309–320. http://dx.doi.org/10.1007/s10346-010-0249-1
KLIMEŠ, J., BLAHŮT, J. (2012): Landslide risk analysis and its application in regional planning: an example from the highlands of the Outer Western Carpathians, Czech Republic. Nat Hazards 64, 1779-1803. http://dx.doi.org/10.1007/s11069-012-0339-6
KLIMEŠ, J. (2013): Landslide temporal analysis and susceptibility assessment as bases for landslide mitigation, Machu Picchu, Peru. Environ Earth Sci 70, 913–925. http://dx.doi.org/10.1007/s12665-012-2181-2
KLIMEŠ, J., BENEŠOVÁ, M., VILÍMEK, V., BOUŠKA, P., RAPRE, A. C. (2014): The reconstruction of a glacial lake outburst flood using HEC-RAS and its significance for future hazard assessments: an example from Lake 513 in the Cordillera Blanca, Peru. Nat Hazards 71, 1617–1638. http://dx.doi.org/10.1007/s11069-013-0968-4
KOJAN, J., HUTCHINSON, J. N. (1978): Mayunmarca rocks slide and debris flow, Peru. In: VOIGHT B (ED.), Rockslides and Avalanches: 1. Natural Phenomena. Elsevier, Amsterdam, 315–361. http://dx.doi.org/10.1016/B978-0-444-41507-3.50017-9
PLAFKER, G., ERICKSEN, G. E., CONCHA, J. F. (1971): Geological aspects of the May 31, 1970, Perú earthquake. Bulletin of the Seismological Society of America 61, 543–578.
RABATEL, A., FRANCOU, B., SORUCO, A., GOMEZ, J., C'ACERES, B., CEBALLOS, J. L., BASANTES, R., VUILLE, M., SICART, J. E., HUGGEL, C., SCHEEL, M., LEJEUNE, Y., ARNAUD, Y., COLLET, M., CONDOM, T., CONSOLI, G., FAVIER, V., JOMELLI, V., GALARRAGA, R., GINOT, P., MAISINCHO, L., MENDOZA, J., MENEGOZ, M., RAMIREZ, E., RIBSTEIN, P., SUAREZ, W., VILLACIS, M., WAGNON, P. (2013). Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. The Cryosphere 7, 81–102. http://dx.doi.org/10.5194/tc-7-81-2013
SCHNEIDER, D., HUGGEL1, C., COCHACHIN, A., GUILLÉN, S., GARCÍA, J. (2014): Mapping hazards from glacier lake outburst floods based on modelling of process cascades at Lake 513, Carhuaz, Peru. Adv Geosci 35, 145–155. http://dx.doi.org/10.5194/adgeo-35-145-2014
VALDERRAMA, M. P., VILCA, O. (2010): Dinámica del aluvión de la Laguna 513, Cordillera Blanca, Ancash Perú: primeros alcances. Congreso Peruano de Geología, Cusco, 27 September – 1 October 2010. Extended abstracts, Sociedad Geológica del Perú, Lima, 336–341.
VALDERRAMA, M. P., CÁDENAS, J., CARLOTTO, V. (2007): Simulación FLOW 2D en las ciudades Urubamba y Ollantantambo, Cusco. Sociedad Geológica del Perú, Boletín 102, 43–62.
VILÍMEK, V., ZAPATA, M. L., STEMBERK, J. (2000): Slope movements in Callejón de Huaylas, Peru. AUC Geographica 35, Supplementum, 39–51.
VILÍMEK, V., ZAPATA, M. L., KLIMEŠ, J., PATZELT, Z., SANTILLÁN, N. (2005): Influence of glacial retreat on natural hazards of the Palcacocha Lake area, Peru. Landslides 2, 107–115. http://dx.doi.org/10.1007/s10346-005-0052-6
VILÍMEK, V., HANZLÍK, J., SLÁDEK, I., ŠANDOVÁ, M., SANTILLÁN, N. (2012): The share of landslides in the occurrence of natural hazards and the signifance of El Niño in the Cordillera Blanca and Cordillera Negra Mountains, Peru.
VILÍMEK, V., KLIMEŠ, J., EMMER, A., BENEŠOVÁ, M. (2014): Geomorphologic impacts of the glacial lake outburst flood from Lake 513 (Peru). Environmental Earth Sciences. http://dx.doi.org/10.1007/s12665-014-3768-6
ZAVALA, B.,VALDERRAMA, P., LUQUE, G., BARRANTES, R. (2009): Riesgos geológicos en la regiónAncash. INGEMMET, Boletín, Serie C: Geodinámica e Ingeniería Geológica 38, 280 pp.

RESUMÉ

Nebezpečí vzniku povodní z ledovcových jezer a sesuvů v povodí řeky Chucchún, Cordillera Blanca, Peru

Pohoří Cordillera Blanca leží ve středním Peru a je součástí kontinentálního rozvodí mezi Atlantským a Tichým oceánem. Pohoří je budováno převážně granodiority a tonality třetihorního stáří, které na jeho úpatí v údolí řeky Santy přecházejí do druhohorních sedimentárních a vulkanických hornin. Ty bývají často překryty čtvrtohorními glaciálními a fluvioglaciálními sedimenty. Pohoří je na západě vymezeno výrazným normálovým zlomem. Studované povodí řeky Chucchún je pravým přítokem řeky Santy. V jeho

horní části se nacházejí ledovce a tři ledovcová jezera. V roce 2010 se pod vrcholem Hualcán (6125 m n. m.) uvolnila lavina ledu a sněhu, která zasáhla jezero 513. Došlo k přelití vody přes skalní práh tvořící hráz a vznikla povodeň, která zničila několik domů a mostů v údolí. Tato relativně malá povodeň vyvolala velké obavy místních obyvatel, a proto byly zahájeny práce k vytvoření mapy nebezpečí pro možné budoucí povodně. Vzhledem k tomu, že pohoří Cordillera Blanca i údolí řeky Santy jsou silně náchylné ke vzniku různých forem svahových pohybů, byla vytvořena také mapa nebezpečí pro tyto jevy.

Mapa nebezpečí pro povodně je vytvořena na základě modelování rozlivů povodní s různým maximálním průtokem. Výpočty byly provedeny v programu HEC-RAS na základě topografických profilů zaměřených přímo v terénu. Vzhledem k velmi omezeným historickým informacím o vzniku povodní z ledovcových jezer, byly velikosti povodní stanoveny na základě události z roku 2010. Během této povodně byl modelovaný maximální průtok 580 $m^3 s^{-1}$. Předpokládáme, že povodně podobné velikosti jsou v daném území nejčastější. Proto rozliv této povodně definuje vysoký hazard. Povodeň dosahující maximální úrovně hladiny o 1 m vyšší než povodeň z roku 2010 a s průtokem 965 $m^3 s^{-1}$ definuje oblast středního nebezpečí z povodní.

Mapa nebezpečí vzniku sesuvů byla vytvořena na základě inventarizace sesuvů s pomocí dostupných snímků GoogleEarth s vysokým rozlišením. K vymapovaným svahovým deformacím byly na základě zkušeností ze studované oblasti a morfologických poměrů, dokresleny oblasti předpokládaného nejzazšího dosahu jednotlivých svahových deformací. Nejvyšší stupeň nebezpečí byl přiřazen k přívalovým proudům, které v širší studované oblasti vznikají nejčastěji. Střední nebezpečí bylo přiděleno k sesuvům a nejmenší nebezpečí představují hluboké svahové deformace. Mapy nebezpečí vzniku sesuvů a povodní byly zkombinovány, aby daly lepší přehled o přírodních nebezpečích ve studovaném povodí.

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LINGUISTIC INTEGRATION OF MIDDLE SCHOOL IMMIGRANT CHILDREN IN CZECHIA

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ABSTRACT

Acquiring the language of the host country is an important factor that influences the process of integration of immigrants into society. For the children of immigrants, proficiency in the official language of their new country is crucial for their success and their smooth integration into the education system and the wider community. This article analyses Czech language proficiency of immigrant children enrolled in middle school[1] in Czechia and seeks to examine how their language skills develop over time and what factors impact the process of Czech language acquisition. The authors created a special diagnostic instrument to test students' communicative competence. Subsequently, they used it in a pilot study they carried out on a sample of immigrant children enrolled in selected middle schools in Prague. The findings of this pilot study confirmed that the linguistic distance between Czech and the students' mother tongue had a significant influence on how and how quickly they mastered the Czech language.

Keywords: integration, children of immigrants, language acquisition, diagnostic test

1. Introduction

Integration of immigrants into host societies has always been an issue for both policy makers and scientists in countries with a long history of immigration like the USA (Bernard 1967). However, it also became an important issue in the Western Europe of several decades past, because if we use Heckmann and Schnapper (2003) words, the "illusion of temporary migration has disappeared" (p. 9). Czechia has been for a long time rather a country of emigration, while in direct relation to changes after 1989, the country experienced transition from an emigration to immigration country (Drbohlav 2011). Thus, the country had to adjust its institutions and policies to this changed situation in a relative short time span (Drbohlav et al. 2010) in order to deal with the problem of integration. As Berry (2002a) has pointed out, it has been believed for a long time that immigration in general can lead to both psychological and social problems of immigrants in the host country. Nowadays, he claims, it is widely believed that the outcome of immigration is very much individual: while some of the immigrants adapt to the new situation very well, others may experience deep problems. In reality, factors on both the group and individual levels (Berry 2002b) come into play. They create a unique mix of conditions for each individual immigrant that is either conducive or unconducive to success. Such a situation directly calls for research that can shed light on these various factors and their interplay of which can under different conditions either aid in the successful integration of immigrants or make it more difficult.

Various factors and their influence on the process of integration of immigrants into host societies have been already studied in a great detail. Researched factors are various: the long list includes structural changes in economy (Bevelander 2000), institutional setting and migration policies (Heckmann, Schnapper 2003), social capital (Tillie 2004), legal system (Carens 2005), interplay between origin, destination and community effects (Van Tubergen, Maas, Flap 2004), religion (Foner, Alba 2008), cognitive skills (Suarez-Orozco 2007), adaptation strategy chosen by immigrants (Berry 2002b) or language acquisition (Chiswick, Miller 2001). Some of the factors underlying the reasons for immigration have already been studied in Czechia as well. Drbohlav (2011) summarized several key findings from the empirical research on immigration integration in Czechia that has been achieved so far. He namely emphasized the role of ethnicity and the citizenship of immigrants (Drbohlav, Dzúrová 2007), the assimilation strategy (Drbohlav, Dzúrová, Černík 2007), and the interplay of such factors influencing the integration of immigrants. Janská et al. (2007), using the model of a case study, studied in one *middle school* on the outskirts of Prague the role of language acquisition, familial relations and role involvement during the process of integration of Vietnamese children within their own ethnic community.

The aim of this article is to contribute to the analyses of factors that influence the integration of immigrants in Czechia by studying the process of language acquisition and its interplay with other factors like gender, ethnicity or exposure to the Czech language. We conducted a case

[1] In the Czech environment this mean pupils from 6th grade to 9th grade, i.e twelve to fifteen year old pupils.

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study with immigrants who enrolled in *middle schools* in Prague, and primarily devoted attention to Czech language acquisition. Furthermore, we used our own diagnostic test (Kostelecká et al. 2013). For the first time in Czechia, we were able to receive not only more detailed information on language acquisition by school-aged immigrants, but also to gather more reliable information than that based off of the evaluation of language acquisition by the immigrants themselves.

2. Immigrants at Czech *middle schools* and their integration

After 1989 as increasing numbers of immigrants moved to the country, Czech schools experienced a notable increase in the number of pupils whose first language was a language other than Czech. After the country joined the European Union, there was a particularly sharp rise in the number of immigrants. While in 1985 there were just 37,000 foreign nationals dwelling on the territory of Czechia, a figure equal to approximately 0.36% of the total population, in 2008 the Ministry of the Interior registered a record number of 437,000 foreign nationals, practically a twelvefold increase over that period (ČSÚ, Cizinci v ČR – monthly basic data) and equating to more than 4% of the total population. Although the economic recession which began in 2008 reduced the attractiveness of the Czechia for immigrants, the number of registered foreigners remained basically unchanged (ČSÚ, 2014). Drbohlav, Dzúrová and Černík (2007) analysed in detail the available statistical information about foreigners enrolled in elementary and middle school in the early 2000s, showed that the number of immigrant students grew similarly quickly. During the school year 2002–2003, 3,592 foreigners were enrolled in preschools, 12,770 in elementary and middle schools, and 3,592 in high schools (p. 164). Data from school statistics shows that despite the economic crisis the number of immigrant students grew at every level of the educational system between 2003 and 2011. During the 2010–2011 school year, there were 4,223 children of immigrants in preschool facilities in Czechia or 1.4% of the total number of children in institutions of this type; there were 14,109 children of immigrants enrolled in elementary and middle schools, making up 1.7% of all elementary and middle school students; there were 9,020 children of immigrants at high schools, or 1.5% of all students at this level (Statistická ročenka školství 2010/11). There were 37,688 foreign students in Czech post-secondary institutions (10.2% of all students at this level); however post-secondary students are a specific group due to a very selective enrolment process whereas only those applicants that fulfil the requirements of the given school, including language proficiency, are admitted. Many programmes at the post-secondary level are moreover taught not in Czech but in another major language. Ukrainians, Vietnamese, Slovaks, Russians and Chinese represent the largest immigrant minorities in the Czech educational system.

How education systems and teaching curriculum respond to the integrative needs of the children of immigrants and to the ethnic and cultural diversity of society has been the subject of studies in intercultural and multicultural education (e.g. Berry 1992b, 1997). Although immigration is a relatively new phenomenon in Czechia, a number of theoretical studies have already been conducted on the integration of children of immigrants into the educational system and the factors that can influence this process (e.g. Průcha 2007, 2010, 2011; Šindelářová 2005, 2008; Hájková, Strnadová 2010).

For our study, the article of Drbohlav, Dzúrová and Černík (2007) who analysed in detail how foreigners in elementary and *middle schools* integrate into schools and Czech society is of a special relevance. The abovementioned authors combined three main theoretical concepts of integration: Heckmann's (1999) concept of integration, which distinguishes and defines four types of integration: structural, cultural, social, and subjective forms of integration; Portes' segmented assimilation theory (2001); and Berry's concept of the adaptation strategy chosen by immigrants (1992b). Drbohlav, Dzúrová and Černík (2007) conducted an empirical study using a mixed quantitative-qualitative design to test a series of hypotheses regarding how integration proceeds and which factors influence the integration. They conducted a survey with 80 foreign students and 47 Czech students who served as a reference group. They found that the process of integration was very complex: factors that influence the success of integration were various and included psychological, economic and factors related to identification and self-identification as well. They discovered that the level of integration as well as the level of life satisfaction of immigrant students depends on cultural background. Moreover, it was shown that the integration of Asians was influenced by a different set of factors than the integration of students of Slavic origin. The authors explicitly mentioned cultural and language similarity/distance as an important factor.

Similarly, a series of empirical studies published to date and based on research conducted in schools (e.g. Kocourek 2001, 2002; Kostelecká et al. 2010, 2011, 2012, 2013) found that a key factor for the successful integration of students is proficiency in the Czech language. Although many immigrant students master basic communicative skills in the Czech language relatively quickly after arriving to Czechia (they have what Cummins (1979) calls 'basic interpersonal communicative skills'), it is not at a proficiency level that enables them to cope with the educational demands placed on them at school since that would require what Cummins calls a higher 'cognitive/academic language proficiency' (ibid.).

It has previously been shown that those foreigners enrolled in *middle schools* in Czechia with a low level of Czech language proficiency tend to have difficulties at school and not just with their Czech lessons, but also with many other subjects (Kostelecká et al. 2013). Not only does this significantly reduce their chances of obtaining a good education, but they may also suffer feelings of social isolation and be ostracised by others. This can have a negative effect on their self-identity and trust in others. These students are in a difficult situation, because the Czech education system has had little practical experience over the years with pupils and students speaking Czech as a second language (Janská et al. 2011).

In countries with a long history of immigration, many studies have been conducted on the linguistic integration of adults from minorities into society. The linguistic aspects of integration into American society have been studied, for instance, by Espenshade and Fu (1997); Beenstock (1996) examined the linguistic integration of immigrants in Israel; and Van Tubergen and Kalmijn (2008) focused their research on immigrants in the Netherlands. Empirical studies conducted outside of Czechia have demonstrated a clear link between the proficiency of adult immigrants in the official language of a society and their overall success in the labour market (Böhlmark 2009) which is connected to their level of earnings (McManus 1985).

However, there are comparatively far fewer studies on the educational integration of children. One of the problems that scholars interested in researching this issue encounter is the lack of data on the level of the language skills of children in primary and *middle schools* in relation to other personal characteristics. While in some countries (e.g., United States or France) standardised tests of children's language skills are used to measure the proficiency of school-age children in the dominant language of the country, the results of such tests are intended mainly to benefit children and their teachers and are not usually used for any other purpose. Hence, no other information on the children or their family background is gathered during testing.

Even when empirically exploring proficiency of adult immigrants in the dominant language, authors of studies rarely use standardised diagnostic tests for measuring skill levels but rather rely either on observations and evaluations of the researcher (Li 2007) or, more commonly, on the self-ratings of the research subjects (Bachman, Palmer 1989, 2009; Redstone Akresh 2007; Ender and Straßl 2009; Cort 2010). It is somewhat rare to find the results of standardised language tests being used for this purpose (Bang et al. 2009).

Czech language acquisition among immigrant children in schools in Czechia has not yet been the subject of systematic research. The main reason for this is that the country has no official tests to measure Czech language proficiency among students whose mother tongue is not Czech. Because there are no such standardised diagnostic tests and nor even any self-reported information on Czech language skills (rare exceptions are the work of Drbohlav et al. 2005 and Janská et al. 2011), we cannot objectively quantify the amount of progress such students make over the course of a year or evaluate whether linguistic integration is, for example, more difficult for one ethnic minority than another. Nor can we determine how large the language barrier these students face is, or how many of these children – and in what areas – reach the 'threshold level' of communicative competence. A threshold level is reached when a student acquires the minimum level of linguistic skills necessary to function as an independent user (Šára et al. 2001; Cvejnová 2006, 2007; Šindelářová 2010). Under the Common European Framework of Reference for Languages the B1 level of language proficiency is considered to be the threshold.

This article aims to present selected results of a research project that sought to overcome the limitations of exploring this subject due to a lack of any standardised tests. In the scope of our project, a special diagnostic instrument was developed for the purpose of measuring the Czech language skills of immigrant children attending Czech *middle schools*, and that instrument was then tested in a pilot study at selected schools in Prague (the details of this study are presented in Kostelecká et al. 2013; Vodičková 2014; Vodičková, Kostelecká 2014). An analysis of the data produced in this study made it possible to describe the process of Czech language acquisition by the children of immigrants, as well as identify some of the factors that interact with language acquisition and influence the acquisition process. Below, we will first briefly introduce the testing instrument that was used and then provide information about the students who were tested. The core part of this paper contains an analysis of the results of the language tests and how they relate to certain explanatory factors.

3. The language skills of the children of immigrants – a pilot study

3.1 Research methodology

Since there is no standardised test in Czechia that could be appropriately used to measure the level of communicative competence of pupils who speak Czech as a second language, we created such a test ourselves. To create this test we drew inspiration both from existing *Czech Language Diagnostic Tests for Adults* (Cvejnová 2007), as well as the *Czech Language Certificate Exam for Young Learners* (for details see http://ujop.cuni.cz/cce-mladez) and from internationally recognised tests like Cambridge English tests for young learners. We also took advantage of test development methods described in the methodological literature (for example Harrison 1983; Davies 1990; Smith 1995; Hasselgreen 2005; McKay 2006; Hughes 2007; Bachman, Palmer 2009; Vlasáková 2009). The diagnostic tests were developed in conformity with the Common European Framework of Reference for Languages and the European Language Portfolio for the respective groups, and (in conformity with) the recommendations of the international organisations for language testing: Association of Language Testers in Europe (ALTE) and European Association for Language Testing and Assessment (EALTA).

The individual tasks in the texts were designed bearing in mind that this was to be a test for young learners whose age, mental characteristics, and cognitive development must be taken into account when considering the length of the test, the selection of topics, the test techniques, the text types, the communicative situations, and the inclusion of visual aids for a test which started from the level of zero knowledge of the language up to the B1 level. This diagnostic instrument was designed to test the four language skills: reading, listening, writing, and speaking. We were unable to assess the language skill levels of children in their mother tongue, while some experts (Abdelilah-Bauer 2008; Kielhöffer, Jonekeit 2006) note that the ability to read and write in the mother tongue may positively influence the acquisition of these skills in another language; this task would have gone well beyond the scope of our research project.

The diagnostic test was developed in three consecutive steps. In the first step, we developed the test specifications (which describe the constructs of the skills tested, the intended population, the format of the test, etc.), assessment criteria, and created a first draft of the test which consisted of four subtests: Reading, Listening, Writing, and Speaking. Additionally, guidelines for the examiners were developed. The first version of the test was then submitted for review to professional reviewers. In the second step, the test was revised based on the recommendations of the reviewers, and then was submitted to a pre-testing process. Based on the results of the pre-tests, the test was revised again in order to arrive at a final version intended for testing in schools. Throughout this process great care was devoted to amending the test specifications to accurately reflect proficiency; these specifications were not only an important guideline for designing, revising, and assessing the test, but also served as an important source of information for the professional public as to who should be tested (characteristics of the target group for whom the test was intended), what should be tested, and how the testing should be carried out.

As a measurement of internal consistency of the test, the alpha coefficient ($\alpha = 0.96$, see Cronbach 1951) and split-half reliability (0.91) coefficient were computed (Kuder, Richardson 1937). The alpha coefficient is higher than 0.9 equating to proof of excellent (High-Stakes) testing. The alpha coefficient is also higher than the split-half reliabilities, which again demonstrates that this test is reliable. The quality of the test is also confirmed by the very high score in the Spearman-Brown Prophecy test (0.95). We used descriptive analysis (Horn 1993) for the description of the language test results and correlation analysis for the measurement of the relationships between language test results and selected indicators.

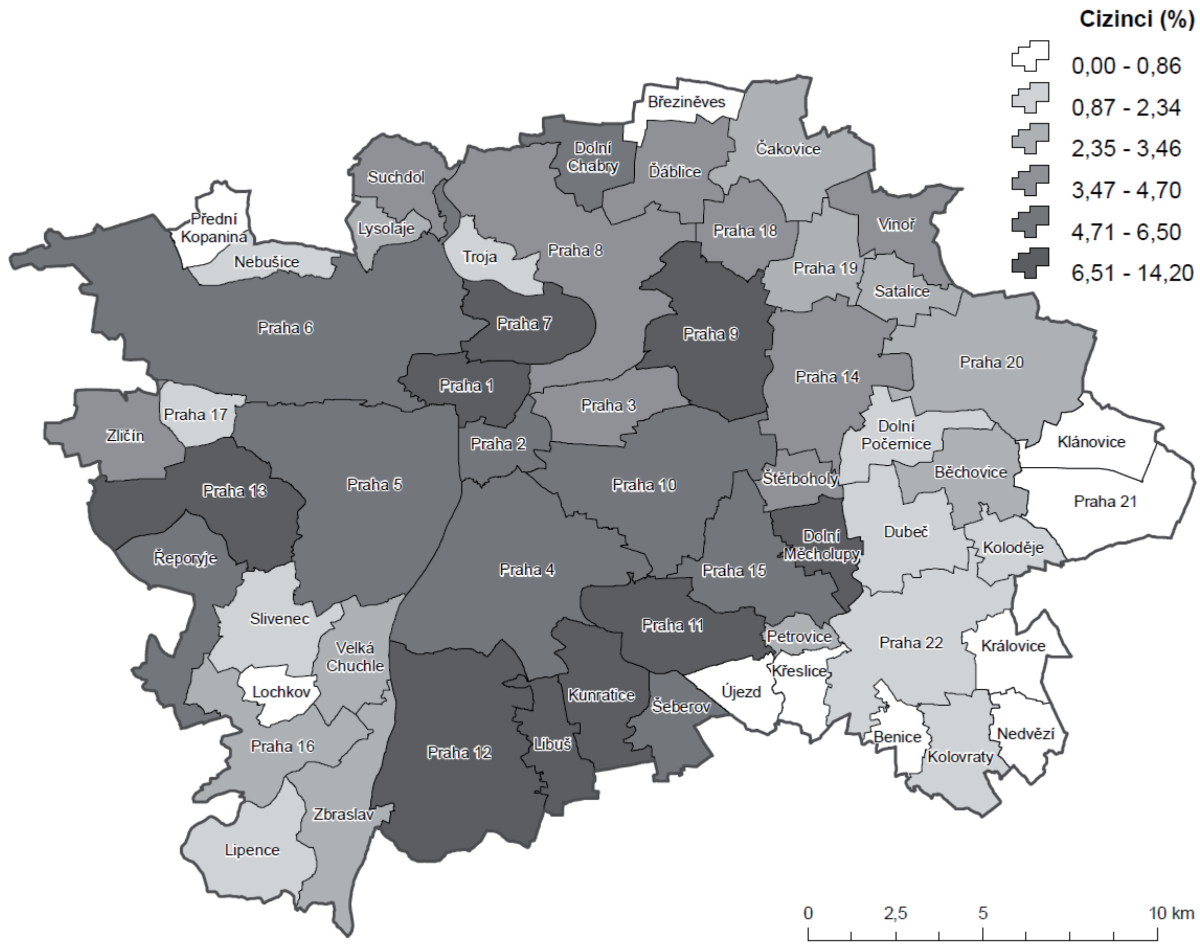
The diagnostic test was employed during a pilot study in 2010 on a sample of 153 children at selected *middle schools* in Prague. We deliberately selected schools with a larger percentage of children of immigrants making up the student body. We submitted a request for cooperation with schools in different areas within the city of Prague that have the largest shares of immigrant minorities (Ukrainians, Russians, Vietnamese, and Chinese) and where we predicted to find linguistic integration to be an issue. Given the strong similarities between the Czech and Slovak languages allowing people from a Slovak background to integrate without any difficulty into Czech society, we did not include Slovak students in our tests. The chosen schools were quite diverse in other respects, differing in size, their location within Prague, and their peripheral or central location within the city (see Map 1). Eight of the selected schools agreed to allow testing of the target group on the condition that each individual tested obtain prior written consent from his or her parents. On the agreed test date, three to four experienced testing specialists conducted an on-site visit to the individual schools in order to perform the testing exercise. All children of immigrants that were present at school on the day of the testing and whose parents agreed on their children's participation in the diagnostic testing were tested.

First, all pupils were subjected to three subtests at the basic A1 level: the subtests were in reading, listening, writing, and speaking. The group of tested students was given approximately 30 minutes to complete the A1 level test. After a break of 10 to 15 minutes, the students proceeded to complete subtests in reading, listening, and writing at the A2 level, which again took a total of approximately 30 minutes. After a second break, students were given approximately 50 minutes to complete reading, listening, and writing subtests at the B1 level. Finally, students' oral skills were tested, wherein each student spoke with an examiner face to face for about ten minutes. Each student's performance was then evaluated.

3.2 The number of tested students and the age and ethnic structure of the sample

A total of 153 children enrolled at the selected *middle schools* in Prague were given the test; the number of students tested at each school ranged from 8 to 38. The average age of the tested students was 13 years. The youngest child tested was 10 years old, while the oldest was 17 years old. The largest age group was of 14-year-olds.

There were considerable differences between schools in terms of the cultural background of the students tested and the students' mother tongues. For example, at one school more than half of the students tested were Chinese, at four other schools there were no Chinese students, and each of the remaining three had just one or two Chinese students. There were also large concentrations of Russians and Vietnamese at certain schools: one-third of the total



Map 1 Percentages of foreigners among primary school pupils according to city parts Prague and the location of schools involved in research (school year 2008/2009).
Source: Map based on data of Ministry of Education

number of children tested from these ethnic groups were students at one school. Ukrainians made up the largest group in the sample of tested children. The proportion they represented among the tested students was smaller than the actual proportion of Ukrainian students enrolled at primary and *middle schools* in Prague. Ukrainian children make up one-third of all non-Czech children at elementary and *middle schools* in Prague (Kostelecká et al. 2013). In our sample, however, they accounted for just around 20% of the students.

One of the things we ascertained during the testing was how long the students had resided in Czechia. There were major differences in the length of time students had been in the country. In some schools, more than half of the students tested had resided in the country for only a short period – 0 to 2 years. By contrast, at two schools only a small minority of the students tested – less than 10% – were relatively recent immigrants. Similarly, there were differences in the proportion of students who had been living in Czechia for at least 7 years: ranging from 11% to 75% of the students tested at any given school. The average length of time the students in the test had resided in Czechia ranged from 3.4 to 8.6 years.

3.3 The test results

The maximum score that a student could obtain with a perfect performance in each of the subtests area was 30 points (10 points for each of the three levels of difficulty tested). A perfect performance in all four skill areas at all three language levels would produce a maximum test score of 120 points. The actual total scores ranged from 0 to 118 points, with an average score of 92.5 points and a median score of 101.0 points. With each higher level of language skill difficulty, the students' test score averages deteriorated. The average total score for all three tests differed considerably between schools, ranging from 77.3 to 104.9 points. A clear link was observed between the results of the diagnostic tests at different schools and the length of time students had resided in Czechia: The schools whose students scored lowest were also the schools that had the largest share of children who had resided in Czechia for just a short time. Conversely, the schools whose students scored highest had the smallest proportion of children who had resided in Czechia for a short period. The tests also revealed that the children generally had more difficulty with productive skills (speaking and writing) than receptive skills (reading and listening comprehension). On average, students scored lowest on the test of written expression (21.3 points out of 30). By contrast, they scored best on average on the reading comprehension test (24.7 points).

The differences observed between schools could theoretically have been due to variations in the quality of teaching (or to the different methods schools employ to teach the children of immigrants), matters on which we have no quantifiable information; but they could also simply reflect differences in the structure of children of immigrants at individual schools. We therefore proceeded in the next step to analyse available selected individual characteristics of the tested children and how they might relate to the test results.

3.4 Factors influencing students' test results – sex, length of residence in Czechia, cultural background

In the literature on the linguistic integration of immigrants, there are numerous hypotheses as to the effect of different factors on their success in the acquisition of the official language of the destination country. Chiswick and Miller (2001) formulated a general theory of language acquisition by immigrants in the destination country (referred to as the 'destination-language acquisition framework'), in which they identify the main factors of progress in language acquisition to be 'exposure' to the acquired language, 'efficiency' in language acquisition, and the 'impact of economic incentives.' The foundation of successful linguistic integration is spending time in an environment where the destination language is used. The more time immigrants are exposed to the destination language, the faster the acquisition process. Exposure to the destination language increases the longer an immigrant resides in the destination country (Thomas 2010), while acquisition is also contingent on a number of other factors, such as opportunities for contact with the destination language prior to immigration, and in the case of children, whether or not they obtain their preschool education in the destination country, attend school regularly, and are involved in extracurricular activities in the destination country (Iddings 2009). Another important factor in a child's exposure to the destination language is family, in particular the language of communication used in the family (Dustmann 1997; Li 2007), the number of siblings who are able to speak the destination language (Thomas 2010), as well as the informal environment the child spends time in (Chiswick, Miller 2001; Asgari, Mustapha 2011).

Even with the same exposure to the destination language, the pace of destination-language acquisition still varies between immigrants because the efficiency of the acquisition process also varies. According to Chiswick and Miller (2001), the efficiency of language acquisition is primarily influenced by the age at which an immigrant moves to the destination country, his/her education, and the distance between the immigrant's mother tongue and the destination language (see also Beenstock et al. 2001). Many empirical studies have shown that the younger an immigrant is at the time of migration, the faster the language acquisition process (Espenshade, Fu 1997; Stevens 1999; Böhlmark 2009). While it is not possible in the case of school-age children to speak of the effect of their education level on the speed at which they acquire the destination language, parental education has been demonstrated to have an effect (Li 2007; Cort 2010). Efficiency is also significantly influenced by the distance between the immigrant's mother tongue and the destination language: the greater the linguistic distance between them, the slower the process of language acquisition (Chiswick, Miller 2005). Hedbávná et al. (2009) make a similar argument in the case of Czechia.

We drew on the theory of Chiswick and Miller (2001) to consider what factors might influence the speed of Czech-language acquisition by the children of immigrants at elementary and *middle schools* in Czechia. To explain differences in the pace of linguistic integration of children of immigrants in Czechia, we therefore identified key factors to be the differences in their exposure to the Czech language and the differences of efficiency influencing the acquisition of Czech. Our analysis was somewhat impeded by a lack of sufficient data on the children we tested, as we only had a limited amount of information available to us. We knew only the children's age, sex, length of residence in Czechia, mother tongue, and cultural background. We did not have any information on their families, how they spent their free time, or on any of the children's other personal characteristics.

Therefore, we began by formulating three hypotheses. *Hypothesis 1* assumes that the process of language acquisition would be significantly influenced by gender. Many studies have shown over the long term that girls attain slightly better results in language skills, and this could also have an effect on the diagnostic test we conducted. *Hypothesis 2* assumes that a child's test results would be significantly influenced by how long he/she had been residing in Czechia. The longer a child has been in Czechia, the better his/her results. *Hypothesis 3* assumes that a child's test results would also be dependent on his/her cultural background, or more specifically, by the linguistic distance between the child's mother tongue and the Czech language. We assume that children from countries in which a Slavic language is spoken are able to learn the Czech language more quickly than children whose mother tongue is not a Slavic language.

We realise that the test results must also be influenced by a number of other factors. One obvious one is the intellectual skills of the children; other influences could relate to how they spend their free time, how many siblings they have, how many Czech-speaking friends they have, their socio-cultural position, the economic background of the child's family, and the education of his/her parents. However, it was beyond the scope of our research to undertake a measurement of the intellectual skills of the children or to gain information about their families, so we do not have information on these potential factors and therefore do not address them here.

3.4.1. The effect of sex on language acquisition

There were 79 boys and 74 girls who took part in the language skill tests. Sinke (1999) and Abu-Rabia (1997) have documented gender differences in regards to second-language acquisition; additionally Catalán (2003) has proven the better test results of girls. Therefore, we expected the girls to do better than the boys on the tests. To test whether the average scores of girls and boys were different, we used an analysis of variance (ANOVA procedure from the SPSS package of statistical programs). While the average total test score of the boys was 87.3 points (out of a possible total of 120 points), the average score of the girls was 98.1 points. The results of the analysis confirm a statistically significant difference (F = 8.53, sig. 0.004). Thus, our hypothesis was unequivocally confirmed.

In the next step we proceeded to examine whether the differences between the girls' and boys' test results were in some way related to their length of residence in Czechia. We found that the differences between boys and girls were not constant, but changed in relation to the length of time the children had been in Czechia. The biggest differences in the test results were apparent among children who had been in Czechia for just a short time. These differences diminished as length of residence increased meaning that minor differences were identified among students who had been in Czechia for at least seven years, whereas the differences between boys and girls were almost negligible (Figure 1).

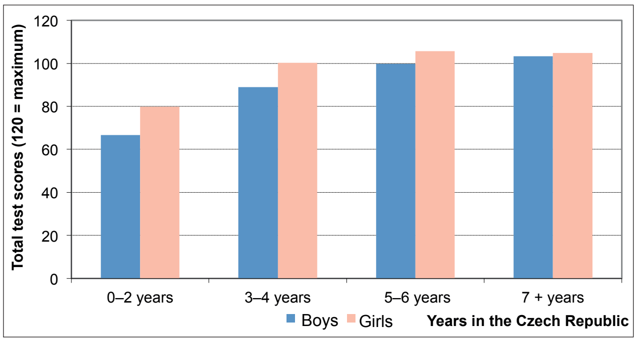


Fig. 1 Total test scores in relation to the children's sex and length of residence in Czechia.
Source: Authors' calculations based on their own data (Kostelecká et al. 2013).

We were also interested in whether the girls' test results were better in every skill area, or if girls or boys were stronger or weaker in any particular skill area. We found that the girls generally scored better in every skill area. The biggest differences in the performance of girls and boys were found in one of the productive skill areas: writing. Looking at how sex and length of residence in Czechia impacted the results of the diagnostic tests of language skill areas, again we found that the boys' and girls' test scores converged the longer they had resided in Czechia. Among the children who had been in Czechia for at least seven years, there were almost no differences between the scores of boys and girls in individual skill areas (Table 1).

Tab. 1 Average score in individual skill areas in relation to sex and length of residence in Czechia

No. of years in Czechia	Sex	Listening score	Reading score	Writing score	Speaking score
0–2 years	Boys	18.3	19.9	13.6	14.8
	Girls	22.9	21.8	18.2	16.9
3–4 years	Boys	23.9	24.1	18.9	21.9
	Girls	26.9	26.0	25.3	22.1
5–6 years	Boys	24.4	27.1	23.4	24.9
	Girls	25.6	27.3	25.3	28.1
7 or more years	Boys	27.0	26.8	24.8	26.0
	Girls	25.8	26.8	25.0	27.1

Source: Authors' calculations based on their own data

3.4.2. The effect of length of residence in Czechia on the children's test results

We attempted to verify the hypothesis that the length of residence in Czechia has a significant influence on the children's test scores. In the first stage, we looked at how much total test scores were correlated with the length of residence in Czechia. Figure 2 clearly shows a positive correlation between the children's test scores and their length of residence in Czechia. The longer the child had resided in Czechia, the higher the number of points attained on the test. This is not, however, a linear relation (Figure 2). The figure was created using the Curve Estimation procedure from the SPSS package of statistical programmes. This procedure plots a trend in a manner that as precisely as possible represents individual measurements in a single curve. Unlike the more common linear interpolation procedure, Curve Estimation can be used to plot a trend not just as a line but also as various mathematically defined curves. The testing revealed that the changes measured in the total test scores in relation to length of residence in Czechia are best captured in a graph of the logarithmic function $y = a + b \times \ln(x)$, where y is the estimated score in the test, x is the years of residence in Czechia, and variables 'a' and 'b' are the calculated parameters of the function (R Square = 0.45).

The results attained from the diagnostic test do not improve evenly with the increasing length of residence in Czechia. The children's test scores improve much more rapidly during a student's first years in Czechie as opposed to later on. This suggests that the most visible progress in Czech proficiency can generally be observed and expected among children during the first several years after they arrive to Czechia. Students who had been in the country for approximately two years obtained on average a total of 80 out of 120 points. Figure 2 also clearly shows that many of the tested children attained A1 level language skills very quickly after arriving to Czechia.

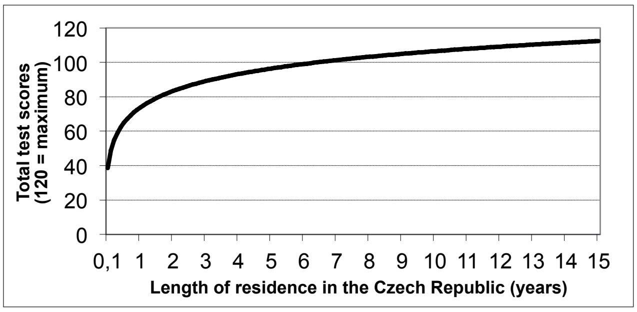


Fig. 2 Children's total test scores in relation to their length of residence in Czechia.
Source: Authors' calculations based on their own data (Kostelecká et al. 2013).

3.4.3. The effect of cultural background on test results

The initial hypothesis assumed that students from a Slavic-speaking language background would make faster progress with Czech proficiency than children whose mother tongue is not a Slavic language. Slavic languages have many similarities in grammar and vocabulary. We assumed that this would make comprehension much easier for Slavic-speaking children and give them an advantage over children from other language backgrounds. This assumption was confirmed. While children from a Chinese background attained an average of 70.2 points on the test and those from a Vietnamese background 85.1, Ukrainian-speaking children attained an average score of 99.7 and Russian-speaking children 101.8. The analysis of variance confirmed the statistical significance of such differences (F = 12.86, sig. 0.000). Figure 3 shows the total test scores in relation to length of residence and cultural background. Like in the preceding case, the Curve Estimation was again used. Here, however, it must be noted that the trends for individual ethnic groups were plotted from calculations based on a small number of cases. The results of these calculations are therefore subject to a greater sampling error. They are to be regarded simply as indicative results and the information on trends should be interpreted with caution.

Despite the methodological limitation of the method, it reveals significant differences in the development of language skills for different ethnic groups in relation to the length of residence in Czechia. Children who came to the country from Asia, particularly in the period immediately after their arrival to Czechia, had much lower proficiency levels in this period than children from Slavic-speaking countries. While Asian children had almost no Czech language skills after arriving to Czechia, the opposite was true for children of Slavic origin. They reached a high level of proficiency within the relatively short period of one to two years, while children of Asian origin needed seven to ten years. Although the level of Czech proficiency of children from different cultural backgrounds varied widely during the period immediately after arrival to Czechia, over time these differences decreased.

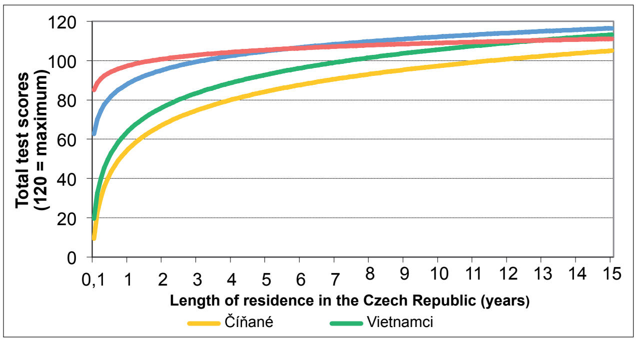


Fig. 3 Children's total test scores in relation to length of residence and cultural background.
Source: Authors' calculations based on their own data (Kostelecká et al. 2013).

4. Conclusion

Successful integration into society requires proficiency in the language of that society (see, for example, the study of Remennick (2003), which shows how language acquisition was the main vehicle of the successful social integration of Russian immigrants into Israeli society in the 1990s). The first step towards successful social integration is the integration of students into a country's education system. How proficient in the Czech language are the children of immigrants at Czech *middle schools*? This question is difficult to answer because there is no instrument in Czechia with which to objectively measure Czech language proficiency among the children of immigrants. This fact has led our research team to devise an instrument to test these language skills. In this research project, our researchers developed this diagnostic instrument and tested it in a pilot study on the children of immigrants at selected *middle schools*in Prague. The diagnostic test examined the proficiency level of children in four language skill areas: reading, listening, writing, and speaking.

The children who were tested came from both large and small schools, located both on the periphery and in the inner city (Map 1). In all of the schools from the testing sample, immigrant children made up just a small percentage of the student body (between 6% and 22%). The immigrant children tested were from various cultural backgrounds: the majority were Ukrainians, Vietnamese, Russians, and Chinese. All of the students were enrolled in *middle school* and were between the ages of 10 and 17. The results confirmed the expected gender difference in the pace of second-language acquisition, with girls doing better than boys in the proficiency tests in the case of students still relatively new to Czechia. Length of residence in Czechia had a significant and expected effect on the test results of the children of immigrants and proved to be the most significant factor examined here. Generally, students' proficiency in Czech improves the longer they live in Czechia. Our test results agree with those of other similar studies. For example, Redstone Akresh's analysis (2007) of the New Immigrant Survey data indicates that the longer immigrants live in the United States, the more likely they are to use English with friends, at work, at home, and with a spouse. While the probability of newly-arrived immigrants using English to communicate with friends was 0.44, after 15 years in the country that probability doubled. However, the relation between length of residence in Czechia and proficiency level in Czech is not a linear one. Czech language proficiency improves very quickly during the first years in the country, but the pace of progress slows later on. Furthermore, as the length of residence in Czechia increases, the initially pronounced differences in proficiency between different categories of children, such as the differences between girls and boys, gradually fade.

The findings in this study indicate that the process of Czech language acquisition is also significantly influenced by cultural background and specifically by the linguistic distance between Czech and the mother tongue of the children of immigrants. This is again in accord with the results of other studies (Beenstock at al. 2001, Chiswick and Miller 2001, 2005; Isphording 2013) that have documented a more rapid progress in the acquisition of a host country's language by students whose mother tongue is linguistically closer to it. Children of Asian background in Czechia had almost no knowledge of the Czech language upon arriving to the country and required more time to acquire basic Czech language skills than students from countries where a Slavic language is spoken, who early on made very rapid progress with learning Czech. Over time, of course, the differences between children from different cultural backgrounds decreases, so that after residing in the country for a long time Vietnamese children have a level of proficiency in Czech that is comparable to children from a Slavic background. The diagnostic tests also showed that students from a Chinese background relatively have the most difficulty integrating into the Czech language environment and lagged behind the other students tested particularly in the area of Czech conversation skills. However, the longer they were in Czechia, the more their skills progressed towards the same level as other children.

The results of our analyses fully support the conclusion of Drbohlav (2011) who points to a need of using more of an "individual approach to designing integration policies," that is to "systematically apply integration policies that will respect specific features of individual group of immigrants" (p. 414). The study of Czech language acquisition by secondary school students indeed showed that tailor-made policies for different groups of migrants would be useful and may help to ease their integration into schools as well as into the society.

The abovementioned conclusion would not have been possible without the development of the pilot version of the diagnostic instrument measuring the level of language acquisition by foreign students. This diagnostic test is of multiple use. It can serve research purposes, as in the case presented in this paper, but it can also serve as a diagnostic tool useful for the children themselves, their parents, and their teachers. Testing the level of language acquisition may help teachers to monitor the progress of individual pupils, to identify their strengths and weaknesses, and to prepare tailor-made educational plans for them. Periodically repeated use of diagnostic tests may motivate children and provide feedback to them and their parents. The development of the pilot version of this diagnostic test represents the first step towards a more exact way of evaluation of language acquisition progress by the children of foreigners. Thus, the educational integration of students who are non-native speakers of Czech is a subject that warrants further observation and research. It is also a subject that, given the rapid increase in immigration to Czechia in the past twenty years, is a very relevant issue today. Furthermore, since the number of immigrants in the Czech population is likely to continue to grow, its relevance will only increase further into the future.

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REFERENCES

ABDELILAH-BAUER, B. (2008): Zweisprachig Aufwachsen. Mnichov: C. H. Beck.

ABU-RABIA, S. (1997): Gender Differences in Arab Students' Attitudes Toward Canadian Society and Second Language Learning. Journal of Social Psychology 137(1), 125–128.

ASGARI, A., MUSTAPHA, G. (2011): The Influence of Informal Language Learning Environment (Parents and Home Environment) on the Vocabulary Learning Strategies. English Language and Literature Studies 1(1), 7–13. http://dx.doi.org/10.5539/ells.v1n1p7

BACHMAN, L. F., PALMER, A. S. (1989): The construct validation of self-ratings of communicative language ability. Language Testing 6(1), 14–29. http://dx.doi.org/10.1177/026553228900600104

BACHMAN, L. F., PALMER, A. S. (2009): Language testing in practice: designing and developing useful language tests. Oxford: Oxford University Press.

BANG, J., SUÁREZ-OROZCO, C., PAKES, J. (2009): The importance of homework in determining immigrant students' grades in schools in the USA context. Educational research 51(1), 25pp. http://dx.doi.org/10.1080/00131880802704624

BEENSTOCK, M. The (1996): Acquisition of Language Skills by Immigrants: The Case of Hebrew in Israel. International Migration 34(1), 3–30. http://dx.doi.org/10.1111/j.1468-2435.1996.tb00178.x

BEENSTOCK, M., CHISWICK, B. R., REPETTO, G. L. (2001): The Effect of Linguistic Distance and Country of Origin on Immigrant Language Skills: Application to Israel. International Migration 39(3), 33–60. http://dx.doi.org/10.1111/1468-2435.00155

BERNARD, W. S. (1967): "The integration of immigrants in the United States". International Migration Review 1(2), 23–33. http://dx.doi.org/10.2307/3002806

BERRY, J. W. (1992a): Acculturation and Adaptation in a New Society. International Migration 30, Special Issue: Migration and Health in the 1990s, 69–85.

BERRY, J. W. (1992b): Cross-cultural psychology: research and applications. New York: Cambridge University Press.

BERRY, J. W. (1997): Handbook of Cross-cultural Psychology. Vol. 3 Social behaviour and applications. 2nd ed. Boston: Allyn and Bacon.

BEVELANDER, P. (2000): Immigrant employment integration and structural change in Sweden, 1970–1995. Lund: Lund University.

BÖHLMARK, A. (2009): Integration of Childhood Immigrants in the Short and Long Run – Swedish Evidence. International Migration Review 43(2), 387–409. http://dx.doi.org/10.1111/j.1747-7379.2009.00769.x

CARENS, J. H. (2005): "The integration of immigrants". Journal of Moral Philosophy 2(1), 29–46. http://dx.doi.org/10.1177/1740468105052582

CATALÁN, R. (2003): Sex differences in L2 vocabulary learning strategies. International Journal of Applied Linguistics 13(1), 54–77.

CHISWICK, B. R., MILLER, P. W. (2001): Model of Destination-Language Acquisition: Application to Male Immigrants in Canada. Demography 38(3), 391–409. http://dx.doi.org/10.1353/dem.2001.0025

CHISWICK, B. R., MILLER, P. W. (2005): Linguistic Distance: a Quantitative Measure of the Distance Between English and Other Languages. Journal of Multilingual and Multicultural Development 26(1), 1–11. http://dx.doi.org/10.1080/14790710508668395

CORT, D. A. (2010): What happened to familial acculturation? Ethnic and Racial Studies, vol. 33, no. 2, 313-335.

CVEJNOVÁ, J. (2006): Úroveň B1 – Prahová úroveň. In: ŠTINDLOVÁ, B., ČEMUSOVÁ, J. (ed.): Sborník Asociace učitelů *češtiny* jako cizího jazyka (AUČCJ) 2005–2006. Praha: Akropolis.

CVEJNOVÁ, J., PAPÍRNÍKOVÁ, I., BENEŠOVÁ GRUNTOVÁ, D. (2007): Diagnostika úrovně znalosti českého jazyka: (diagnostická příručka). Praha: Centrum pro integraci cizinců.

CUMMINS, J. (1979): Cognitive/academic language proficiency; linguistic interdependence, the optimum age question and some other matters. Working Papers on Bilingualism 19, 121–129.

DAVIES, A. (1990): Principles of language testing. Cambridge, Mass., USA: B. Blackwell, 1990, 147 pp.

DRBOHLAV, D., ČERNÍK, J., DZÚROVÁ, D. (2005): Dimensions of Integration: Migrant Youth in Central European Countries, Country Report on the Czech Republic. International Organization for Migration (IOM), Vienna.

DRBOHLAV, D., DZÚROVÁ, D. (2007): "Where Are They Going?" (2007): Immigrant Inclusion in the Czech Republic (A Case Study on Ukrainians, Vietnamese, and Armenians in Prague). International Migration 45(2), 1–25.

DRBOHLAV, D., DZUROVÁ, D., ČERNÍK, J. (2007): Integrace cizinců, žáků základních a středních škol, do české společnosti: Příklad Prahy. Geografie 112(2), 161–184.

DRBOHLAV, D., MEDOVÁ, L., ČERMÁK, Z., JANSKÁ, E., ČERMÁKOVÁ, D., DZÚROVÁ, D. (2010): Migrace a (i)migranti v Česku „Kdo jsme, odkud přicházíme, kam jdeme". Praha: Sociologické nakladatelství (SLON), 207 pp.

DRBOHLAV, D. (2011): Imigrace a integrace cizinců v Česku. Několik zastavení na cestě země v její migrační proměně z Davida na téměř Goliáše. Geografie 116(4), 401–421.

DUSTMANN, Ch. (1997): The Effects of Education, Parental Background and Ethnic Concentration on Language. Quarterly Review of Economics and Finance 37, Special Issue, 245–262. http://dx.doi.org/10.1016/s1062-9769(97)90068-5

ENDER, A., STRAßL, K. (2009): The acquisition and use of German in a dialect-speaking environment: facets of inclusion and exclusion of immigrant children in Switzerland. International Journal of Applied Linguistics 19(2), 173–187. http://dx.doi.org/10.1111/j.1473-4192.2009.00218.x

ESPENSHADE, T. J., FU, H. (1997): An Analysis of English-Language Proficiency among U.S. Immigrants. American Sociological Review 62(2).

FONER, N., ALBA, R. (2008): Immigrant religion in the US and Western Europe: Bridge or barrier to inclusion? International Migration Review (42) 2: 360–392.

HÁDKOVÁ, M., LÍNEK, J., VLASÁKOVÁ, K. Čeština jako cizí jazyk. Úroveň A1. Praha: MŠMT, Olomouc: Univerzita Palackého v Olomouci. Available at: www.msmt.cz/uploads/soubory/mezinarodni_vztahy/cestinaA1.pdf.

HÁJKOVÁ, V., STRNADOVÁ, I. (2010): Inkluzivní vzdělávání. Teorie a praxe. Praha: Grada, 2010.

HARRISON, A. (1983): A Language testing handbook. Reprint. London: Macmillan.

HASSELGREEN, A. (2005): Assessing the language of young learners. Language Testing 22(3), 337–354. http://dx.doi.org/10.1191/0265532205lt312oa

HECKMANN, F., SCHNAPPER, D. (2003): The integration of immigrants in European societies: National differences and trends of convergence. Lucius & Lucius DE, 2003.

HEDBÁVNÁ, B., JANOUŠKOVÁ, J., VEROŇKOVÁ, J. (2009): Výslovnost češtiny u cizinců – poznámky k metodám výuky. In: LÍNOVÁ, K. (ed.): Sborník Asociace učitelů *češtiny* jako cizího jazyka (AUČCJ) 2007–2009. Praha: Akropolis ve spolupráci s Asociací učitelů češtiny jako cizího jazyka, 16–23.

HOLUB, J., ADAMOVIČOVÁ, A., BISCHOFOVÁ, J., CVEJNOVÁ, J., GLADKOVA, H., HASIL, J., HRDLIČKA, M., MAREŠ, P., NEKVAPIL, J., PALKOVÁ, Z., ŠÁRA, M. (2005): Čeština jako cizí jazyk – Úroveň B2. Praha: MŠMT.

HUGHES, A. (2003): Testing for language teachers. 2nd ed. New York: Cambridge University Press, 2003, 251 pp.

IDDINGS, A. Christina DaSilva. (2009): Bridging Home and School Literacy Practices: Empowering Families of Recent Immigrant Children. Theory into Practice 48(4), 304–311. http://dx.doi.org/10.1080/00405840903192904

ISPHORDING, I. (2013): Disadvantages of linguistic origin: Evidence from immigrant literacy scores. Forschungsinstitut zur Zukunft der Arbeit Institute for the Study of Labor. http://dx.doi.org/10.2139/ssrn.2221277

JANČAŘÍK, A., KOSTELECKÁ Y. (2014): 'How test questions influence student scores in diagnostic assessment of language proficiency', Efficiency and Responsibility in Education 2014: Proceedings of the 10th International Conference, v tisku.

JANSKÁ, E., PRŮŠVICOVÁ, A., ČERMÁK, Z. (2011): Možnosti výzkumu integrace dětí Vietnamců v Česku: příklad základní

školy Praha-Kunratice. Geografie: sborník České geografické společnosti 114(4), 480–496.
KIELHÖFFER, B., JONEKEITS, S. (2006): Zweisprachige Kindererziehung. Tubingen: Stauffenburg.
KOCOUREK, J. (2001): Vietnamci v České republice. In: ŠIŠKOVÁ, T.: (ed.) Menšiny a migranti v České republice: my a oni v multikulturní společnosti 21. století. Praha: Portál, pp. 99–107.
KOCOUREK, J. (2002): Poznáváme svět dětí z Vietnamu: hledání společné řeči: stručná příručka pro pedagogické pracovníky o podmínkách života dětí „nečeských" národností přijíždějících do ČR a o jejich vlasti. Plzeň: Foto & Tisk Znamenaný.
KOHNOVÁ, J., KOSTELECKÁ Y, (2013): Proekt Integraciâ detej inostrancev v sisteme češskih načal'nyh škol. In: NIKOLAEVA, A. I., PIMTCHEV, S.: Integracionnye processy v škol'nom obrazovatel'nom komplekse: idei i opyt dlâ edinoj obrazovatel'noj sredy (praktičeskij aspekt). Moskva: Moscow open education institute, 162–173.
KOSTELECKÁ, Y. et al. (2010, 2011, 2012): Integrace dětí příslušníků národnostních menšin a cizinců do českého vzdělávacího systému. Závěrečná zpráva z projektu podpořeného z dotačního programu MŠMT na podporu vzdělávání v jazycích národnostních menšin a multikulturní výchovy. Praha: Univerzita Karlova v Praze, Pedagogická fakulta.
KOSTELECKÁ, Y., KOSTELECKÝ, T., KOHNOVÁ, J., TOMÁŠOVÁ, M., POKORNÁ, K., VOJTÍŠKOVÁ, K., ŠIMON, M. (2013): Žáci-cizinci v základních školách. Fakta, analýzy, diagnostika. Praha: Pedagogická fakulta Univerzity Karlovy, 179 pp.
KOSTELECKÁ, Y., JANČAŘÍK, A. (2013): Factors influencing language proficiency of foreign children attending Czech primary schools. In: KVASNIČKA, R. Efficiency and Responsibility in Education 2013: Proceedings of the 10th International Conference. Praha: Czech University of Life Sciences Prague, 291–299.
KOSTELECKÁ, Y., JANČAŘÍK, A. (2014): The Process of Czech Language Acquisition by Foreign Pupils at Lower Secondary School. Journal on Efficiency and Responsibility in Education and Science 7(1), 7–13. http://dx.doi.org/10.7160/eriesj.2014.070102
LI, G. (2007): Home environment and second-language acquisition: the importance of family capital. British Journal of Sociology of Education 28(3), 285–299. http://dx.doi.org/10.1080/01425690701252028
MCMANUS, W., GOULD, W., WELCH, F. (1983): Earnings of Hispanic Men: The Role of English Language Proficiency. Journal of Labor Economics 1(2), 101–130.
McKAY P. (2006): Assessing young language learners. Cambridge: Cambridge University Press.
PRŮCHA, J. (2001): Multikulturní výchova: teorie–praxe–výzkum. Praha: ISV.
PRCHA, J. (2007): Interkulturní psychologie: sociopsychologické zkoumání kultur, etnik, ras a národů. 2. rozš. vyd. Praha: Portál.
PRŮCHA, J. (2010): Interkulturní komunikace. Praha: Grada, 199 pp.
PRŮCHA, J. (2011): Multikulturní výchova: příručka (nejen) pro učitele. 2., aktualizované a rozš. vyd. Praha: Triton.
REDSTONE AKRESH, I. (2007): Contexts of English Language Use among Immigrants to the United States. International Migration Review 41(4), 930–955. http://dx.doi.org/10.1111/j.1747-7379.2007.00106.x
REMENNICK, L. (2003): Language acquisition as the main vehicle of social integration: Russian immigrants of the 1990s in Israel. International Journal of the Sociology of Language 164, 83-105.
ŘIHÁKOVÁ, A. (2011): Interkulturní komunikace v kontextu organizace občanské společnosti. Brno. Disertační práce. Masarykova univerzita. Přírodovědecká fakulta. Ústav antropologie.
SINKE, S. M. (1999): Gender in Language and Life: A Dutch American Example. Gender Issues 17(1), 26 pp.
SMITH, K. (1995): Assessing and Testing Young Learners: Can we? Should we? In: ALLEN, D. (ed.): Papers from a symposium of the research, testing, and young learners special interest groups. Kent, England: IATEFL, 1–10.
SOUKUP, V., VODÁKOVÁ, A., VODÁKOVÁ, O. (2000): Sociální a kulturní antropologie. Praha: Sociologické nakladatelství.
Společný evropský referenční rámec pro jazyky: Jak se učíme jazykům, jak je vyučujeme a jak v jazycích hodnotíme. 2. vydání. Olomouc: Univerzita Palackého v Olomouci, 2006. Available at http://www.msmt.cz/mezinarodni-vztahy/spolecny-evropsky-referencni-ramec-pro-jazyky.
STEVENS, G. (1999): Age at Immigration and Second Languge Proficiency among Foreign-Born Adults. Language and Society 28(4), 555–578.
SUÁREZ-OROZCO, M. M. (ed.). (2007): Learning in the global era: International perspectives on globalization and education. Los Angeles: University of California Press.
ŠÁRA, M., CVEJNOVÁ, J., CONFORTIOVÁ, H., ČADSKÁ, M., TURZÍKOVÁ, M., HOLUB, J., BISCHOFOVÁ, J., LÁNSKÁ, L., PALKOVÁ, Z. (2001): Prahová úroveň – Čeština jako cizí jazyk. Strasbourg: Council of Europe.
ŠINDELÁŘOVÁ, J. (2005): Socio-kulturní zázemí žáků a studentů-imigrantů přicházejích ze zemí s odlišnou kulturou: (příručka pro učitele o vzdálených zemích, z nichž tito žáci a studenti přicházejí). Ústí nad Labem: Univerzita J. E. Purkyně.
ŠINDELÁŘOVÁ, J. (2011): Metodická doporučení k začleňování žáků-cizinců do výuky v českých základních školách. [cit. 2013-01-06]. Available at http://clanky.rvp.cz/clanek/c/Z/14329/metodicka-doporuceni-k-zaclenovani-zaku-cizincu-do-vyuky-v-ceskych-zakladnich-skolach.html/.
ŠINDELÁŘOVÁ, J. (2008): Čeština jako cizí jazyk v evropském kontextu. Ústí nad Labem: Univerzita Jana Evangelisty Purkyně v Ústí nad Labem. Acta Universitatis Purkynianae 146. Studia linguistica.
THOMAS, K. J. A. (2010): Household Context, Generational Status, and English Proficiency among the Children of African Immigrants in the United States. International Migration Review 44(1), 142–172. http://dx.doi.org/10.1111/j.1747-7379.2009.00801.x
TILLIE, J. (2004): Social capital of organisations and their members: explaining the political integration of immigrants in Amsterdam. Journal of Ethnic and Migration Studies 30(3): 529–541. http://dx.doi.org/10.1080/13691830410001682070
VAN TUBERGEN, F., MAAS, I., FLAP, H. (2004): The Economic Incorporation of Immigrants in 18 Western Societies: Origin, Destination, and Community Effects. American Sociological Review 69: 701–724. http://dx.doi.org/10.1177/000312240406900505
VAN TUBERGEN, F., KALMIJN, M. (2008): Language Proficiency and Usage among Immigrants in the Netherlands: Incentives or Opportunities? European Sociological Review 25(2), 169–182.
VAŇKOVÁ, I. (2005). Nádoba plná řeči. In: VAŇKOVÁ, I., NEBESKÁ, I., ŠLÉDROVÁ J. et al. (2005): Co na srdci, to na jazyku: Kapitoly z kognitivní lingvistiky. Praha: Karolinum.
VLASÁKOVÁ, K. (2009): Vybrané problémy při tvorbě Certifikované zkoušky z češtiny pro cizince [B. Štindlová, J. Čemusová eds.]. Sborník Asociace učitelů češtiny jako cizího jazyka (AUČCJ) 2007–2009. Praha: Akropolis.
VODIČKOVÁ, K. (2014): Designing Diagnostic Tests in Czech for Young Migrant Learners In: KVASNIČKA, R. Efficiency and Responsibility in Education 2014: Proceedings of the

10th International Conference. Praha: Czech University of Life Sciences Prague.
VODIČKOVÁ, K., KOSTELECKÁ, Y. (2014): Diagnostic tests in Czech for the children of immigrants attending primary schools in the Czech Republic. E-pedagogium 4, 38–51.

Data sources

ČSÚ, Trvale a dlouhodobě usazení cizinci v ČR, 1985–2012 (31. 12.). Available at: http://www.czso.cz/csu/cizinci.nsf/t/B9003347F1/$File/c01r01.pdf
Statistická ročenka školství – Výkonové ukazatele 2010/11.

RESUMÉ

Jazyková integrace dětí imigrantů navštěvujících 2. stupeň českých základních škol

Po pádu železné opony, ale především po vstupu Česka do Evropské unie, prudce vzrostl počet imigrantů. Tomuto fenoménu se musely přizpůsobit všechny složky společenského života, včetně vzdělávacího systému, jehož úkolem se stalo vytvořit vhodné podmínky pro integraci děti imigrantů do všech typů škol na všech jeho úrovních. Empirické studie (například Kostelecká et al. 2013) zabývající se problematikou integrace žáků-cizinců do systému českých základních škol upozornily na význam češtiny jako jednoho z klíčových determinantů úspěšnosti dítěte ve škole. Zároveň ukázaly na určité nedostatky ve způsobech identifikace úrovně češtiny jednotlivých dětí. Problém spočíval v neexistenci nástroje, kterým by bylo možno objektivně diagnostikovat úroveň zvládání češtiny u žáků s odlišným mateřským jazykem. Tato skutečnost vedla výzkumný tým ke snaze takový nástroj vyvinout a pilotně ověřit na vzorku žáků-cizinců zapsaných na 2. stupni vybraných pražských základních škol Výsledný test diagnostikoval úroveň češtiny dětí ve čtyřech řečových dovednostech: čtení s porozuměním, poslech s porozuměním, úroveň psaného textu a úroveň verbální komunikace, a to od nulových dovedností až po úroveň B1. Mezi cizinci, kteří prošli testováním, byli zastoupeni žáci 2. stupně základních škol pocházející z různých kulturních prostředí. Výsledky této pilotní studie prokázaly, že samotný testovací nástroj je použitelný pro účely, ke kterým byl vyvinut. Výsledky šetření podle očekávání potvrdily, že lepších výsledků v testech v prvních letech pobytu v Česku dosahují dívky. Oproti očekávání se naopak neprokázalo, že by starší žáci zvládali češtinu lépe než žáci mladší. Významný a očekávatelný vliv na výsledky testů měla délka pobytu dítěte v Česku, která se ukázala jako nejvýznamnější faktor vůbec: žáci mají tím lepší znalosti češtiny, čím déle v Česku žijí. Závislost mezi délkou pobytu v Česku a úrovni češtiny však není lineární. S prodlužující se délkou pobytu v Česku se znalosti češtiny nejprve zlepšují velice rychle, později už pokrok tak rychlý není. S rostoucí délkou pobytu v zemi se postupně stírají i zprvu znatelné rozdíly mezi jednotlivými skupinami – například mezi dívkami a chlapci. Průběh osvojování českého jazyka je podle výsledků šetření významně ovlivněn tím, k jaké etnické skupině testování žáci patřili. Rozdíly mezi dětmi různého etnického původu se ovšem v čase postupně zmenšují.

Integrace žáků, jejichž mateřským jazykem není čeština, do českých základních škol, je tématem, které stojí za další sledování a zkoumání, protože úspěšnost migrace není náhodným jevem, ale je ovlivněná celou řadou individuálních a společenských faktorů, jejichž spolupůsobení má významný vliv na průběh i dopad migrace. Důležitou roli v poznávání vlivu jednotlivých faktorů ovlivňujících integraci migrantů by podle Berryho (2001) měly sehrát společenské vědy, které tímto mohou významným způsobem přispět k utlumení negativních dopadů migrace a umocnění pozitivních stránek tohoto procesu

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DIGITAL ROCK DRAWING ON CZECH TOPOGRAPHIC MAPS: THE CURRENT STATE AND HISTORICAL CIRCUMSTANCES

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ABSTRACT

This article presents a method of digital cliff drawing that is used in the production of large-scale topographic maps by the Land Survey Office of the Czech Republic, with respect to the history of topographic mapping in the Czech Republic and former Czechoslovakia, which greatly influenced contemporary digital processing. The core of this article details the principles of this type of digital rock portrayal, illustrated with a variety of examples. The method described is based on filling a polygon with lines that resemble stylized hachures. The advantages, disadvantages and limitations of this approach are also discussed.

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

1. Introduction

Rocks are often dominant features of the landscape, and therefore can expect to be present in large-scale topographic maps. However, the vivid portrayal of such a feature has always been a challenging task, even for a skilled cartographer. The term "rock drawing" (also often referred to as "cliff drawing") denotes the production of rock hachures: a way of providing the map reader a clear impression of the passability of rocky terrain, generally dictated by its relative height or structure. Various types of rock hachures have been developed, especially in alpine countries. While the style used in Swiss maps is generally considered to reach highest degree of perfection, this is not the case for the rock hachures commonly used in Czech maps. With very few high mountain rocky peaks, and only an insignificant part of its territory covered in other types of rocks, the demand for such precise depictions is lower in Czech maps. Moreover, in the era of contemporary GIS systems, some practitioners consider traditional rock hachures to be an anachronism or nothing more than a surviving curiosity.

Traditional work on rock drawing in analogue cartography comes from Imhof (1965), who argues for using hachures, and provides an in-depth description of the rules and best practices for Swiss-style rock depiction. Another approach was used by Austrian cartographers Brandstätter (1983) and Ebster (cf. also Čapek 1976). Works that are better suited to Czech cartographic traditions also exist, but are generally rare. These include Boguszak & Šlitr (1962), Kavan (1965), a complex thesis by Čapek (1973) and its later published parts (Čapek 1974; Čapek et al. 1992), and Lysák (2010). Over the years, the technology has changed from analogue drawing on plastic foils to digital drawing using a computer. However, the problem itself remains the same, or even worsens, as working without special hardware (e.g. a graphics tablet) and software is more time-consuming than using pen and paper, which is rare nowadays. Despite this, a more important issue seems to be the automation of rock drawing, and this has yet to be resolved. A key part of a solution to this is an in-depth analysis. For Swiss-style rock depiction it was done by Jenny et al. (2014), some notes about the Czech-style of rock drawing including digital processing were also published in Lysák & Traurig (2013).

This article aims to elaborate on the previously mentioned work to provide a more thorough description and analysis of the principles of digital rock drawing with respect to special cases of digital processing. The focus is on digital cartography and large-scale topographic maps produced by the Land Survey Office of the Czech Republic, whose experts have developed remarkable solutions to the problem.

Firstly, a short historical overview of rock drawing in modern, large-scale Czech topographic maps is given, as it has contributed concepts that are more or less used in contemporary digital processing. The principles and concepts of digital processing are described more thoroughly in the next section, as well as the advantages and drawbacks. Based on the description, a user can easily create suitable and visually acceptable representations of rock formations for large-scale maps. This paper may be useful not only for cartographers or GIS practitioners, but also researchers dealing with the large-scale mapping of rocky terrains, such as geomorphologists or

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geologists. Moreover, a detailed description of the digital portrayal can be used for the development of an algorithm that enables this type of representation to be created automatically.

2. Historical Overview

Contemporary digital rock processing is related to previous work on analogue maps, which warrants a brief discussion of the history of modern large-scale topographic mapping in the Czech Republic. Between 1957 and 1971, the entire territory was mapped in a large scale of 1 : 10,000 (Čapek 1985), resulting in the Topographic map (*Topografická mapa*) state military map series (TM 10). Cartographical symbols, including rocks, were drawn according to Soviet standards in order to unify maps for all countries of the former Communist Bloc.

Rocks were depicted by brown rock hachures in an attempt to express the jaggedness of the terrain. Drawings were based on an identification of the main ridges and gully lines of the rock formation. From ridges or cliff tops, lines following the fall direction were placed more or less mechanically and regularly. These were shaded based on the north-west illumination; i.e. tending to be thinner on the light sides, and thicker on the shaded sides. Generally, they also narrowed downwards. The fall lines were connected with short transverse horizontal strokes, which together formed a structure resembling a ladder (thus often referred to as "ladder manier"). The strokes were numerous on the side facing away from the direction of light, and placed only rarely on sunlit slopes. In both cases, they were thicker close to the ridges or cliff top. The closer to the bottom of a cliff, the thinner, shorter, and less frequently the lines were placed (Kavan 1965). An example is shown in Figure 1 (top). Based on these general principles, every mapmaker processed their map sheet significantly differently based on their own style, although such portrayals should be consistent across all map sheets. This presented a drawback, as the resulting image strongly depended on the experience and abilities of the author, varying from good artistic work to a schematic jumble of lines. More general disadvantages lie in the uniformly placed fall lines, which limit the possibility of expressing any specific feature of a certain rock, and which also evoke non-existing ridges. Although the main goal of this representation was to express the structure and passability of rocky terrain, this was hardly ever achieved, as noted by Čapek (1973).

In the TM 10 map key, a special symbol for sandstone rocks is present as such rocks tend to be smoother and more rounded. A typical cartographic portrayal of sandstone landscapes is based on a series of sack-like symbols (Figure 1, bottom). The symbol represents a stylised sandstone rock seen from an oblique view. These elements are ordered into adjacent rows one next to another to represent a rock face. The gaps between elements express

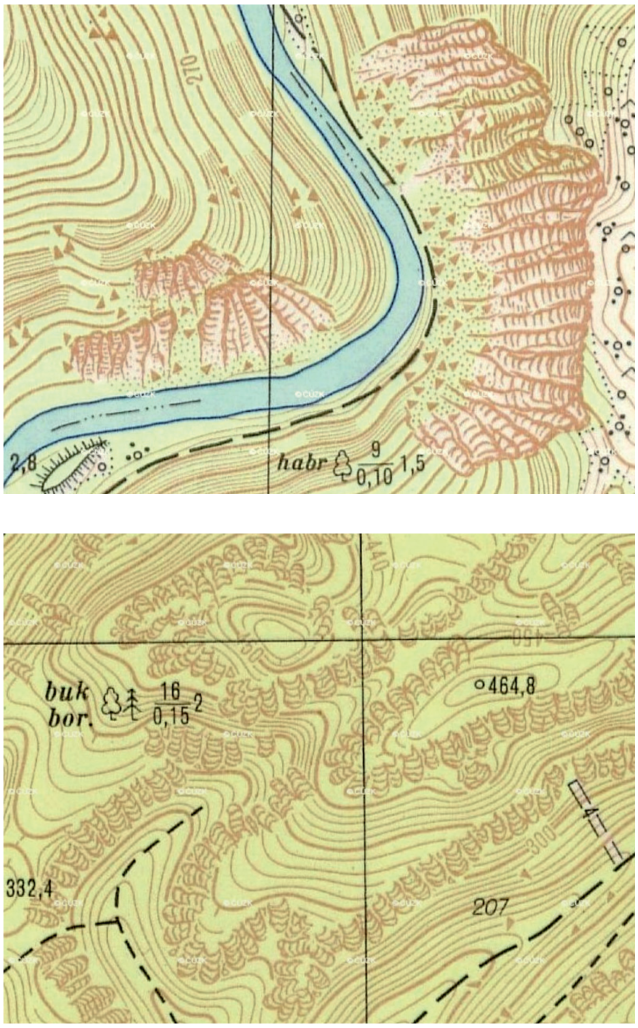

Fig. 1 A typical rock representation in TM 10 (top) and a sandstone landscape on the same map (bottom). Maps kindly provided by the Central Archives for Land Survey and Cadastre (*Ústřední archiv zeměměřictví a katastru*), © ČÚZK.

passages between the walls (whereas when connected together they represent impassable terrain); stacked rows of symbolsrepresent "terraced" escarpments separated from each other by normal (i.e. non-rocky) ground. In some cases, the size of a symbol can be interpreted as the relative height of a cliff. This was not done consistently and the quality of the resulting image strongly depended upon the abilities of the mapmaker. These means of cartographic representation themselves pose another problem. As sandstone cliffs are usually almost vertical and thus very narrow in a plan view, the area of a map covered with symbols overestimates the actual size of the cliff. This leads to a very inaccurate depiction of reality, especially for a more rugged sandstone relief, as either the relief form is too generalized, or the result is a disorganized mixture of strokes and circles.

Eventually, the army stopped updating TM 10 and after 1968 these maps served as a basis for the civil national map series. The first edition of large-scale topographic maps with a scale of 1 : 10,000, Base Map (*Základní mapa*, ZM 10) was published between 1971 and 1988

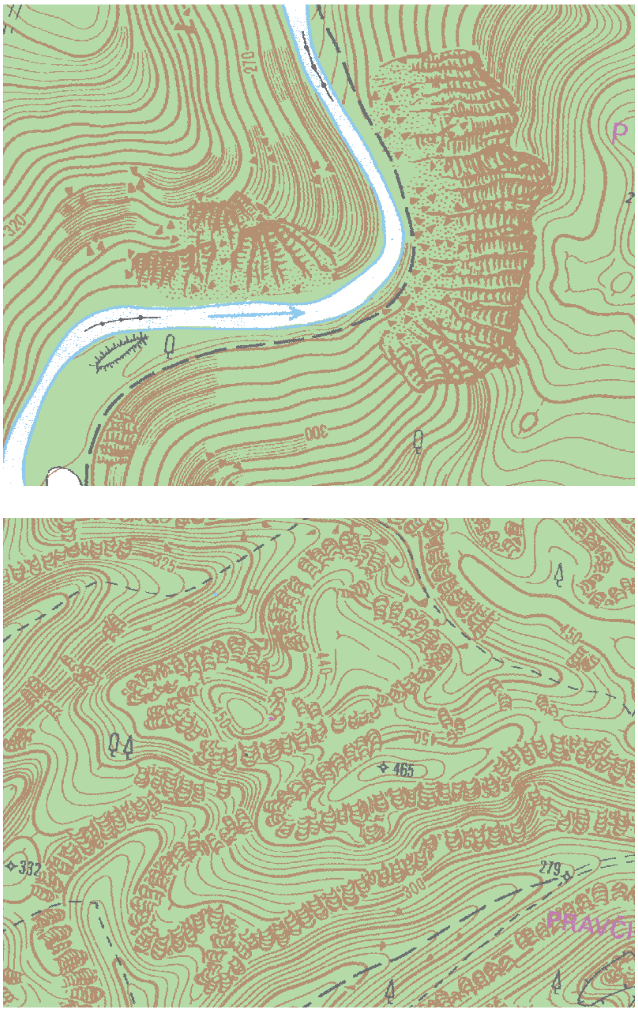

Fig. 2 The same areas as shown in Figure 1 in ZM 10. Maps kindly provided by the Central Archives for Land Survey and Cadastre (*Ústřední archiv zeměměřictví a katastru*), © ČÚZK.

and included a total of 4,533 sheets. Until the mid-1990s, these maps were regularly updated. Although the map content was reduced compared to TM 10, the cartographic portrayal of rocks remained almost the same (cf. Figure 2), exhibiting the disadvantages discussed earlier.

3. Digital Processing

Digital processing of Czech topographic maps is based on ZABAGED, a large-scale digital topographic database (Fundamental Base of Geographic Data, *Základní báze geografických dat*). Work on ZABAGED started in 1995 with scanning and georeferencing of the printing masters from the most current edition of ZM 10, which were later vectorised. Populating the database was mostly finished in 2001, and finalized in 2004. Since 2001, this database has been regularly updated using orthophotos, field work, and external data. In ZABAGED, rocks are represented using points for small objects, and polygons for larger ones. The polygons originated from outlines of hachured areas in ZM 10 and their accuracy was improved by topographers where possible. Their total count exceeds 40,000.

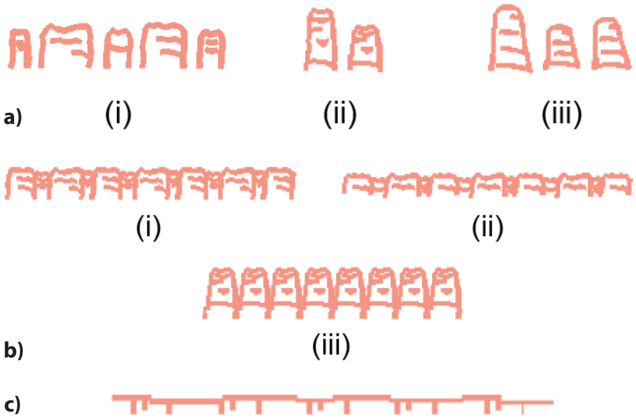

Fig. 3 The "anatomy" of digital rock drawing in the digital edition of ZM 10: a) upper symbols, b) lines derived from upper symbols, c) lower line. See below for a detailed explanation. Taken from the legend of topographic maps produced by the Land Survey Office, © ČÚZK.

Based on ZABAGED, base maps in the scale 1 : 10,000 have gradually been created using digital technology since 2001. The final sheet of the first digital edition was completed in 2006 and updates have been made continuously, since then. When processing the map sheet with rocks, the cartographer had to fill a polygon from ZABAGED with stylised hachures. Their style reflects hachures used in the analogue version of ZM 10, but the objective was to draw them more easily and not in a stroke-by-stroke fashion. For this purpose, several symbols are combined in order to achieve the desired results (Figure 3).

The first step was to create various symbols for a single stylised hachure (Figure 3a). We will refer to this as "upper symbols" in the following text (cf. Figure 4). Two general types of symbols were used; one for sandstone rocks (more rounded) and one for other rock types. Notes from topographers distinguished the type of rock. In practice, this was not done consistently. Figure 3a, group (i) depicts the most commonly used symbols. Group (ii) depicts the symbols used for sandstone rocks (not used in new production). Group (iii) depicts the symbols formerly used for sandstone rocks, which were probably not used in production at all, despite being present in the legend of earlier digital editions of ZM 10. In each group, there are more symbols due to the irregularity of the resulting representation.

From these upper symbols, several lines were derived (see Figure 3b), putting one or more types of symbols sequentially like pearls on a necklace (often colloquially referred to as "cartridge belts"), especially the sandstone variant, cf. Figure 3b (iii) and Figure 5b. This is done using Marker Line Symbol in ArcGIS for Desktop or using other cartographic software that also supports this feature. The main advantage of this approach is that a mapmaker does not need to place and rotate each symbol individually, but instead can simply draw the

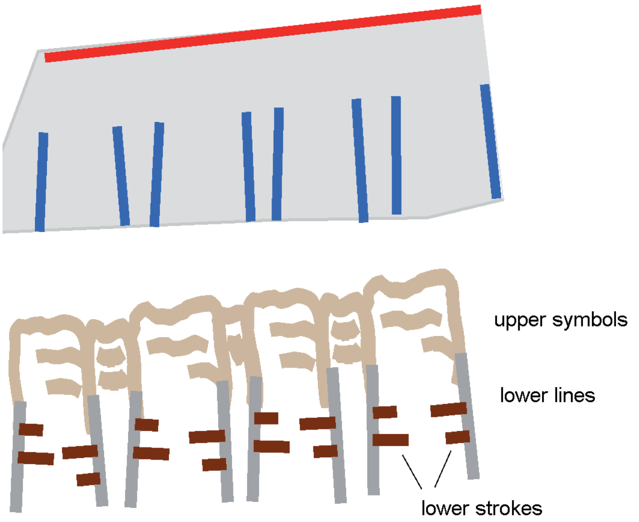

Fig. 4 From lines to hachures. The upper figure portrays the polygon geometry from ZABAGED with lines that needed to be drawn by a cartographer. The lower figure illustrates the resulting representation. For better illustration, single components of the result are distinguished by colour. ZABAGED data from Geoportal ČÚZK, © ČÚZK.

line and the cartographic software places the symbols next to each other automatically, perpendicular to the line. The smaller symbols serve as transitional strokes between the larger ones, which to some extent helps to avoid undesired regularity. There are also variants for wide (using a larger symbol, cf. Figure 3b (i)) and narrow (using a smaller symbol cf. Figure 3b (ii)) rocks. For sandstone rocks, no transitional strokes were used and the result tends to be of poorer visual quality (cf. Figure 3b (iii) and Figure 5b). This may be the reason that the "sandstone variant" is not used any more for the production of new hachures, and can rarely be found in map sheets that were produced earlier. When filling a polygon, the described lines were drawn along the upper edges. To increase output irregularity, not only was a single line along the upper edge used, but shorter sections with slight displacements or spaces between line parts are also often present.

Finally, the line for depicting the lower part of a rock was utilised, cf. Figure 3c. These lines (referred to below as "lower lines"), which generally follow the fall direction, were drawn to fill the section of the polygon not covered by the upper symbols. The lower lines meet the lower part of each upper symbol. They were used for larger (and especially wider) polygons and can be omitted for polygons that are narrow enough. For extensive polygons, these lines were placed more unevenly to avoid an excessively regular pattern. This was also sometimes achieved by bending the lower lines slightly (cf. Figure 5c). The impression of irregularity was supported by short, transverse strokes, perpendicular to a lower line (referred to as "lower strokes" in the following text). Although they seem to be distributed randomly, this effect was achieved by a simple symbolization using uniform placement with

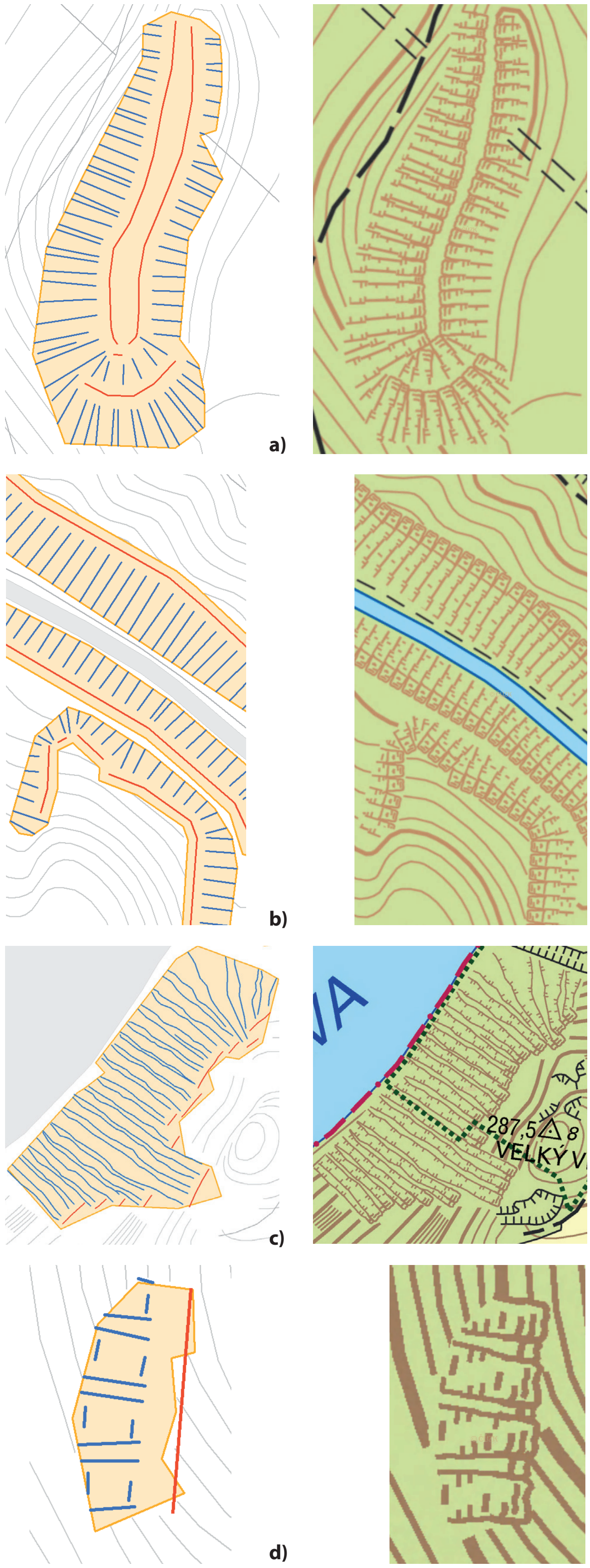

Fig. 5 Practical examples of the use of a combination of lines. Each pair shows in the left figure geometry from ZABAGED, and the lines were drawn by a cartographer. In the right figure, the result of the digital edition of ZM 10 is shown. See above for a detailed explanation of cases a–d. ZABAGED data and maps taken from Geoportal ČÚZK, © ČÚZK.

a long period for repeating and especially by changing the direction of the drawing (if one lower line was drawn from top to bottom, the next was sketched from bottom to top, and vice versa). These individual strokes do not have to be drawn by a cartographer as they can be easily done using Hash Line Symbols in ArcGIS. However, in rare cases when the lower lines were too far from each other and even decoration with lower strokes did not help to fill a polygon enough, additional lines were drawn freely between them (Figure 5d).

While processing data from ZABAGED for the first digital edition, no automation was used and all lines mentioned above were drawn by operators. During the vectorization of rock polygons for ZABAGED, details inside the rocky areas (e.g. ridges or upper edges) were not captured and the orientation of hachures had to be inferred from the original analogue ZM 10 or other relevant sources. In the case of more complicated shapes, the cartographer had to use these lines for creating a ridge or a valley (as in Figure 5a). For the next edition of the map sheet, the data was adapted from the previous edition and only minor changes were made (based on the update of polygons in ZABAGED).

A very similar approach for rock portrayal is used for the base map in scale 1 : 25,000. For scales of 1 : 50,000 and 1 : 100,000, lines alone are used to depict the upper edges in various widths using upper symbols, i.e. lower lines are not used. Very short lines with just a single upper symbol are used more often in these maps. At a scale of 1 : 200,000, only one type of line is used for upper edges.

In terms of technology, between 2001 and 2010, the digital processing was carried out using MicroStation and MGE. Since 2010, maps have been produced in a new technological line called IS SMD (Information System of National Map Series, *Informační systém státního*

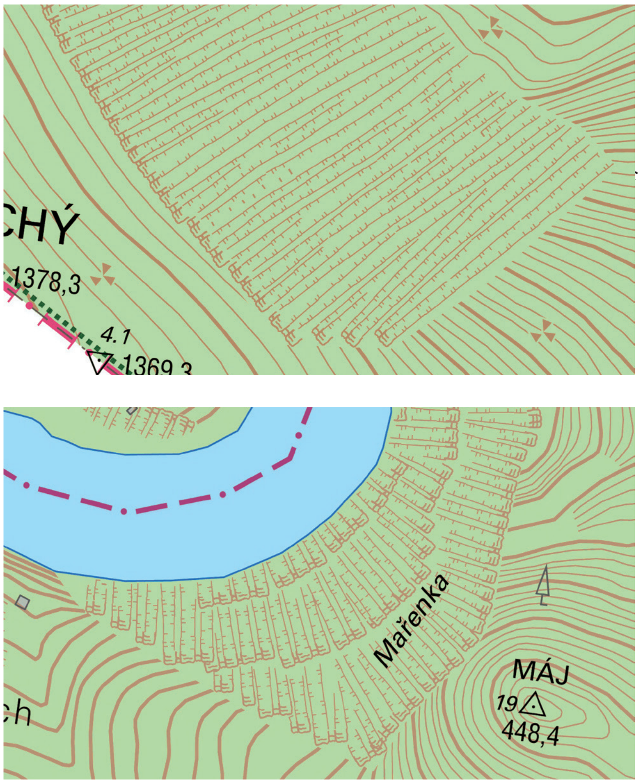

Fig. 6 Digital rock drawing for large polygons. The upper figure illustrates long lower lines. The lower figure includes more lines consisting of upper symbols. Maps taken from Geoportal ČÚZK, © ČÚZK.

er level of stylisation, it is visually better than a simple filling with a regular (or irregular) pattern, that can often be found in contemporary geoportals and poor digital maps. It also helps the map reader identify the upper and lower part of cliffs, but can be unsatisfactory for bigger polygons with extra elongated lower lines (cf. Figure 6, top) and more complicated shapes inside of a polygon. The

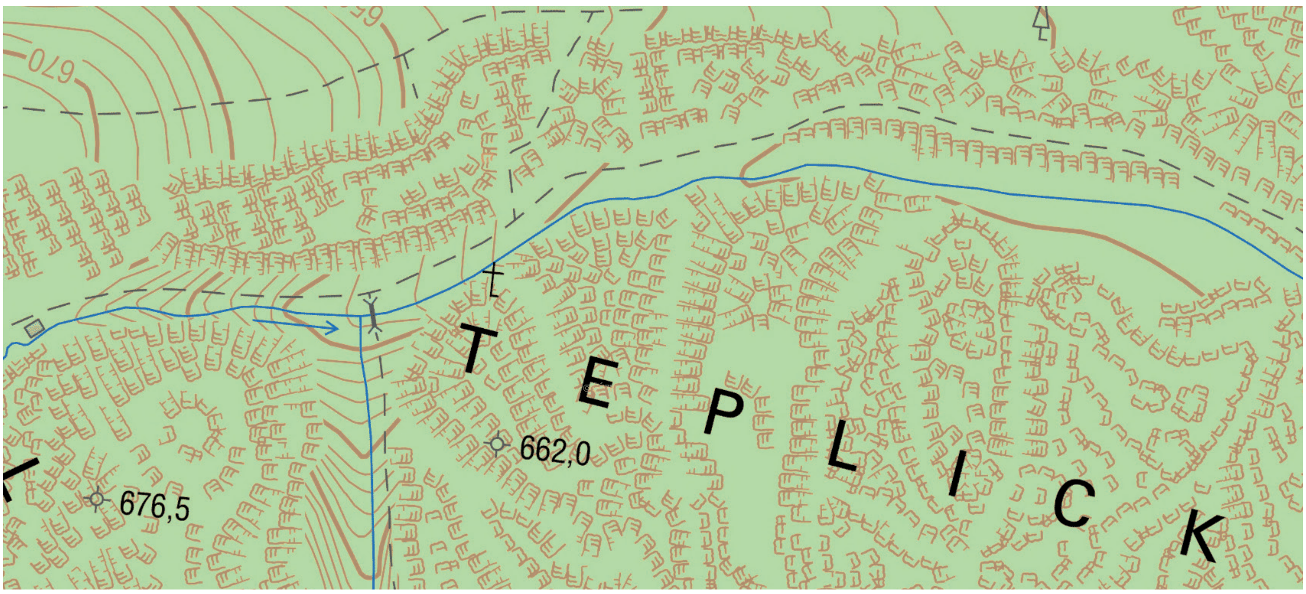

Fig. 7 Digital rock drawing for a complicated sandstone relief. Map taken from Geoportal ČÚZK, © ČÚZK.

monotonous structure of long lower lines can be mitigated by adding more horizontal rows of upper symbols (cf. Figure 6, bottom). This breaks the undesired uniformity of the representation, but also evokes unrealistic terracing of the cliff, which can lead to a misinterpretation of the relief form.

For the cases mentioned above, in particular, the described solution does not reach the clarity and beauty of classic, hand-drawn rock portrayal for obvious reasons; drawing is too stylised and fades out the detailed information about the structure of a rock, as sometimes expressed in ZM 10.

Another disadvantage is in regards to the portrayal of rugged sandstone landscapes with high, steep, almost vertical and sometimes overhanging rock escarpments, bizarre-shaped pillars and needles, narrow and hardly accessible gorges, as well as wildly-jagged plateaus. The main challenge for the cartographer is the predominant vertical dimension of sandstone objects, which leaves little space for drawing even a dominant feature in a map, as its size in the horizontal plane is insignificant. The described method requires at least the placement of upper symbols, which often results in disorganised placement and orientation (cf. Figure 7). The overall impression of such work is a formless drawing that lacks any information. From a local point of view, this problem becomes more serious if we consider the fact that sandstones are a predominant type of rocky relief in the Czech Republic. The northern portion of the country occupies a major part of the Bohemian Cretaceous Basin which also extends partly into Poland and Germany, and is probably the most extensive sandstone area in Europe (Härtel 2007).

4. Conclusion

This article presented a local method of digital cliff drawing, developed and used by the Czech Land Survey Office, including its historical roots and the general principles and guidelines for its application. Although the result is very schematic, this method can bring to a map reader extra information about the morphology of a rock formation. A cartographer may not require any special artistic skills to create the described type of a digital cliff drawing; however, the process of filling a polygon with hachures based on the rules described above is quite time-consuming. On the other hand, the individual steps seem to be clear and simple enough to be algorithmized. Thus, the automation of this process will be the subject of the author's further research. The author hopes that this article contributes somewhat to improvements in the depiction of rocky terrains, often expressed poorly in contemporary digital maps.

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Author's Note

Significant parts of this article were presented at the 26th International Cartographic Conference in Dresden, Germany, and published in the conference proceedings. This article is an extension of the conference publications, and is more analytically-oriented, serving as a necessary precursor to the automation of the entire process. Style files for ArcGIS for Desktop can be downloaded from: http://goo.gl/VkjuHz.

REFERENCES

BOGUSZAK, F., ŠLITR, J. (1962): Topografie. SNTL, Praha.

BRANDSTÄTTER, L. (1983): Gebirgskartographie. Franz Deuticke, Wien.

ČAPEK, R. (1973): Znázorňování skal [manuscript]. Praha, 184 p. Rigorous thesis at Faculty of Science, Department of Cartography and Physical Geography, Charles University in Prague.

ČAPEK, R. (1974): Kresba skal na mapě Bystré doliny. Acta Universitatis Carolinae – Geographica 1974(1), 23–50.

ČAPEK, R. (1976): Metody kresby skal na rakouských mapách. Acta Universitatis Carolinae – Geographica 1976(supplementum), 37–44.

ČAPEK, R. (1985): Československé topografické mapy. Acta Universitatis Carolinae – Geographica 1985(2), 33–47.

ČAPEK, R., MUCHA, L., MIKŠOVSKÝ M. (1992): Geografická kartografie. Státní pedagogické nakladatelství, Praha.

HÄRTEL, H. et al. (2007): Sandstone Landscapes. Academia, Praha.

IMHOF, E. (1965): Kartographische Geländedarstellung. DeGruyter, Berlin. http://dx.doi.org/10.1515/9783110843583

JENNY, B., GILGEN, J., GEISTHÖVEL, R., MARSTON, B., HURNI, L. (2014): Design principles for Swiss-style rock drawing. The Cartographic Journal. http://dx.doi.org/10.1179/1743277413Y.0000000052

KAVAN, G. (1965): Kresba skal, ssutí a ledovců. Vojenský topografický obzor 3(2): 203–206.

LYSÁK, J. (2010): Skalní útvary v kartografii a GIS. Geodetický a kartografický obzor 56/98(3): 52–58.

LYSÁK, J., TRAURIG, M. (2013): Digital Rock Drawing on Czech Topographic Maps: Present and Future Development. In: BUCHROITHNER, M. F. (eds.): Proceedings of the 26th International Cartographic Conference (12 pages). Dresden, Germany.

RESUMÉ

Znázorňování skal na českých digitálních topografických mapách: současný stav a historické souvislosti

Článek podrobně představuje metodu pro znázorňování skal s využitím prostředků digitální kartografie, vyvinutou Zeměměřickým úřadem a používanou na topografických mapách jím vydávaných. Podstatou této metody je vyplňování půdorysu skalního útvaru liniemi, které mají připomínat stylizované skalní šrafy. Samotný popis metody byl vytvořen na základě analýzy práce kartografů a výsledné reprezentace na mapách. Představuje podrobný návod, ilustrovaný na řadě příkladů a lze podle něj uvedený způsob kresby bez problémů reprodukovat ve většině kartografického software. Souhrn používaných pravidel může také posloužit jako vhodný podklad pro automatizaci popisovaného způsobu znázornění skal, kterou kartografové dosud vytváří ručně, což je poměrně časově náročně. Součástí textu je i hodnocení této metody, kde jsou shrnuty její hlavní výhody a nevýhody. V úvodních částech článku je rovněž stručně popsána historie znázorňování skal v československých topografických mapách vydávaných po druhé světové válce, protože popisovaná metoda na ni v určitém smyslu navazuje.

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