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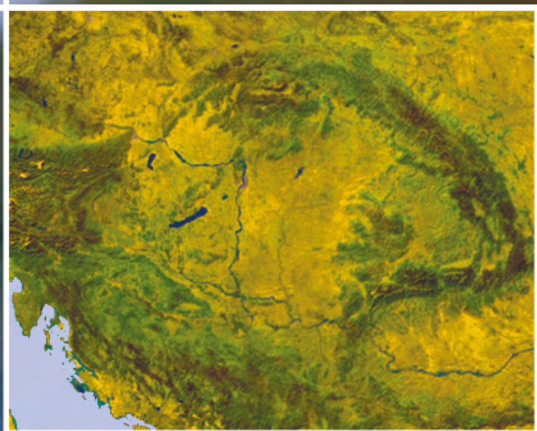

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CONTENT

Book review section

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Natural reduction of Ukraine's population: Regional dimensions of the national threat

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Abstract

A significant decline in Ukraine's population is mainly due to its natural decrease, which began in the 1970s and 1980s in the rural areas and had been determined by the objective trends in demographic transition, the inertia effect of the demographic losses in the past and the social policy of the political regime at that time. Likewise, the social and economic crisis of the 1990s deepened the depopulation processes. In the present research, correlation analysis demonstrated a relationship between the current dimensions of natural population decline and a number of socio-demographic factors (proportion of the rural population, mean age of the population, divorce rate and the mean age at first marriage). In recent years, the effects of the demographic crisis have been particularly acute in North-eastern and Central Ukraine, due to the deepening disproportions in the age and sex structures of the population. However, in the capital of Ukraine, Kyiv, and in some western regions, the natural decrease in population is less acute because of more balanced social and demographic indicators. Although religious and ethnic factors contribute to some extent to greater natural population growth, especially in the western and south-western regions, their impact on the processes of population reproduction in Ukraine is generally not significant. To sum up, in order to stop natural population decline in Ukraine, it is important to ensure more favourable conditions for demographic development in the economic, social, informational and cultural spheres of society. Furthermore, in areas of acute demographic crisis, it is important to raise the issue of rural reconstruction involving a variety of organisational and economic mechanisms.

Keywords: natural population decline, depopulation, demographic transition, demographic crisis, age structure, birth rate, death rate, Ukraine

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Introduction

The ongoing population decline since the beginning of the 21st century is characteristic of all the post-Soviet states of Central and Eastern Europe (Skryzhevska, Y. and Karácsonyi, D. 2012). Some authors even consider the process of depopulation that developed countries have experienced in recent decades a global direction in the demographic development of society, the so-called *Second Demographic Transition* (SDT) (Van de Kaa, D.J. 2002). However, while in most Central and Eastern European countries population decline has been primarily attributed to the negative balance of external migration, the main factor in the significant reduction of the demographic potential of Ukraine and most of its regions has been depopulation. The population decline is, thus, due to a negative natural increase, rate which is so substantial that it already poses a national threat.

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According to official statistical bodies, from 1993, when the first decrease in the population of Ukraine was recorded, to 2020 the population of Ukraine decreased by 10.342 million people (19.8%). In the same period, the loss of population due to a negative migration balance was 1.221 million people, i.e. about 11.8 percent of the total population decline. Meanwhile, natural decrease resulted in a decline of 9.121 million between 1993 and 2020, i.e. an average of more than 330,000 people annually. As a result of its declining population, Ukraine dropped in the World Population Ranking from the 22nd place at the beginning of the 1990s to the current 35th place.

However, the actual migration losses are larger and therefore the general population demographic losses also, because a significant part of Ukrainian migrant workers while still retaining Ukrainian citizenship, became permanent residents in the countries that had provided employment to them. Such a critical demographic situation poses a real nationwide threat of an increase in negative socio-political and economic consequences, such as ageing, declining human resources, a growing economic burden on working age people, declining rural settlements and their gradual disappearance in some regions.

Since depopulation in Ukraine is significantly differentiated by regions, and given the general negative trends, the demographic situation is particularly critical in some areas whereas in others it is more favourable due to different natural, historical and geographical, socio-economic and ethno-geographical conditions. Therefore, determining the role of various factors in natural population decline in Ukraine is first of all an important cognitive problem and an opportunity to understand the mechanisms of demographic development in the post-Soviet space in general. Nonetheless, identifying the causes, consequences and regional differences of depopulation in Ukraine may serve as an information basis for a demographic policy aimed at addressing various impacts of the demographic crisis and balancing regional demographic trends.

Scientific considerations of population decline

The analysis of the demographic situation in Ukraine should be considered in the context of demographic development in other countries as well as with regard to different methodological approaches to their assessment. In particular, in order to understand the problems of population ageing in Ukraine, it is important to analyse the processes of age structure change of the US population in the context of social problems which was dealt with in the studies of Brown, D.L. and Glasgow, N. (2012) and Kulcsár, L.J. (2019). In these works, the authors emphasise the relationship between a low employment rate, social infrastructure and population ageing. Likewise, Champion, T.G. and Shepherd, J. (2006) consider the objectivity of the preconditions for the decrease of the rural population in Great Britain. Furthermore, the dependence of age structure change in the context of various aspects of employment is revealed in the works of Stockdale, E. (2011). In addition, he draws attention to some positive aspects of population ageing, such as increasing social activity in such an environment. However, the most heated discussions about depopulation are being conducted among Russian demographers, since a number of experts – e.g. Vishnevskii, A.G. (2005), etc. – reasonably emphasise the processes of natural population decline in view of industrialisation and urbanisation. Other authors (e.g. Levashov, V.I. and Staroverov, V.I. 2000), however, see the causes of population decline exclusively in the contradictions of the social, political and economic transformations that have taken place in Russia over the past thirty years. This is, however, a biased approach. At the same time, Polish demographic analysis focuses on the impact of the migration of Polish youth on depopulation in Poland and its geography, primarily in rural areas, (Bański, J. and Wesołowska, M. 2020).

The demographic crisis in Ukraine has caused a significant resonance, primarily among Ukrainian academics and scientists.

This is especially true of the scholarly works of academic researchers such as Rohozhin, O.H. (2004), Terets, V.M. (2009), Shvydka, H.Y. and Shevchuk, P.Y. (2009), Gladun, O.M. (2013), Libanova, E.M. (2014), and others who emphasise the social and economic aspects of the demographic crisis. A geographical analysis of the demographic processes underlying the crisis of population reproduction especially in relation to its ageing and increasing mortality, presented by regions of Ukraine, was carried out by Melnyk, I. (2012), Yavorska, V.V. (2015), and Yeliseyeva, L. (2015). Further, Dzhaman, V.O. (1998), Baranovskyi, M. (2009), Sehida, K. (2009), Hudzelyak, I.I. (2011), Poruchynska, I. (2014), and others carried out research in individual regions. As most of these studies were conducted at the level of individual regions, it was not possible to fully reproduce the problem of depopulation on a nationwide scale.

The seriousness of the demographic crisis in Ukraine has also been highlighted in the publications of foreign authors (e.g. Rowland, R.H. 2004). However, few publications in English devoted to rural depopulation in Ukraine have been published. The study by Skryzhevska, Y. and Karácsonyi, D. (2012) analysed major trends and regional variations in Ukraine's rural population decline, as well as the problems of rural areas that have been affected by the demographic crisis. In addition, it attempted to provide recommendations that would help revitalise rural areas. Still, the available academic literature does not make it possible to create a holistic image of the formation and reproduction processes of natural population decline in Ukraine, as a number of issues in understanding the problem have remained unresolved. These are, in particular: 1) lack of conceptual explanation of regional demogeographic differences, including the emergence of negative demographic trends in the north-eastern regions of Ukraine; 2) not all socio-cultural mechanisms of depopulation have been investigated, no interdependence of demographic and social indicators has been revealed; 3) ethno-demographic and some territorial and political aspects of the problem have not been covered.

Given the lack of knowledge in the field of natural population decline in Ukraine, *the purpose* of this study is to identify trends in the genesis and evolution of this demographic phenomenon, determine the main mechanisms of its reproduction in the context of modern socio-economic conditions and identify practical opportunities to thwart some negative demographic trends. In order to accomplish the set goals, *the following tasks* shall be addressed: 1) determine the historical and geographical trends in the reproduction processes for the population of Ukraine over the past 50 years; 2) identify modern socio-demographic relationships and interdependencies in the process of natural reduction, their socio-political significance, as well as allocating areas of demographic disaster and areas with a relatively favourable demographic situation; 3) substantiating perspective variants of regional policy in the demographic sphere, which would contribute to a certain improvement of the demographic situation.

Conceptual and methodological frameworks

The present study is based on the theory of demographic transition that emphasises the objectivity of moving away from the traditions of a large family and natural population decline in the process of industrialisation and urbanisation. A working hypothesis of the study is also the statement that the emergence and spread of depopulation in Ukraine within the command-administrative system was influenced by some features of the then state policy, whereas in transition economies the process of deepening population decline occurred under the influence of socio-economic uncertainty. Based on these methodological principles, the following sequence of research steps was executed: 1) in order to identify the origins of depopulation, a historical and geographical analysis of natural growth decline in the regions of Ukraine in the second half of the twentieth century was carried out; 2) a structural and functional analysis of the current demographic situation in Ukraine was conducted using correlation analysis to determine the system of relationships in modern socio-demographic relations; 3) the areas of critical demographic situation at mid-level administrative units were identified by means of the cartographic method; 4) using a promising approach, proposals to halt the processes of natural population decrease in the context of socio-economic development in Ukraine were substantiated.

Pearson's parametric coefficient of correlation was used to identify the relationships between natural increase values and other social indicators according to paragraph 2. The precondition for its use has been the normal distribution of variables. The Kolmogorov–Smirnov tests demonstrate no difference from normal at 95 percent confidence level in the majority of these indicators, except for marriage, GRP per capita and migration balance (but at a 99% confidence level their distribution does not differ from normal either). Consequently, the use of Pearson's correlation coefficient is valid.

Correlation analysis found significant 95 percent direct and inverse relationships between natural increase and various socioeconomic indicators. The detected correlation may be an indicator of the existing causal relationships between the phenomena, though it may indicate dependence of the phenomena under analysis on some common factor. To avoid redundancy (repeated consideration of the same factors due to the interdependence of factors), a multiple regression analysis was performed using the SPSS program. The influence of factors such as, mean age of the population, number of marriages (per 1,000 people), mean age at first marriage (for both men and women respectively), rate of divorces, proportion of the rural population, proportion of females in total population, proportion of Ukrainians and Russians in total population, percentage of working-age women (15–64 years) in total female population on birth and death rates as well as on natural increase was analysed. In addition, the impact of the number of arrivals, departures and migration balance (per 10,000 people), the number of students of higher education institutions (per 1,000 people), gross regional product (GRP) per capita, average monthly income of household members and average monthly household expenditures were also considered. Data of the regions of Ukraine and the city of Kyiv for the year 2019, except for the fully or partially occupied Crimea, Donetsk and Luhansk regions, a total of 23 administrative units were used for the analysis.

Main results of the research

Europe's most developed countries abandoned the traditionally large family model before World War II. This process was associated with cultural and attitudinal changes in the midst of rapid industrial development, urbanisation and education of the population. Such trends led, on the one hand, to a sharp decline in birth rates and to a reduction in mortality on the other. Following the post-WW2 baby boom, the processes of declining birth rates resumed, laying the groundwork for the upcoming fall in reproduction in these countries.

When, where and why did depopulation begin in Ukraine?

Ukraine's demographic development in the early second half of the 20th century generally corresponded to European trends with regard to declining natural growth. Yet, it had its differences, which were due to the greater influence of traditional views on the family and the peculiarities of the socio-demographic policy of the then USSR. Thus, it can be stated that based on a gradual and steady decrease in birth rates (from 20.5‰ in 1960 to 15.1‰ in 1975) and natural increase (from 13.6‰ in 1960 to 5.1‰ in 1975) (The population of USSR 1988. Statistical Yearbook 1989), Ukraine underwent, like other European countries, a new stage of demographic transition toward a shrinking reproduction.

The ongoing processes in Ukraine had, nevertheless, specific features related to the demographic losses of the past and the then state policy. In particular, state policy promoted artificial urbanisation and a negative ideological attitude to rural areas, which had been seen as a source of socio-political conservatism. As a result, most rural settlements were declared unpromising (Gladun, O.M. 2013). Shvydka, H.Y. and Shevchuk, P.Y. (2009), in their analysis of the influence of previous age cohorts on the sex and age structure of the population, determined the significant changes in the population structure of Ukraine which had been caused by the two world wars, forced collectivisation and the famines of 1932–1933 and 1946–1947. Similarly, the historian Kovpak, L.V. (2010) states that, as a result of the expanding and resettlement campaign forcibly carried out by the state, out of the 58.5 thousand farms in Ukraine in the 1960s, only 8.4 thousand survived. Therefore, a retrospective reflection on the annual indicators of natural increase in Ukraine's rural and urban areas testifies that it was in rural areas where the process of depopulation began in the 1970s and 1980s. This is evidenced by the fact that the rate of natural increase in rural areas of Ukraine has been negative since 1979 (The population of USSR 1988. Statistical Yearbook 1989). According to Karácsonyi, D. *et al.* (2014), the 1960s and 1970s witnessed the mass resettlement of the rural population in cities, which resulted in an annual increase of half a million in the population of the block of flats-cities ("Khrushchovka-cities"). The rural areas experienced a fall in population, first caused by emigration, then – from the 1970s onwards – by the low natural increase rate of an ageing society.

In regional terms, depopulation processes in rural areas began in North-eastern Ukraine (Chernihiv, Sumy, Poltava regions), in territories located in the area of influence of the largest cities of the country – Kyiv and Kharkiv. The economic opportunities and relatively well-developed infrastructure of these cities attracted the young rural population, which had been dissatisfied with the socio-economic living conditions in the then Ukrainian village. Meanwhile, mass migrations of young people from these regions to cities caused a steady ageing of the rural population and a decrease in natural growth. This first occurred in the villages of Chernihiv, Sumy, Poltava regions and later in the neighbouring regions. Against that backdrop in 1980, when the average natural growth rate of the rural population in Ukraine was -0.7 per thousand, in the Chernihiv region it dropped to -7.6 per thousand, in Sumy to -7.5 per thousand, and in Poltava to -7.3 per thousand (The national economy of the Ukrainian SSR in 1990, 1991). Thus, the excessive focus of economic development policy on large urban centres, in combination with unfavourable social and living conditions of rural areas caused large disparities in the age structure of residents of large cities and rural areas in the north-eastern and central regions. The decline in natural growth rates in these regions was influenced by the indirect demographic losses of rural areas stemming from the 1932–1933 famine (Levchuk, N.M. *et al.* 2015) as well as by the state policy, which encouraged the younger population to leave for the eastern regions of the former USSR to raise their economy. Meanwhile, migrants from rural areas faced housing and other social problems in the major cities, so under the pressure of domestic problems and urban lifestyles, they switched to the "one family – one child" model. As a result, in rural areas, where the traditions of the large family had been retained, the age structure did not promote simple or extended reproduction, whilst in large cities a socio-psychological transition to narrow reproduction was already underway (Dnistrianskyi, M.S. 2012).

In consequence of the negative demographic transformations of the 1970s, by 1980 the coefficient of natural growth of the whole population (both rural and urban) had become negative in five regions (Vinnytsia, Poltava, Sumy, Cherkasy, Chernihiv), to which the Kirovohrad region was added in 1985 (The national economy of the Ukrainian SSR in

1990, 1991). Later on, the demographic transition spread to all regions, albeit to varying degrees. Therefore, in general, the natural increase in the population of Ukraine was steadily declining. In 1990, depopulation spread to almost half of the regions of the country, and the total rate of natural population growth in Ukraine became minimal (only 0.6‰). Such trends in demographic development resulted in a natural decrease in population, which occurred in 1991, when the natural growth rate became negative (-0.8‰). This was mainly due to the growth of depopulation processes in villages, because in urban settlements in 1991, the natural increase remained positive (1.1‰) (State Statistics Service of Ukraine 2021). However, by 1992, the natural decline had already taken place in the urban environment due to new approaches to family modelling in the process of the demographic transition. Since then, Ukraine's depopulation has continued to this day, though in some western oblasts (regions), given the larger proportion of the rural population, its optimal age structure and the preservation of large family traditions, the natural growth rate kept positive for a long time. In particular, during the 1990s the natural growth rate remained positive in the Zakarpattya and Rivne regions. However, at the beginning of the 21st century, depopulation expanded to most of the western regions. Thus, since then, Ukraine has entered a phase of acute demographic crisis. The term "demographic crisis" was first used in Ukraine in 1985 by the Ukrainian demographer Steshenko, V. (Skryzhevska, Y. and Karácsonyi, D. 2012).

Accordingly, the trends leading to a natural population decline, which had appeared in the 1980s, deepened as a result of the economic crisis of the 1990s. Certain economic problems, especially job losses and forced travel abroad to earn money, deepened social problems at the family level, which in turn, led to a sharp increase in the number of divorces and a significant decline in marriages. Thus, whereas in 1991 there were 9.5 marriages and 3.9 divorces per thousand people, in 2000 the number of marriages dropped to 5.6 and the number of divorces increased to 4.0 per thousand (State Statistics Service of Ukraine 2021). However, it is difficult to identify a direct relationship between declining natural growth and economic development, as economic indicators in the western regions with a relatively favourable demographic situation were worse than in regions where unfavourable demographic processes (declining birth rates and rising mortality, ageing population, growing demographic burden on the working population, etc.) were particularly noticeable. It seems, therefore, that the natural population decline was due mostly to the inertia of demographic processes of the pre-war and post-war periods. A secondary factor was the combined effect of a number of socio-demographic factors, primarily deepening disparities in sex-age and socio-age structures of the population in the process of urbanisation, socio-psychological changes to marriages and divorces, which had violated the mechanisms of reproduction in general.

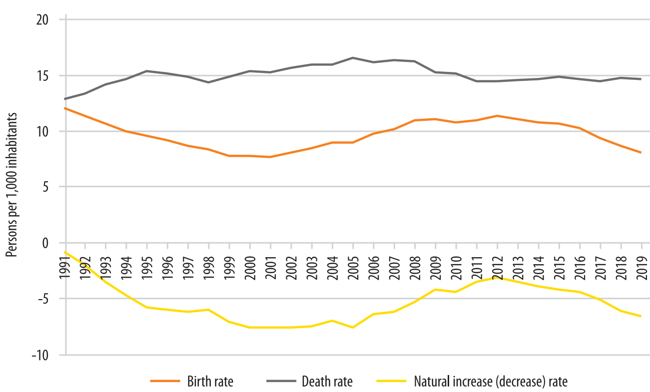


Fig. 1. Dynamics of the natural movement of the population of Ukraine

From 2006 to 2012, there was a generally positive tendency to an increase in the natural growth rate (in 2005 this indicator was -7.6‰, in 2012 only -3.1‰) *(Figure 1)*. This increase in natural growth occurred due to a slight rise in birth rates (in 2005 the birth rate was 9.0‰, in 2012 it amounted to 11.4‰). This growth is associated, as evidenced by the study of Hudzelyak, I.I. (2011), with an intensification of the demographic policy of the state, manifested in an increase in financial support in case of childbirth, and a slight decrease in mortality, mainly only among the urban population. At the same time, there were some positive socio-cultural changes in approaches to family planning at the level of individual families, in particular, withdrawal from the principle of "one family – one child". This was evidenced by a gradual increase in the total fertility rate per woman (2005: 1.213, 2013: 1.506). At the same time, since the beginning of the 21st century there has been a steady increase in the average age of men and women marrying for the first time: from 25.2 years for men and 22.0 years for women in 2000 to 26.3 years for men and 23.3 for women in 2013 (State Statistics Service of Ukraine 2021). In fact, however, since 2014, all demographic indicators in Ukraine have steadily deteriorated due to the new social instability caused by military actions that have resulted in the violation of the territorial and political integrity of Ukraine (Yavorska, V.V. 2015). Given the socio-political instability, the demographic situation in areas close to the front line has deteriorated sharply.

According to official information from statistical bodies, since 2005 the migration balance in Ukraine has been positive and this trend continues to this day. In particular, during 2019, the population of Ukraine as a result of external migration increased by 21,512 people (State Statistics Service of Ukraine 2021). However, in fact, the external migration situation is not optimistic at all because of the growing numbers of Ukrainian citizens moving abroad to study and work between 2014 and 2019. According to some estimates, from 7 million to 9 million people were involved in the foreign migration process at that time every year, negatively affecting all aspects of population reproduction in Ukraine (www.slovoidilo.ua 2019).

What national and regional trends in demographic development are characteristic of modern Ukraine?

In present-day Ukraine, the natural population decline continues (in 2019, the natural growth rate was -6.6‰) as a result of decreasing birth rates and high mortality rates, including infants under 1 year. The population has been ageing rapidly. According to Yeliseeva, L. (2015), this trend poses "a serious challenge to the financial and economic system, especially in the field of public finances, the pension system and the labour market". The gender structure of Ukrainian society also remains unbalanced, especially in the eastern and central regions, where there are many more females because of the ageing society. Equally noticeable is the differentiation of the regions of Ukraine by all demographic parameters, in particular by birth, death and natural increase rates *(Figures 2–4).* The cartographic representation of these indicators reveals a certain correspondence of the main areas with the highest mortality and the lowest birth rate and vice versa, which indicates primarily the role of basic social, gender and age population parameters.

Both in terms of fertility and mortality, crisis situations can be observed in the north-eastern regions, where due to all mechanisms of population reproduction, the trend towards depopulation has only deepened: natural growth rates are the lowest (from 0 to 8‰) and mortality rates the highest (from 18‰ to more than 22‰) there. As a result, in certain places natural reduction has reached -20 per thousand and less (see *Figures 2–4*). In recent years, the central and some eastern regions have come close to these crisis regions by the main demographic dynamics, thus, testifying to the interconnectedness of a number of socio-demographic factors, which has also been confirmed by the calculated correlation coefficients *(Figure 5).* Thus, correlation analysis reveals a close inverse relationship between natural increase, on the one hand, and mean age as well as the predominance of women over men (correlation coefficients (-0.91) and (-0.80), respectively) on the other.

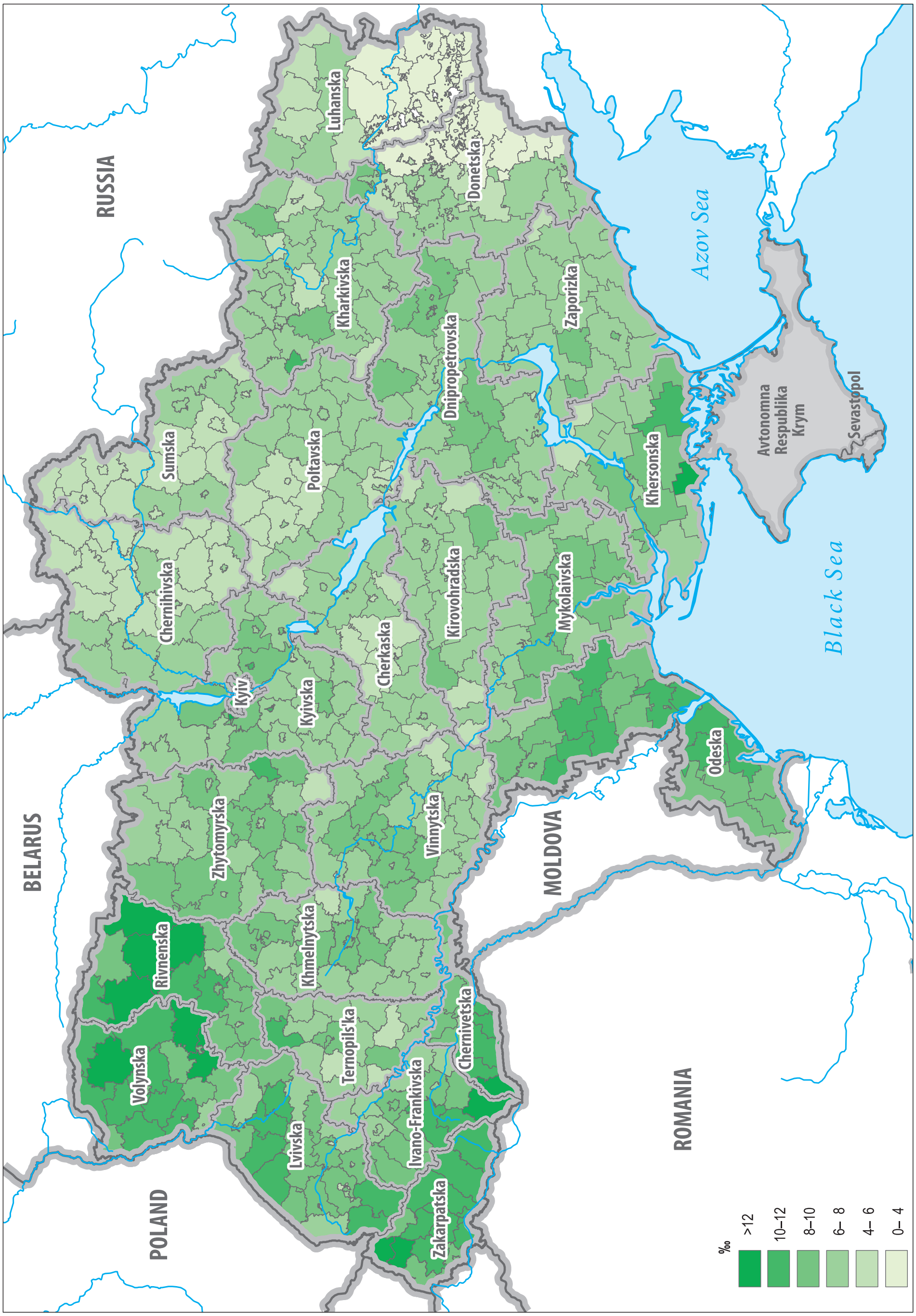
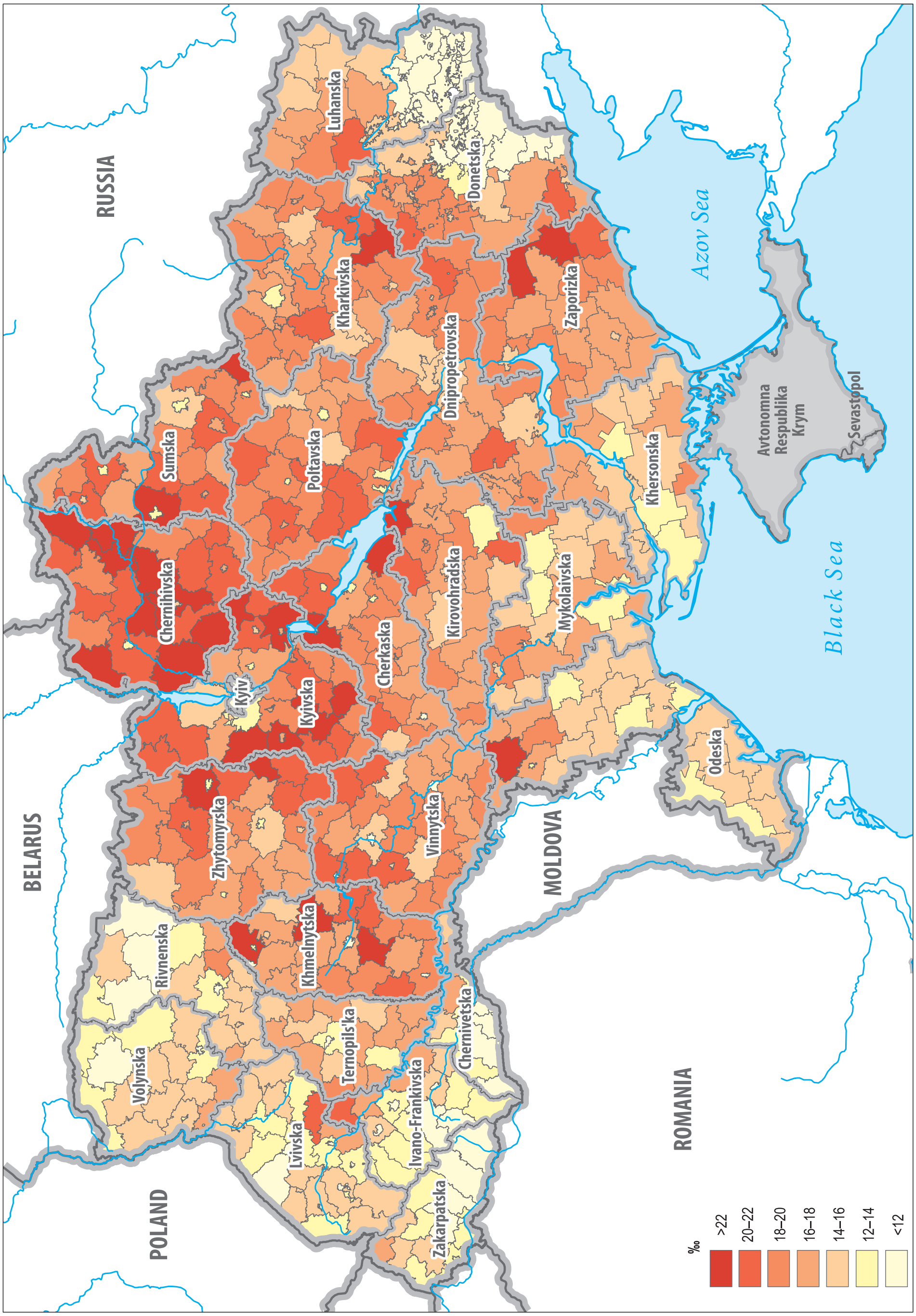


Fig. 2. Crude birth rate in Ukraine by rayon, 2019.



FFig. 3. Crude death rate in Ukraine by rayon, 2019.

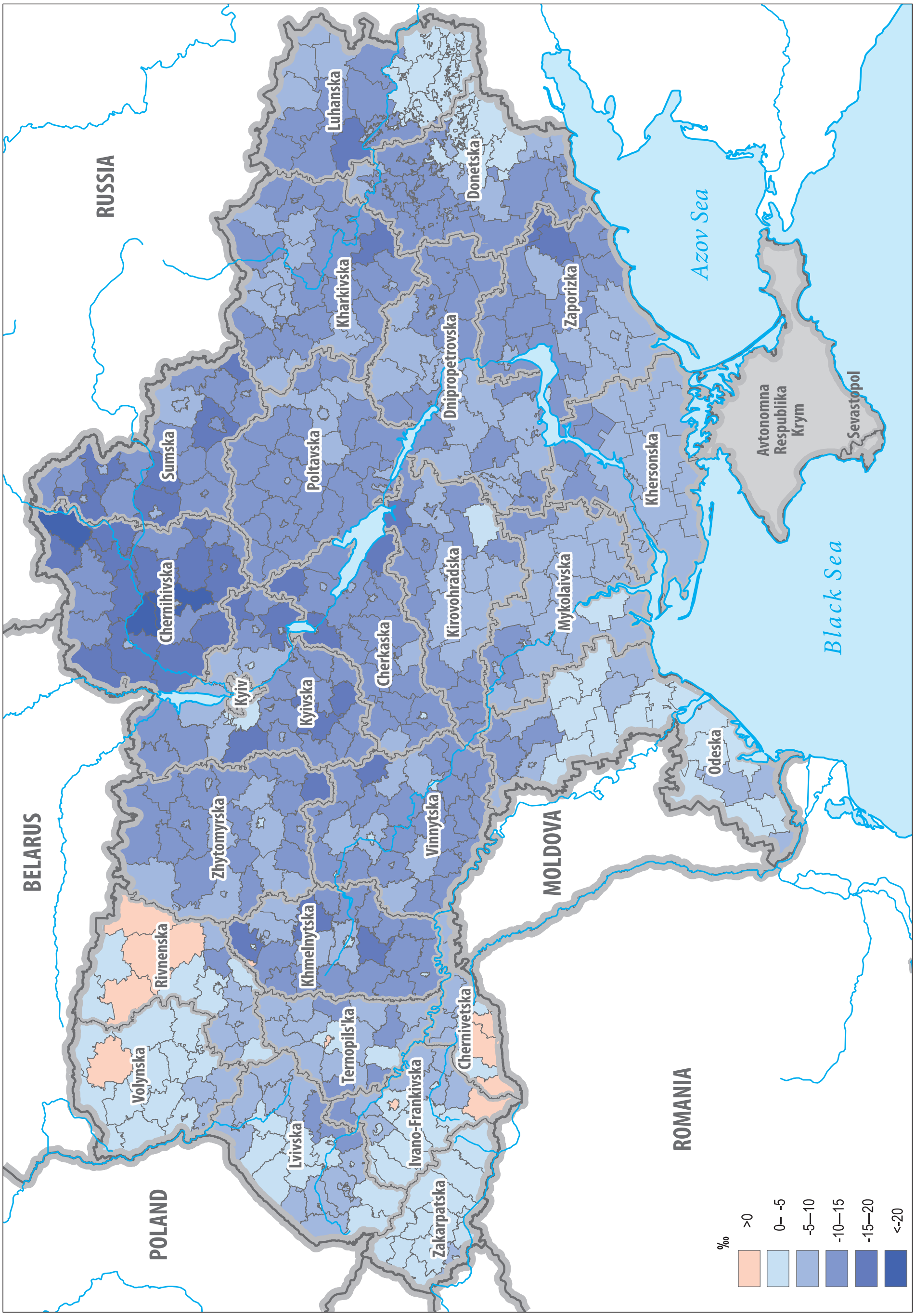


Fig. 4. Rate of natural increase in Ukraine by rayon, 2019.

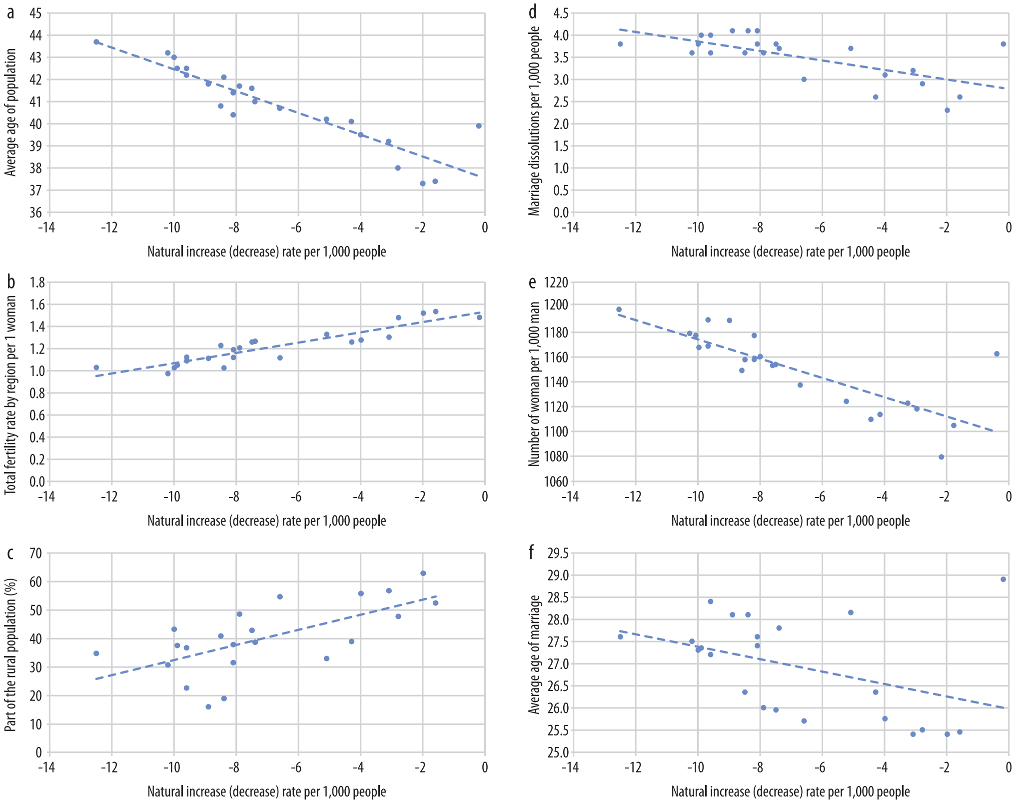


Fig. 5. Graphs of correlations of: a = natural growth rate and mean age of the population (-0.91); b = natural growth rate and fertility rate (0.91); c = natural growth rate and proportion of the rural population (0.65); d = natural increase and divorce rate (correlation coefficient (-0.67); e = natural growth rate and degree of female dominance over males (-0,80); f = natural growth rate and the mean age at first marriage (-0,41).

There is some connection, but not a close one, between natural growth rate and the proportion of rural population by regions, which indicates that in regions with a larger proportion of rural population, its gender and age structure has been better balanced, which in turn, contributes to greater natural growth. Similarly, correlation analysis confirms a negative impact of the divorce rate on the natural population growth and a somewhat less distinct relationship between natural decrease and increase in the age at first marriage. Therefore, *particularly noteworthy* in this regard is the relationship of all negative demographic trends. As Terets, V.M. (2009) emphasises, in a truly demographic sense, the ageing population of Ukraine will slow down the process of putting an end to depopulation, firmly maintaining the vicious cycle of "low birth rate – ageing – depopulation". At the same time, correlation analysis did not reveal a dependence of natural growth by regions on GRP per capita and the official unemployment rate.

S*tepwise multiple regression analysis* was used to produce a statistical model which, through the inclusion of three variables (mean age of the total population, number of full-time students per thousand people, proportion of rural population), explains 97.2

percent ($R^2 = 0.972$) of the dispersion of natural increase. The formula for calculating the natural increase (*NI*) of administrative units of the highest level in Ukraine is:

$$NI = 50.486 - 1.491\ MA + 0.108\ SP + 0.040\ PRP,$$

where *MA* is the mean age of the total population (years), *SP* is the proportion of full-time students (per 10,000 people), *PRP* is the proportion of the rural population (%) in the administrative unit. The average deviation of natural increase values, calculated on the basis of the obtained formula from the real values, was -0.4 per thousand *(Figure 6).*

The role of mean age of the population in natural increase is obvious both in view of the increased proportion of young people of childbearing age and the smaller proportion of elderly people, which reduces mortality (obviously, an inverse effect is also traced here: higher growth reduces the mean age of the total population). As for the proportion of full-time students in higher education institutions, it may be interpreted as a complex indicator that is also related to the higher proportion of young people on the one hand, and to the level of material well-being, which significantly correlates with both birth and death rates, on the other hand. The inclusion of the proportion of the rural population in the formula is explained by the increased indicators of the total birth rate in rural areas, especially in the Rivne, Volyn and Chernivtsi regions.

The identified socio-demographic interdependencies objectively reveal and explain other modern regional-demographic differences, some of which appeared in the late 20th–early 21st centuries (Dzhaman, V.O. 1998). Thus, the relatively high proportion of people in the younger age categories and the capital's lowest mortality rate in Ukraine (see *Figure 3*) due to better medical care, determine generally the lowest level of natural population decline in Kyiv (see *Figure 4*). The demographic preconditions in the regions of Western Ukraine have also remained quite favourable, which is attributed to the social and age characteristics of the population. For instance, in some administrative districts of Volyn, Rivne, Ivano-Frankivsk and Chernivtsi regions a positive natural increase is maintained. However, most districts of Ternopil region have already entered the phase of more intensive depopulation (natural reduction here ranges from -5.0‰ to -10.0‰) (see *Figure 4*). Similarly, marriage rates are traditionally higher in western Ukraine whereas divorce rates are lower, due to some religious and cultural characteristics and a significant proportion of a more conservative rural population.

The negative consequences of the natural population decline in Ukraine are especially noticeable in rural areas, leading not only to a decrease in the average population of settlements, but also to their gradual disappearance, especially in the Chernihiv, Sumy, Poltava, Kyiv, Zhytomyr and Kirovohrad regions *(Figure 7)*. Thus, during 1991 and 2016, 460 villages were struck from the state register. Further, there were no more permanent resi-

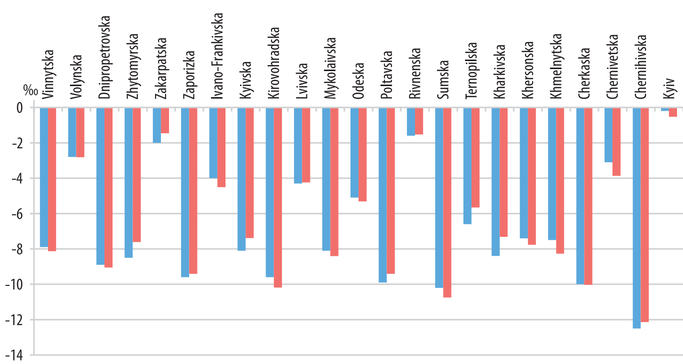


Fig. 6. Natural population growth in the regions of Ukraine (‰, year 2019) according to the State Statistics Service of Ukraine 2021 (in blue), and the multi-regression model (in red).

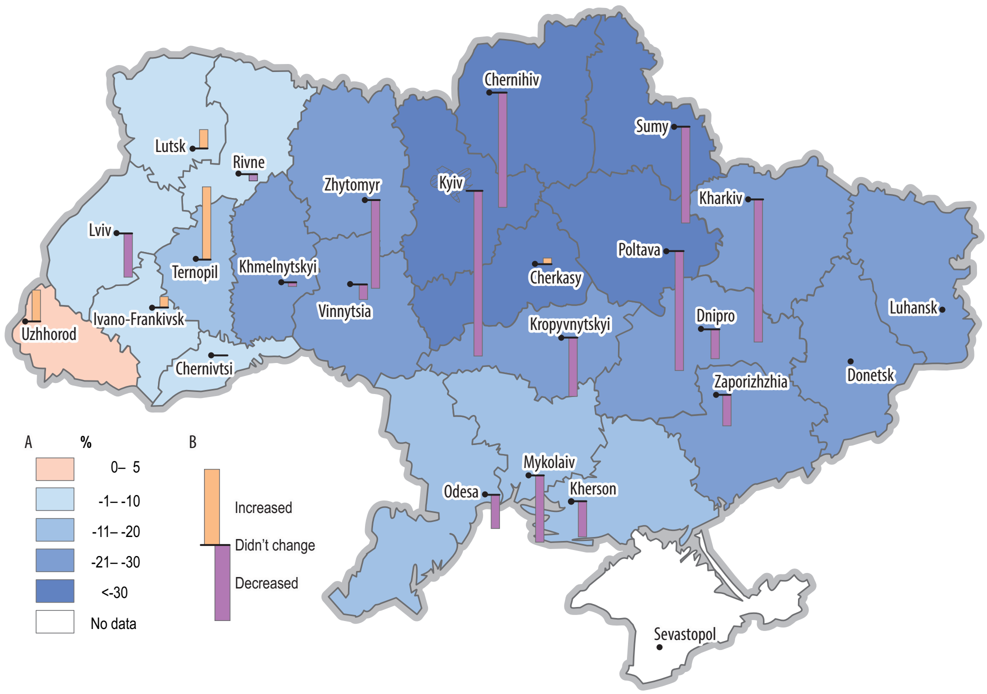


Fig. 7. Change in the number of rural population and rural settlements in the period 1991–2019. – A = The part of rural population increase (decrease) as a result of natural increase (decrease) relative to 1991, in percent. B = Change in the number of villages (1 mm represents 2 villages).

dents in several hundred other settlements. In addition, in 35 percent of villages in the Sumy region, and in 32 percent of villages in the Chernihiv region not one child was born during 2011 and 2013 (Chaika, I.M. 2018). Given the particularly critical situation in the rural areas of the northern districts of Kyiv, Chernihiv and Sumy regions, where the natural population growth is lower (-20%) and rural depopulation has been particularly intense, this territory may be defined as *a special area of demographic disaster.*

The processes of population reproduction were indirectly influenced and have been influenced by various cultural, attitudinal and ethnic factors. In particular, a higher level of religiosity in the western regions which, according to sociological research, amounts to 81 percent, and is, thus, much higher than in the central (70%), eastern (53%) and southern (52%) regions (Razumkov Centre, 2020), resulted in a much smaller number of divorces, and indirectly (due to significantly less abortions) has contributed to rising birth rates.

The ethnic structure of the population is to some extent an additional factor for differentiating regional demographic development. The analysis of the ethnic factor has been complicated by the lack of official statistics of the components of natural increase in terms of nationalities. Therefore, we must limit ourselves to indirect indicators. Thus, because of immigration, more than 200,000 Crimean Tatars arrived in the Crimea between 1989 and 2001. They were characterised by a much higher birth rate, as evidenced by the fact that the mean age of the Crimean Tatars at the time of the 2001 census was 33.4 years, which was significantly lower than the mean age of ethnic Ukrainians (38.2

years) and ethnic Russians (41.9 years). The slightly lower average age of Ukrainians compared to Russians indirectly indicates higher values of natural increase in their environment, which has some impact on natural growth rates in the regions with the highest share of Ukrainians, especially in the West. Similarly, according to the 2001 census, the demographic indicators of the Romanian ethnic group were more favourable than the average in Ukraine (mean age 35 years, proportion of the population of retirement age 19.3%) (State Statistics Service of Ukraine 2004), which also affected the reproduction processes in some districts of the Chernivtsi and Zakarpattya regions. However, over the past two decades, there has been a decline in the birth rate of this ethnic group, as evidenced by the current indicators in areas of their mass settlement (see *Figure 2*).

The situation is somewhat different with the Transcarpathian Hungarians, whose reproductive activity has been lagging behind the indicators of Transcarpathian Ukrainians for decades (on average, the birth rate is lower by 2–3‰ – Molnár, J. and Molnár, D.I. 2017). The high natural growth of the Gypsy (Roma) population is well known: it is estimated that the number of births per thousand people among them in the Eastern European region is close to 30 (Molnár, J. *et al.* 2016; Taylor, A. *et al.* 2018). This affects primarily the reduction of depopulation of the regions of their mass population, especially the Transcarpathia and Odessa regions. In the south-west of the Odessa region, in Budzhak, there are also large numbers Bulgarians, Moldovans and Gagauz. Demographically, they are characterised by a slightly higher birth rate relative to all-Ukrainian indicators (Ganchev, O.I. 2020), but the rate does not stand out against the background of the local Ukrainian and Russian populations.

Differences in mortality rates among the ethnic groups are less noticeable and are related primarily to the age structure: within the young Roma population it varies between 5–10 per thousand, among Romanians it is about 11 per thousand, and among others it reaches 13–16 per thousand (Molnar, J. 2013). Thus, the difference in the natural population growth of nationalities is determined primarily by the birth rate.

Is it realistic to halt the processes of population decline in Ukraine?

The development of demographic processes in Ukraine today is extremely detrimental. Moreover, the negative trends may deepen in the Covid-19 pandemic, leading directly and indirectly not only to higher mortality rates but also to a significant reduction in the number of births and marriages. Since stable mechanisms underlying reproduction of various negative demographic phenomena have already been formed, there is no reason to hope for a large-scale and rapid improvement in the demographic situation. We can only talk about mitigating depopulation trends by means of demographic and socio-economic policies, which should not be limited to individual steps, such as financial assistance in case of childbirth, but should have a comprehensive and regionally differentiated nature. Such a policy is possible based on the implementation of interrelated activities of governmental institutions and civil society organisations, which would provide a system of effective measures in various fields (economic, social, informational, cultural, political). However, in this case it is necessary to determine the actual possibilities, taking into consideration the objective realities and the contradictions of the demographic transition. In this context, it is important to identify those parameters in the demographic situation which may actually be influenced to varying degrees. Thus, it is almost impossible to revive the traditions of a large family, given the current trends in the demographic development of developed countries. Nevertheless, the provision of social guarantees and a relevant information policy makes it possible to gradually move away from the “one family – one child” model and ensure a transition to the national average, to simple reproduction (one family – two children). This feasible policy complies with the social and cultural orientations of modern Ukrainian society. Similarly, some other demographic indicators may also be improved by means of a targeted public policy approach. Thus, in particular, it is possible – through social advertising and using information technology – to promote family values. Another step forward, according to European practice, may be the development and practical implementation of programs to support young families and provide them with housing and employment in the related field, which would reduce divorce rates and the average age of men and women at first marriage, as well as indirectly contribute to the growth of birth rate. Additionally, better health care may reduce child mortality, and an effective implementation of life safety systems may reduce unnatural death cases resulting from man-made disasters and traffic accidents. Such measures are obviously unable to balance the gender and age structure of the population in the near future, but they could initiate some trends, the positive consequences of which would become noticeable in the future.

The greatest beneficial effect for finding a delicate demographic balance would be the creation of better socioeconomic conditions to ensure reproductive processes in general. This primarily concerns a significant breakthrough in creation of new jobs, which will reduce labour migration abroad. The latter is currently the major factor causing a negative impact on the demographic situation since permanent residence abroad disrupts family life. Since Ukraine is significantly dominated by urban population (69.5%), the need to create jobs in cities is particularly acute, especially given the negative trends of deindustrialisation of recent years. Therefore, only the re-industrialisation of the state combined with the development of small and medium-sized businesses in the service sector is able to provide a basis for the working age population employment, which is essential for enhancing family social relations and improving relations among generations. It is noteworthy that a new industrialisation policy has every reason to limit the emigration of scientists and technicians abroad, as well as the departure of young people for higher education in neighbouring countries, since these factors pose serious threats to human resources in view of the loss of highly qualified personnel.

However, optimising the reproductive processes in rural areas is even more difficult because of significant regional differences, in particular the deep demographic crisis affecting rural regions. This situation will require highlighting certain all-Ukrainian principles of socio-economic policy to improve the demographic situation in the Ukrainian countryside and at the same time it will need regionally differentiated approaches to solve specific problems. At the national level, a necessary prerequisite for improving the demographic situation in rural areas is strengthening the economic base of rural areas, thereby improving the engineering and socio-cultural infrastructure of the Ukrainian countryside. For their implementation, both favourable internal (first of all, significant agro-climatic resources) and external preconditions (growth of world food needs) exist. On the other hand, the state has extremely unfavourable economic conditions. Hence, it is important to set priorities, because at present leading positions among business entities are being occupied by large agricultural holdings, which do not have the interests of the local peasantry in mind. At the same time, the socio-economic rise of rural areas requires the opposite – strengthening farming and cooperation of small agricultural producers, implementing of which is important in the agrarian reform. National and international experience indicates the requirement for functional diversification in rural areas for their successful development to meet the needs in the 21st century: successful villages, along with agricultural function, acquire other functions, such as tourism, or those, located close to large cities – residential (Žoncová, M. 2018).

Given the existence of remote areas, especially in North-eastern Ukraine, where there are few rural settlements left or where there is a lack of a young population, it is necessary to speak about the rural reconstruction of the countryside rather than its strengthening. The need is to create new settlements in the process of the agrarian reform by encouraging the resettlement of the population from densely populated rural areas or cities. With regard to the aforementioned, Geographer Baranovskyi, M. (2009) has emphasised the need to create resettlement and service support centres in rural depressed areas in order to stop negative demographic trends. Such a necessary and purposeful policy for strengthening the economic foundations of rural areas may be combined with administrative and territorial reforms through the creation of various communal enterprises and the development of roads. Therefore, a high rate of natural population decline is today not only an important social problem, but also a problem of national security, and its solution requires the development of a comprehensive government program and the efforts of central and local authorities and the public in general.

Conclusions

As a result of our research, the following important conclusions can be drawn:

1) Natural population decline in Ukraine began in the 1970s and 1980s in the rural areas of the north-eastern and central regions of Ukraine and had been determined primarily by the objective trends of demographic transition, the inertia of the demographic losses of the past, as well as subjective factors such as artificially accelerated urbanisation combined with the policy of declaring most villages unpromising and encouraging the young population to move to the eastern regions of the then USSR to raise their economy. Adverse social conditions in rural areas and the purposeful encouragement of mass migration of young people from rural areas to large industrial centres laid the groundwork for the mass ageing of the rural population and a sharp decline in birth rates. The socio-economic crisis of the 1990s deepened the depopulation processes, but it was not the main cause of the demographic crisis.

2) Economic difficulties in Ukraine in the 1990s, having formed a state of social uncertainty in society, contributed to a growing number of divorces, a reduction of the number of marriages, an increase in the marriage age and a deterioration of some other demographic characteristics. All these factors have served to deepen the process of depopulation in Ukraine. Nevertheless, the socio-economic crisis was not the main cause of population decline.

3) Correlation analysis found a relationship between the rates of natural population decline and a number of socio-demographic factors (proportion of the rural population, mean age of the inhabitants, divorce rate and the average age at first marriage). Therefore, today the particularly acute effects of the demographic crisis continue to appear in North-eastern and Central Ukraine, where the disparities in gender, age and the socio-age structure of the population are the most noticeable, while a relatively better situation can be observed in the Ukrainian capital Kyiv and in some western regions where the socio-demographic indicators are more balanced. Ongoing and, in some cases, increasing labour migration, which brings instability to family relationships, has been a significant negative prerequisite for demographic development in Ukraine and the other post-Soviet countries.

4) Though religious and ethnic factors contribute to some extent to greater natural growth, especially in the western and south-western regions, their impact on reproduction processes in Ukraine in general has not been significant. Current trends toward a decrease in the religiosity of the population, which replaced the religious upsurge in the 1990s, and are to a varying degree characteristic of all regions of Ukraine and other post-Soviet states, will further limit the im-

portance of marital status. As a result, they may also indirectly complicate the demographic situation.

5) In order to stop the natural decline of the population in Ukraine, it is important to provide better preconditions for demoreproductive activity, which would relate to the economic, social, informational and cultural spheres of society. In areas of acute demographic crisis, it is important to raise the issue of rural reconstruction involving a variety of organisational and economic mechanisms.

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Residential suburbanisation in the hinterland of Bratislava – a case study of municipalities in the Austrian border area

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Abstract

This paper provides an overview of the process of residential suburbanisation in the hinterland of Bratislava. The study focuses on the municipalities around the Austrian border area. The main aim of the paper is to investigate the characteristics of cross-border suburbanisation, which is a significant spatial phenomenon in the municipalities of northern Burgenland and the south-eastern part of Lower Austria. The analysis has a spatio-temporal dimension, as it depicts the time-space characteristics of the phenomenon – both for a single time point, as well as for a time series from the approximate beginning of the onset of suburbanisation up to the present. While monitoring the growth of the number of Slovaks in the study area, we observed a gradual increase in all the selected municipalities of the Austrian border area, with the distance from Bratislava being a significant factor here. The analysis of migration in the surveyed municipalities showed predominantly positive migration efficiency – immigration was negated by emigration only to a small extent (compared to suburbanisation in the Slovak hinterland of Bratislava, which is, however, relatively high). The structural characteristics of Slovak immigrants, where the younger age group of 30 to 44 years followed by a child component up to 14 years predominated, attest to the ongoing process of suburbanisation. The research confirmed the advancing residential suburbanisation and expansion of the cross-border suburban hinterland of Bratislava.

Keywords: residential suburbanisation, cross-border mobility, migration, Bratislava, Austrian border area, Slovaks in the Austrian border area

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Introduction

The following paper is a case study of municipalities in the Austrian border area from the aspect of the process of residential suburbanisation in the hinterland of Bratislava. During the 1980s and 1990s, when the process of residential suburbanisation in the hinterland of Vienna had already reached its peak, socialist urbanisation was gradually subsiding in Bratislava (Matznetter, W. 2004). The fall of socialism in Slovakia in 1989, including the subsequent transformation of society and the economy related to this also resulted in a change in the predominant urbanisation processes of the state.

In the newly founded Slovak Republic, conditions for the wider development of suburbanisation had not yet been created (Šveda, M. 2011a; Šveda, M. and Križan, F. 2011). The construction industry had fallen into a deep recession; financial support mechanisms from both the state and the banking sector (e.g. mortgages) for the development of housing construction were lacking. However, after the resolution of this shortcoming, residential suburbanisation gradually began to develop in our country, which had only begun to show its first signs in the 1990s. And so, residential suburbanisation in the hinterland of Bratislava took on an imaginative dimension after the turn of the new millennium, which had been characterised by the construction of new houses and residential sites on so-called "green-fields", as well as the transfer of the urban population and

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its activities to the surrounding municipalities of the Bratislava hinterland (Šveda, M. 2011a).

However, cross-border suburbanisation is a specific and more complicated form of residential suburbanisation. Its origin and development require that more conditions be fulfilled since it goes beyond state, cultural, and linguistic borders. For this reason, it is understandable that suburbanisation only began to develop in Slovakia after a delay of several years when compared to "common" residential suburbanisation. In the case of Bratislava, Slovakia's accession to the European Union in 2004 and the Schengen Area in 2007 were widely accepted as the starting mechanisms of this process (Ira, V. *et al.* 2011; Balizs, D. and Bajmóczy, P. 2018, 2019). The reason was that the two events led to the formation of an integrated border between the Slovak Republic and the Republic of Austria. The unrestricted movement of people, goods, and capital across the national border was thus ensured.

This paper provides an in-depth analysis of Austrian border area municipalities, which fall into the suburban hinterland of Bratislava within three Austrian districts – Gänserndorf, Bruck an der Leitha, Neusiedl am See – all of which directly border Bratislava itself. The ongoing cross-border suburbanisation in this area has a significant time-space dimension. We assume that the intensity of the process has changed markedly over time, with Slovaks contributing to a large extent in this process. We also believe that the distance of suburban Austrian municipalities from Bratislava plays a significant role as well. Migration flows of Slovak citizens to suburban municipalities as well as their age structure are further aspects that complete the picture of the ongoing process of cross-border suburbanisation.

Theoretical background

There is no uniformly recognised and defined time for the onset of decentralisation tendencies of population distribution in the USA and Western Europe. Some authors tend to date the beginning of modern suburbanisation from either 1815 (Jackson, K.T. 1987) or 1920 (Ptáček, P. 2002). In the case of Austria, suburbanisation reached its highest intensity in the 20th century (Matznetter, W. 2004). However, the development of cross-border settlement of the countries of post-communist Central and Eastern Europe has been different, since the suburbanisation processes only began after the fall of the communist regime and were accompanied by a considerable delay (Stanilov, K. and Sýkora, L. 2014).

Residential suburbanisation is a process that has significantly transformed the social and physical environment of the Bratislava hinterland from rural to suburban in the last two decades. It has affected the spatial structure of settlements (Šveda, M. 2011a; Šveda, M. and Pazúr, R. 2018) and the social and demographic structure of the population (Šveda, M. and Šuška, P. 2014). Further, it has caused significant changes in land use (Šveda, M. and Vigašová, D. 2010; Šveda, M. 2011b).

The term 'residential suburbanisation' is most often understood as the shift of residents, households, and their activities outside the territory of urban centres, usually to their hinterland with a low population density (Ptáček, P. 2002). This is expressed most notably by the construction of new family houses on agricultural land. In addition, residential suburbanisation in these geographical conditions is characterised by increasing residential densities or renovation of the original housing stock (Šveda, M. 2011a). The spatial extent of suburbanisation mostly depends on the population size of the city (Kubeš, J. and Nováček, A. 2019).

As an analogy, it can be said that cross-border residential suburbanisation is a process in which the migration of the urban population and their activities to the adjacent rural area on the opposite side of the border is monitored. Since suburbanisation can be divided into both residential and commercial categories (or in some cases seasonal), it is necessary to state that in this article the term 'cross-border suburbanisation' shall be understood exclusively in its residential form.

The phenomenon of cross-border suburbanisation has been observed in several places in the geographical area of Europe. Examples are known from the German-Netherlands (Strüver, A. 2005), Italian-Slovenian (Jagodic, D. 2011) and German-Polish borders (Barthel, M. and Barthel, E. 2018).

Cross-border suburbanisation in the hinterland of Bratislava represents a rare type of suburbanisation due to the human geographic location of the capital situated on the border of three states. Initially, its development was captured by a few authors who defined the first suburbanised municipalities beyond the Slovak borders (Dillinger, T. 2004; Slavík, V. *et al.* 2011; Šveda, M. 2011a). On the Austrian side of the border, they labelled three municipalities (Kittsee, Berg, Wolfsthal) as cross-border-suburban. Several years later, these Austrian border municipalities in the suburban hinterland of Bratislava were described by Huemer, J. (2018) as the most dynamically growing villages in Austria.

It can generally be stated that the development of cross-border suburbanisation in the hinterland of Bratislava is not only the result of the classical development of suburbanisation, which progressed in conformity with the evolutionary development of the urban organism or the urban region, but is also a specific result, since its realisation required the interplay of several positive circumstances.

As previously mentioned, the first catalyst for the development of cross-border suburbanisation occurred with the Slovak Republic's accession to the European Union in 2004, and the second with its inclusion in the Schengen area in 2007. Both events significantly contributed to the increased mobility of people in cross-border areas and opened the door to new opportunities, including suburbanisation.

According to Decoville, A. and Durand, F. (2018), cross-border population flows are driven by differences between the two sides of the state border, whether in commodity prices, wages, unemployment rates, or real estate prices. In the case of the cross-border suburbanisation studied in this paper, the significant "pull" effects of decentralisation of the population included better transport accessibility and lower real estate prices (Hardi, T. *et al.* 2010; Slavík, V. *et al.* 2011; Šveda, M. 2011a; Huemer, J. 2018).

Nowadays, however, due to the cross-border mobility and migration of the population, the agglomeration of the city of Bratislava extends over the state borders of Austria and Hungary (Hardi, T. 2016). Overall, this is an area which, according to Hardi, T. (2016), is inhabited by a specific group of transnational borderlanders, whose cross-border way of life is not motivated by ethnic or linguistic reasons, but rather by the practicality of everyday life. According to Martinez, O.J. (1994), transnational borderlanders are people who maintain significant ties with a neighbouring nation. They are individuals whose lifestyle strongly reflects foreign influences.

Methodology

We obtained the data for the research from the sources of the Austrian Statistical Office (Statistik Austria) from the STATcube database – Statistical Database. The analytical part was commenced by applying an indicator concerning the share of Slovaks to a wider range of municipalities in the three border districts of Gänserndorf, Bruck an der Leitha, and Neusiedl am See – with a total of 104 municipalities *(Figure 1).* Then, based on an analysis of the number of Slovaks in the border area, we narrowed down the number of municipalities which can be considered subject to cross-border suburbanisation *(Figure 2).*

In the investigated areas, we identified 17 municipalities where the relative share of Slovaks exceeded 5 percent of the municipal population, and it was these municipalities that formed the narrower selection of municipalities as subject of more detailed research. The reason for choosing the above indicator for creating a smaller coverage of municipalities was our fundamental premise that it is not possible to label those Austrian municipalities in the hinterland of Bratislava as suburban that do not have a Slovak popu-

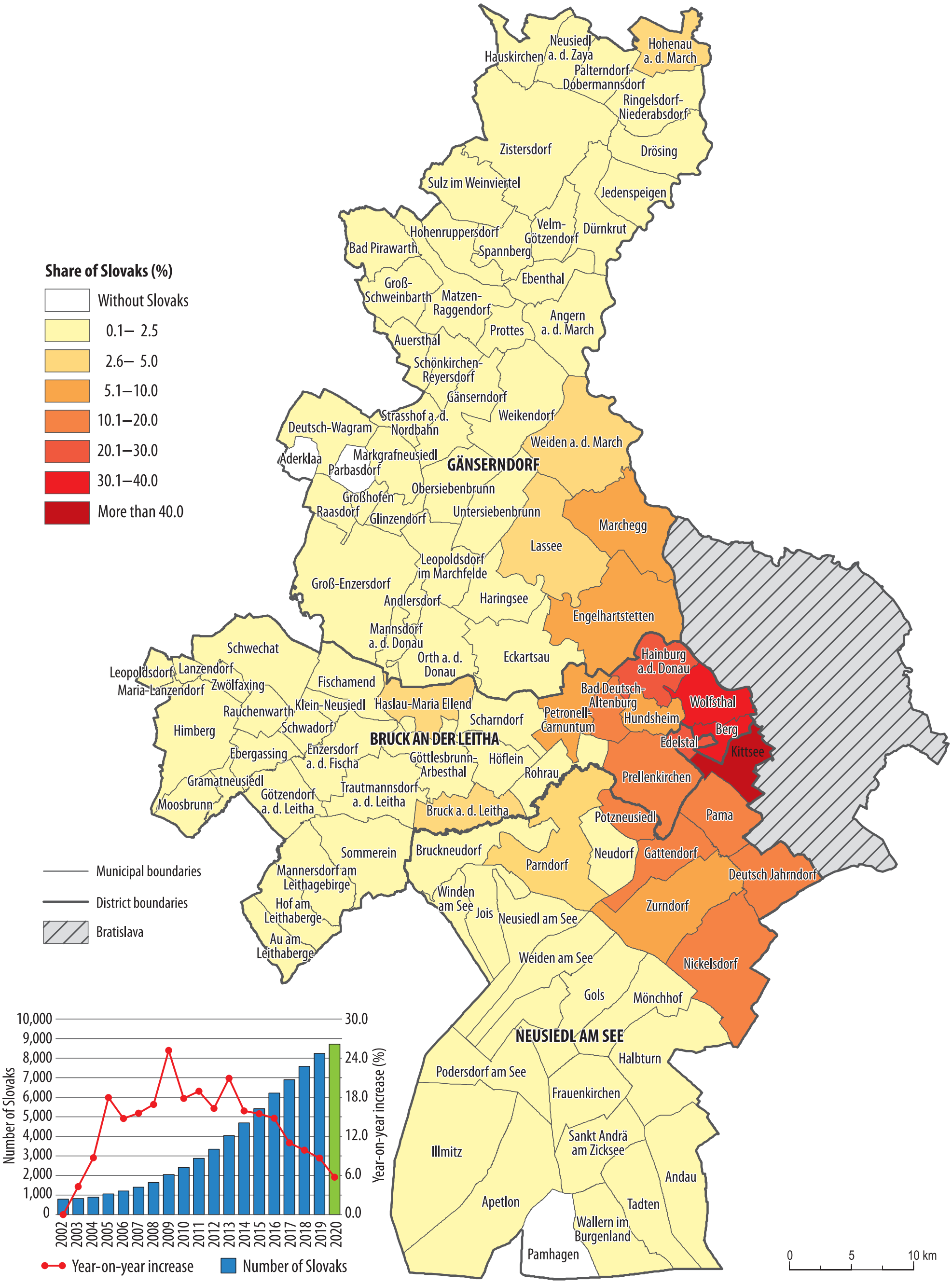

Fig. 1. Relative representation of Slovaks in the municipalities of the districts of Gänserndorf, Bruck an der Leitha, and Neusiedl am See (2020). *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

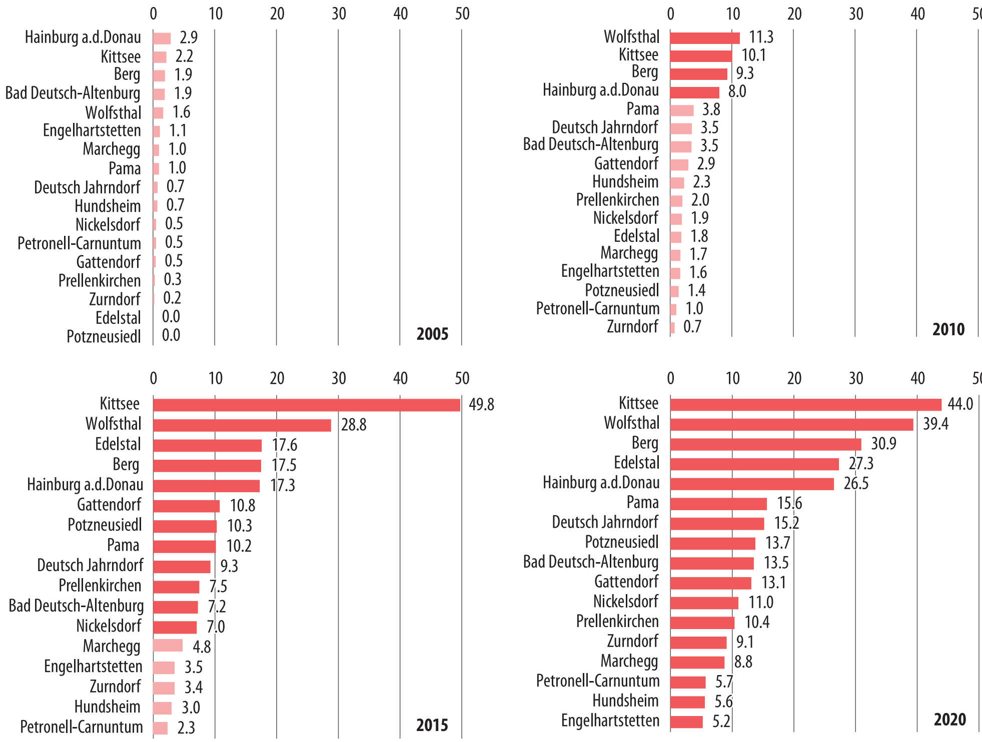

Fig. 2. Relative representation of Slovaks (in %) in selected municipalities of the Austrian border area in the hinterland of Bratislava (2005, 2010, 2015 and 2020). *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

lation. We also had to consider the fact that these three Austrian districts have the phenomenon of double suburbanisation (i.e. from Bratislava and Vienna) (Meyfroidt, A. 2017), and the relative share of Slovaks represented an indicator by which we could define the suburbanising influence of Bratislava.

The migration of the urban population to suburban localities is a crucial aspect of suburbanisation (Šprocha, B. *et al*. 2017). In the scope of the research, we also analysed the migration of residents of the affected municipalities, and in order to do so, we focused on migration efficiency (migration efficiency ratio – *MER*). This relationship applies (Stillwell, J. *et al.* 2000):

$$MER_i = \frac{D_i - O_i}{D_i + O_i} * 100,$$

where MER_i = migration efficiency ratio of the municipality *i*, D_i = the sum of immigrants (inflows) to the municipality *i* from other municipalities, O_i = the sum of emigrants (outflows) from the municipality *i* to other municipalities.

The values range from -100 to +100. With a value of 0, the migration efficiency is zero, which means that there has been no change in population, although both immigration and emigration have taken place. The closer the value of migration efficiency is to the value of +100, the greater the positive migration efficiency (immigration is not "negated" by emigration, or only minimally). In contrast, in the case of values approaching the value of -100, those emigrating are not replaced by those immigrating, or only to a very low extent. Migration efficiency basically measures the degree of imbalance or asymmetry between a pair of migration flows. If flows are symmetrical, they suggest that migration functions as a process that keeps the settlement system in dynamic balance (Rowland, D.T. 1978).

Results

The development of the number of Slovaks in our case represents the significant determinant of the research, which is considered to be an essential prerequisite for demonstrating the cross-border suburbanisation of the Bratislava hinterland. The representation of Slovaks in the population structure of the municipalities of the Austrian border area is a valuable indicator of residential suburbanisation showing the degree of decentralisation processes from Bratislava to its cross-border suburban hinterland. With that said, it is no different in the case of the Hungarian hinterland of Bratislava, where the authors Balizs, D. and Bajmóczy, P. (2019) indicated an increase in the number of Slovaks in the villages of Rajka, Bezenye, and Dunakiliti, as well as others.

According to Šveda, M. *et al.* (2020a), Bratislava, as the dominant residential centre, creates a network of various connections, where the intensity decreases with increasing distance from its core. *Figure 1* depicts the relative share of Slovaks in the total population of the municipalities of the three Austrian districts that neighbour Bratislava. As we can see, the largest share of the Slovak population is in the municipalities closest to Bratislava. We can also observe a gradual decline in the relative number of Slovaks with increasing distance from the Slovak capital, as well as the relatively compact nature of the cross-border region with the representation of the Slovak minority. However, as far as this region is concerned, it is interesting to note that the relative share of Slovaks is higher in its southern part than in the northern part. Outside the mentioned region of the 17 selected municipalities, the share of Slovaks in the districts of Neusiedl am See, Bruck an der Leitha, and Gänserndorf is marginal. We consider the rising number of Slovaks and their increasing share in the population of Austrian municipalities as the essential characteristic of residential suburbanisation. It distinguishes the suburbanisation of Bratislava from the suburbanisation of Vienna. Therefore, we exclude from our research municipalities that have a very low share of Slovaks in the total population of the municipality. For this distinction, we set the lower limit at a level of 5 percent Slovak population in the total population in the given year 2020.

In the set of graphs provided (see *Figure 2*), we can see the development of growth in the number of Slovaks in the selected municipalities of the Austrian border area in 5-year intervals. In summary, it is evident that for the monitored 15 years, significant changes occurred in the relative representation of Slovaks in the total population of the selected municipalities, with the largest growth occurring in 2015 and 2020. While in 2005 no selected municipality had a share of Slovaks over 5 percent, in 2010, Wolfsthal, Kittsee, Berg, and Hainburg an der Donau significantly dominated. The significant rise in the number of Slovaks in the total population of these municipalities is the result of their initial suburbanisation in the hinterland of Bratislava after the Slovak Republic's accession to the European Union and the Schengen Area (Ira, V. *et al.* 2011; Balizs, D. and Bajmóczy, P. 2018, 2019). Furthermore, the excellent transport accessibility to the centre of Bratislava combined with favourable property prices was a crucial criterion for their specific choice (Hardi, T. *et al.* 2010; Slavík, V. *et al.* 2011; Šveda, M. 2011a; Huemer, J. 2018).

In 2015, 12 municipalities had already reached more than a 5 percent share of Slovak residents. For example, in Kittsee, the relative share of Slovaks soared from 11.3 percent (2010) to a record 49.8 percent (2015). From a spatial point of view, in 2015, the number of municipalities directly neighbouring Bratislava was still growing, (e.g. Pama or Deutsch Jahrndorf). However, in this period, the Slovak population began to move more notably to municipalities that were not immediately adjacent to Bratislava (Edelstal, Nickelsdorf, Gattendorf, Potzneusiedl, and Prellenkirchen). We consider the year 2020 to be evidence of the continuing suburbanisation of the hinterland of Bratislava, when the share of Slovaks in the above-mentioned municipalities continued to grow; while in four other municipalities the relative representation of Slovaks rose above the 5 percent threshold (Marchegg, Petronell-Carnuntum, Hundsheim, Engelharstetten). In Kittsee, the share slightly decreased compared to 2015, and according to the relative representation of Slovaks, the village of Wolfsthal came significantly closer to it.

Figure 3 shows the dynamics of the development of growth/decline of the population of the affected municipalities. When looking at the three consecutive periods, the number of inhabitants in the given municipalities developed differently. The majority of the analysed municipalities maintained the trend of population growth in all periods. Of all the municipalities, the most extreme population growth was seen in the municipality directly neighbouring Bratislava, namely Kittsee, which increased by 75.5 percent from the start of the analysed period (2006–2020). According to Šveda, M. *et al.* (2020b), since 2005, the number of inhabitants has increased tenfold in the municipality by migration each year; in the last decade alone, migration reached 150 inhabitants per year. More than 70 percent of this increase was accounted for by cross-border migration. As part of our research, we found that the most dynamic period can be considered the years 2011–2015 when the municipality increased its population by almost 40 percent. We also recorded high growth in population during the three periods in another border municipality: Wolfsthal (from the beginning of the analysed period, the village grew by 55.9%); in Berg, the number of inhabitants increased by 32.5 percent over 15 years, and in Edelstal by 29.6 percent. Constant modest growth of inhabitants during the three periods occurred, for example, in the town of Hainburg an der Donau or in neighbouring Bad Deutsch-Altenburg.

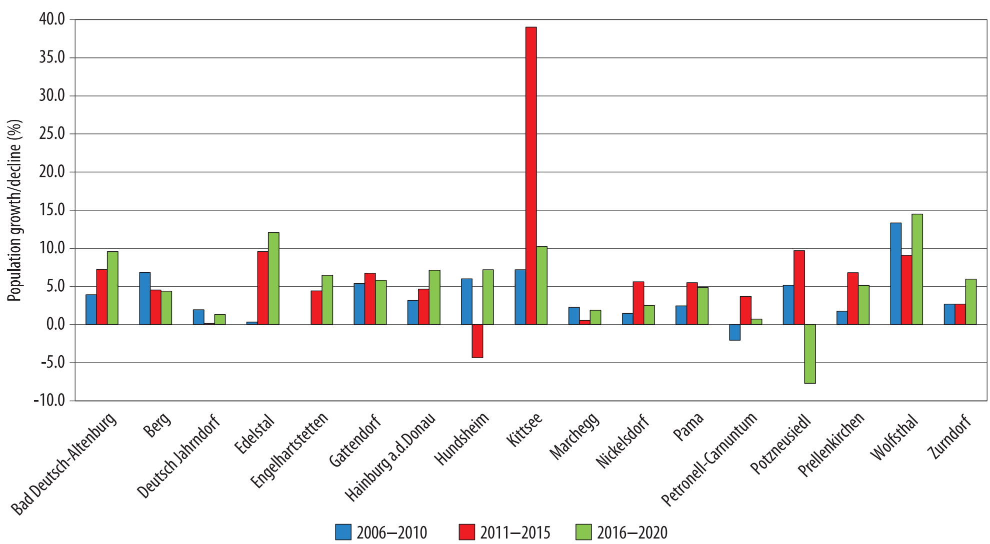

Fig. 3. Growth/decline of inhabitants (in %) of selected municipalities of the Austrian border in the hinterland of Bratislava (2006–2010, 2011–2015, 2016–2020). *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

Migration, which is defined as a dynamic and constantly modifying process that causes changes in the socio-geographical, economic, social, and demographic structures of areas, represents a natural component of people's lives (Káčerová, M. and Horváthová, R. 2014). Citizens of the Slovak Republic, in accordance with European Union legislation on the free movement of EU citizens, have the right to stay in Austria for more than three months. Afterwards, if they come to Austria with the intention of permanent or temporary settlement, they are obligated to register with the competent public authority within four months from the date of arrival, where they will obtain an "Aufenthaltskarte" residence permit upon request. After five years of legal and continuous residency in Austria, they acquire the right to obtain permanent residence. Upon request, they are issued a certificate of permanent residence, the so-called "Bescheinigung des Daueraufenthalts" ("Certificate of permanent residence") (www.oesterreich.gv.at).

The migration efficiency of Slovaks *(Figure 4)* showed positive values in all the analysed municipalities of the Austrian border area; this means that in the examined 5-year periods, immigration (immigrants) exceeded emigration (emigrants). It is clear, however, that in some municipalities, migration efficiency has slightly weakened over the periods (e.g. Gattendorf, Nickelsdorf, Pama, Wolfsthal or Zurndorf), while in others, it has slightly strengthened (e.g. Bad Deutsch-Altenburg, Engelhartstetten) or remained at about the same level (Hainburg an der Donau, Marchegg).

Since 2008, we have witnessed a relatively sudden upswing in the number of immigrating Slovaks. The increase can be explained by the entry of Slovakia into the Schengen Area, which removed the barrier to free movement of Slovak citizens entering Austria. The rapid rise of Slovak immigrants in the surveyed municipalities of the Austrian border area peaked for the first time in 2012 when their number reached 670. Since that year, the number of immigrants has ranged from 600 to 700 people per year. We recorded the highest number of immigrants in 2016 – a total of 676 persons. From the viewpoint of the emigration of Slovaks, we perceive a gradual increase in their number since 2010 with a maximum value in 2019, when 284 Slovaks left selected municipalities in the Austrian border area (https://www.statistik.at). We can also

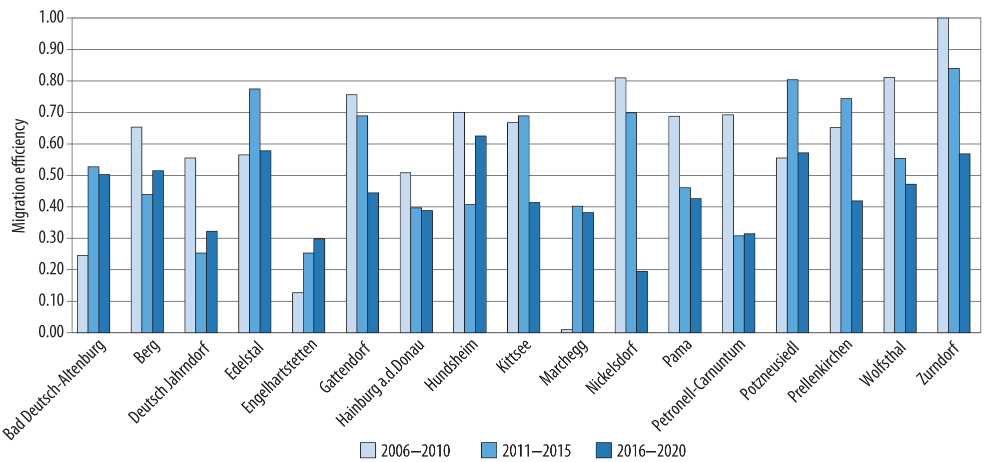

Fig. 4. Migration efficiency in selected municipalities of the Austrian border area in the hinterland of Bratislava (2006–2010, 2011–2015, 2016–2020). *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

perceive the issue of residential stability as a certain compacted result of the evaluation of the ideas and expectations of the population concerning the new environment and its social and material characteristics. The desire to stay in the locality for a longer period can be an important signal, which not only testifies to satisfaction with the quality of housing but can also be an indicator of the integration of new residents into local social structures. On the contrary, the desire to make a change of residence may be a reflection of the nonfulfilment of the original expectations about better housing (Šveda, M. 2016).

Within each of the analysed 5-year periods, the town of Hainburg an der Donau and the municipalities of Kittsee and Wolfsthal showed the largest migration turnover (immigrants + emigrants). Wolfsthal and Hainburg an der Donau have experienced a relatively high level of irregular migration efficiency over 15 years, falling slightly since its peak in 2008 (even with some fluctuations). We observed a similar trend in the municipality of Kittsee as well, which reached its maximum migration efficiency in 2011 *(Figure 5).*

In terms of the available structural characteristics of migrants, we charted the representation of individual age groups in the total number of immigrants *(Figure 6)*, since migration has a significant effect on changes in the population structure and reproductive behaviour of the population (Podolák, P. and Šveda, M. 2019). As we can observe, the 30 to 44 years old group significantly predominates among immigrants, followed by the children's component up to 14 years old. Seniors and people over the age of 60 are relatively absent in the population of Slovak immigrants in selected Austrian municipalities. The presented findings correlate with the general starting points of suburbanisation, which emphasise the significant representation of young couples and families with small children in suburbanisation (Ouředníček, M. 2002), as well as with specific migration characteristics of the Slovak hinterland of Bratislava (Podolák, P. and Šveda, M. 2019).

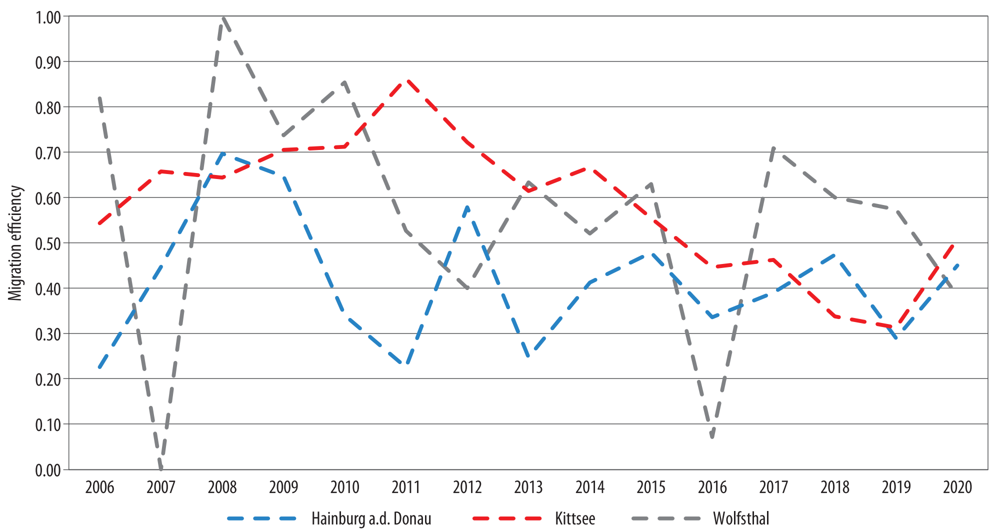

Fig. 5. Migration efficiency in selected municipalities of the Austrian border area in the hinterland of Bratislava (Hainburg an der Donau, Kittsee and Wolfsthal) in the years 2006–2020. *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

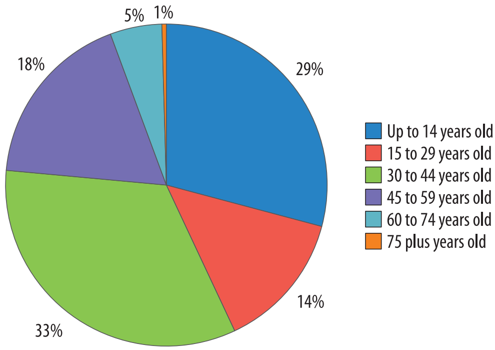

Fig. 6. Age structure of immigrating Slovaks to selected municipalities of the Austrian border area in the hinterland of Bratislava (2006–2020). *Source:* STATcube – Statistical Database (https://www.statistik.at). Processed by the authors.

Conclusions

Bratislava, together with its hinterland, represents an urban region with exceptionally large potential for further development. In 1993, it became the capital of the newly formed Slovak Republic, and its importance was further enhanced by Slovakia's entry into the European Union (2004) and the Schengen Area (2007). Important aspects of Bratislava's macro-location that have influenced the city's formation, historical development, and current development include a strategic location at the point of contact of two great cultures, a location between the cities of Vienna and Budapest, a gateway between the former western (capitalist) and the eastern (communist) world, as well as an important location in respect of other areas of Slovakia (Korec, P. 2013). The presence of the state border with Austria and Hungary should be considered the most important aspect when assessing the micro-location (Korec, P. *et al.* 2020). At the origin and development of the process of cross-border suburbanisation, the specific political and geographical location of the city concerning the state borders of neighbouring countries is important (free movement of population and capital across state borders must be observed).

The position of Bratislava as a dynamic economic, administrative, political, and cultural centre was also connected with the gradual revival of (not only residential) construction. For this reason, there has been a significant increase in real estate and land prices in the city and its Slovak hinterland, as well as a significant increase in the possibilities for further development. Therefore, the Austrian border, with its several accessible municipalities in this area represents an attractive alternative for Bratislava residents considering suburban housing (Ira, V. *et al.* 2011).

When monitoring the development of the number of Slovaks, a gradually increasing number in all the selected municipalities of the Austrian border area was observed. In 2020, the municipalities of Kittsee, Wolfsthal, and Berg had the highest percentage of Slovak inhabitants, while in absolute terms, the most Slovaks lived in the town of Hainburg an der Donau. Therefore, we consider Kittsee, Wolfsthal, Berg, and Edelstal to be the most dynamically growing municipalities.

Within the surveyed municipalities in the hinterland of Bratislava, positive migration efficiency was manifested throughout the 2006–2020 period, that is, the number of arriving Slovaks (immigrants) showed higher values than departing Slovaks (emigrants). Immigrants heading to the Austrian hinterland of Bratislava are characterised by a greater emphasis on the quality of housing (for example, migrants heading to Rajka in Hungary, who are seeking more affordable housing). This quality is represented not only by the aesthetic environment of the "clean and tidy" municipalities of Austria, but also by the provision of services (for example, the availability of school facilities) (Šveda, M. *et al.* 2020b). However, life in Austria is often associated with other additional benefits that may persuade people to move there. In addition to a more favourable traffic situation, more advantageous mortgages or state housing allowances are offered. Often emphasised non-economic factors include higher environmental awareness, better services, and a higher level of office work, community spirit, and other positively perceived characteristics of social and cultural life (Ira, V. *et al.* 2011). Developers specialise in the new local market and build specifically for Slovak clients (Meyfroidt, A. 2016).

Migration in the functional metropolitan region of Bratislava is quite heterogeneous internally, thus migration trends are different between various categories of migrants that are separated by age and education. The Bratislava region attracts the youngest educated migrants (Novotný, L. and Pregi, L. 2019). The continuing process of suburbanisation, however, was also evidenced by structural characteristics, namely the age composition of Slovak immigrants, which was dominated by the age group of 30 to 44 years old, followed by a child component up to 14 years old.

One important topic that enters this issue is the coexistence of Austrians and Slovaks on the border. The results of research on the image of Slovakia and Austria pointed to clear differences in the perception of each neighbour and suggested that the many years of historical, geographical, and cultural affinity of the Austrian and Slovak populations may not yet mean mutual acceptance and cooperation (Kollár, D. 2001). Based on the study of Decoville, A. and Durand, F. (2018), the reason may be that the memory of the Iron Curtain will remains in the minds of people living on both sides of the state border for a long time.

The processes of urban expansion originating from the capital Bratislava will probably continue toward the interior of northern Burgenland (or Lower Austria). It can be assumed that interest in life in these regions will continue to grow. It is therefore necessary to find a way to reconcile the economic development of industrial sites and shopping centres with the residential construction of traditional structures which create an identity in the rural areas of the regions. The question is whether the existing tools (spatial planning, development plans, urban renewal) are sufficiently effective, and whether control measures or activities can continue to support the structural, economic, social, and cultural identity of peripheral zones (Kapeller, V. 2015).

Residential suburbanisation and the expansion of the cross-border suburban hinterland of Bratislava can be scientifically examined in the future through other indicators that are closely related to the suburbanisation process itself, such as research on housing construction in municipalities, analysis of transport accessibility, real estate prices, community behaviour and so on.

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The role of temperature and the NAO index in the changing snow-related variables in European regions in the period 1900–2010

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Abstract

Snow-related variables are analysed in the present paper in the period 1901–2010 on the basis of the ERA-20C dataset. Relationships between different snow characteristics, temperature and the NAO index are investigated on monthly, yearly and decadal scales for eight regions within Europe representing different climatic types (i.e. oceanic, continental, polar) to analyse the differences and similarities between them depending on the climatic conditions. According to our results, the ratio of snow (i.e. snowfall compared to total precipitation) can reach 1 in winter in the colder, northern regions, whereas it is about 0.6 in the continental areas of Central Europe, even in the coldest months. During a strong positive phase of NAO more snow falls in the northern regions of Europe due to the large-scale circulation characteristics. When a negative NAO phase occurs, the temperature and snowfall anomalies are the opposite in northern Europe. The highest temperature values generally occurred after 2000, and the snowfall amount was smaller in the first decades of the 21st century compared to the previous decades. The relationship between temperature and snowfall is the strongest in autumn in the colder regions; in spring in the continental areas and in winter in the oceanic climate.

Keywords: snowfall ratio, ERA-20C, winter climate, decadal change, regional warming, North Atlantic Oscillation

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Introduction

Snow cover has impacts in the Earth System, as it plays an important role in surface energy fluxes (e.g. Ellis, A.W. and Leathers, D.J. 1998) via its high albedo, in atmospheric circulation (e.g. Cohen, J. and Rind, D. 1991) and in catchment hydrology (e.g. Rottler, E. *et al.* 2020) via delaying precipitation towards runoff. Furthermore, snow determines soil moisture (Petersky, R. and Harpold, A. 2018), soil water saturation in the first part of the growing season (Potopová, V. *et al.* 2016), evaporation (Milly, P.C.D. and Dunne, K.A. 2020), and freshwater availability (Fontrodona Bach, A. *et al.* 2018). It can also moderate soil temperature, hence snow acts as a ground insulator with the capability of protecting plants from frost damage (Oke, T.R. 1987). Therefore, it is important to analyse the past tendencies of snow-related variables, so we can possibly deal with the simulated future changes and make adaptation strategies in time.

The Special Report on the Ocean and Cryosphere in a Changing Climate (IPCC 2019) claims that a general decline in low-elevation snow cover emerged in the recent decades according to the observations. The snow extent of the northern hemisphere had a maximum in the period 1950–1970; since 1980 a reduction can be seen. Snow mass also shows a negative trend based on the ensemble of six observation-based dataset (Mudryk, L. *et al.* 2020). According to the Global Historical

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Climatology Network Daily dataset (Menne, M.J. *et al.* 2012), maximum snow depth decreased in many European stations during the period 1960–2015. This process is clearly caused by the poleward and upward elevation shift of snow due to higher temperature values (Kunkel, K.E. *et al.* 2016). Fontrodona Bach, A. *et al.* (2018) found that mean snow depth decreased more than extreme snow depth in Europe from 1951, and these trends accelerated after the 1980s. Kunkel, K.E. *et al.* (2016) found that snowmelt starts earlier in spring, especially at higher latitudes due to the Arctic amplification (Zhang, J. 2005; Hernández-Henríquez, M.A. *et al.* 2015).

In Europe, continental snow conditions may be associated with certain large-scale processes and/or pressure patterns. For instance, Kim, Y. *et al.* (2013) showed that the North Atlantic Oscillation (NAO) is related to European snow cover, especially in January and February: a negative NAO phase (i.e. when the meridional pressure gradient over the North Atlantic region is weaker than usual) results in a snow cover increase, while temperature is lower on average.

In those areas where a relatively large amount of snow accumulated during winter, as the weather gets warmer, it starts to melt and becomes part of the runoff, thus, snowmelt-induced floods can occur in spring. Floods can cause serious damages to the economy and they may also demand human lives; the flood-related losses have increased in recent years (Kundewicz, Z.W. *et al.* 2014). Hydropower can also be affected, as river runoff conditions may change because of altered snowfall, snow cover and snowmelt characteristics (Rottler, E. *et al.* 2020).

Snow can have socio-economical effects as well, as in European mountains skiing and winter tourism has a great role. Due to climate change, winter tourism faces challenges in many regions as snow period and snow depth are likely to reduce in the future. This has quite a great impact on economy and employment, while hotels, restaurants, transportation, local businesses, sport equipment sale and rental are also affected. Using artificial snow can be a solution, but it also needs specific, appropriate weather conditions (Spandre, P. *et al.* 2019), moreover, the production cost and water usage increase in this case (e.g. Moreno-Gené, J. *et al.* 2018).

The response of snow-related variables to temperature and precipitation changes is not straightforward, it can depend on the local climatic conditions and elevation (Brown, R.D. and Mote, P.W. 2009; Brown, I. 2019). There are several studies focusing on snow-related changes in smaller, specific domains (e.g. Klein, G. *et al.* 2016; Potopová, V. *et al.* 2016; Marke, T. *et al.* 2018), however, as far as we know, a comprehensive analysis of different climatic regions based on the same dataset and time period is missing. Instead of separate studies for specific regions and taking into account different time periods, our aims in this paper are (i) to analyse the trends of snow-related variables in the 20th century extended to 2010 and (ii) to investigate how snow is affected by global warming in the selected European regions. For this purpose, we use a unified methodology and a gridded database with time series that are long enough to detect long-term changes and processes. Regional anomalies can play important roles in determining local climates, therefore, subregions with different climatic characteristics are selected for this study. In order to reveal the causality of local and large-scale processes, the possible relationship between snow-related meteorological variables and the NAO index is also analysed with a special focus on the winter half-year.

Data and methods

Time series from the so-called ERA-20C dataset (Poli, P. *et al.* 2016) were used. ERA-20C is designed for climate applications, thus, it provides global atmospheric data for the period 1900–2010. ERA-20C is a reanalysis of ECMWF (European Centre for Medium-Range Weather Forecasts) that assimilates surface pressure and marine wind observations collected in the Observation Feedback

Archive (OFA – Herschbach, H. *et al.* 2015) of ERA-20C. For the assimilation, ERA-20C applies a 24-hour 4D-Var analysis (Rabier, F. *et al.* 2000). ERA-20C is based on the IFS (Integrated Forecast System) Cycle 38r1 (ECMWF 2013), which contains 91 atmospheric vertical levels between the surface and the 0.01 hPa pressure level. The horizontal resolution of ERA-20C is 0.125° (Poli, P. *et al.* 2016), which equals to about 125 km along a meridional. Overall, ERA-20C is considered to be a reliable database generally, which is supported by the study of Wang, Y. *et al.* (2017) and Wegmann, M. *et al.* (2017) for instance. Ideally, it would be more precise to use observational data for the analysis, however, on the one hand, meteorological stations are not evenly distributed in space; on the other hand, Wegmann, M. *et al.* (2017) showed that reanalysis data are able to reproduce daily and sub-decadal snow depth variability well, but a general overestimation of snow depths occurs (e.g. in Russia). The main advantage of using reanalysis data in the snow analysis is that data are available on a regular grid. In addition, reanalysis data take into account satellite data too, which provide a better spatial coverage than interpolated station data.

The monthly means of daily means of the following variables of ERA-20C were downloaded from the public website of ERA-20C (https://apps.ecmwf.int/datasets/data/era20c-moda/levtype=sfc/type=an/): total precipitation, snowfall, runoff and 2 m temperature.

The monthly mean of the NAO index was prepared on the basis of mean sea level pressure of the Icelandic Low and the Azores High for the period 1900–2010 using the ERA-20C database. First, normalised sea level pressures were calculated for the two areas (the region of the Icelandic Low is defined by 60–62.25°N; 33–38°W, and the region of the Azores High is defined by 31.75–34°N; 24–19°W). After that, the difference between them is determined for each year on a monthly scale.

As there are quite substantial differences between climate characteristics within Europe, eight subregions (*Table 1* and *Figure 1*) were determined for this study, so the potential local trends of the selected meteorological parameters can be assessed in the period 1900–2010. We focused on snow-related vari-

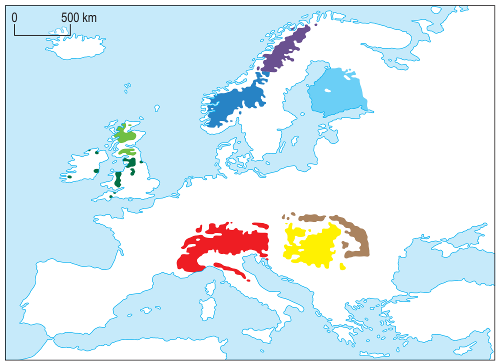

Fig. 1. Location of the selected regions: dark blue = northern Scandinavia; blue = southern Scandinavia; light blue = Finland; light green = northern Great Britain; dark green = southern Great Britain; red = Alps; brown = Carpathians; yellow = Carpathian Basin.

Table 1. Regions defined for the analysis

Name	Domain	Topography criteria, m	Number of grid cells
Northern Scandinavia	65–70°N, 10–25°E	> 500	880
Southern Scandinavia	58–65°N, 5–15°E		1,331
Finland	60–65°N, 20–30°E	< 200	2,077
Carpathian Basin	44–50°N, 16–27°E		1,088
Carpathians	44–50°N, 16–27°E	> 500	616
Alps	43–49°N, 5–15°E		1,484
Northern Great Britain	55–60°N, 0–10°W	> 200	242
Southern Great Britain	50–55°N, 0–10°W		133

ables, therefore, mainly mountainous areas (e.g. Alps, Carpathians) were selected for the detailed analysis, however, two lowlands (i.e. Carpathian Basin, Finland) were also selected in order to compare elevation-related differences. We aim to cover the differences due to the climatic conditions, i.e. northern near-polar regions with colder characteristics (Scandinavia, Finland), and regions from the oceanic climate with wet conditions and relatively low temperature fluctuations (Great Britain), and from the continental climate with higher summer temperatures and precipitation maxima generally occurring in early summer (Central Europe: Alps, Carpathians, Carpathian Basin) were selected.

The calculations are based on monthly values for different time periods, namely, years and decades. Our analysis considers the spatial averages calculated for each variable on different time scales (i.e. month, year, decade, 30-year long period) for the selected regions. In order to measure the linear dependence between two variables, the Pearson correlation method was applied, and to determine significance at 0.05 level, p-values were calculated.

Results and discussion

The present analysis starts with the joint comparison of annual cycles in general and recent changes in monthly values of hydrometeorological variables. First, the snowfall ratio (i.e. the snowfall amount relative to total precipitation) is evaluated as a function of monthly mean temperature. The scatter plot diagrams of *Figure 2* summarise all the monthly values for 1900–2010, where the last 10 years are highlighted with different symbols. The overall patterns clearly show the climatic differences of the selected regions, namely, the British Isles are the warmest among these regions in winter (the average temperature of the coldest month is higher than –5 °C) and Scandinavia is the coldest (where the mean temperature of winter months is often below –10 °C). Both in Scandinavia and in Finland (*Figure 2*, a–c), the snowfall ratio in the winter months and also in March usually exceeds 0.7, sometimes it is even close to 1, the theoretical maximum (which means that all precipitation falls as snow) and mean temperature varies between 0 °C and –20 °C due to the geographic locations, i.e. the vicinity of the polar Arctic. Snow occurred even in June, when the mean temperature was above 0 °C, but its ratio is rather low (< 0.2). In the Central European regions, namely in the Alps, in the Carpathians and in the Carpathian Basin, where the mean temperature is generally higher, snowfall mostly occurs only in winter, when its monthly ratio is greater than 0.6, but rarely reaches 1 (*Figure 2*, d–f). Snow also appears in November and March with a higher ratio (about 0.5), when temperature varies between 0 °C and 10 °C in these areas and in the Alps in October, too. In Great Britain, where the oceanic climate dominates with mild winters, clearly less snow is likely to occur: the snowfall ratio is usually less than 0.4 even in the winter time period of the year (*Figure 2*, g–h).

In northern Scandinavia (*Figure 2*, a), the smallest ratio of snow in January, April, November and December occurred in the last 10 years of the entire 1900–2010 period, whereas in southern Scandinavia (*Figure 2*, b), it occurred in April and November. In 2006, there were two minimum records of snowfall ratio (except for the summer and early autumn/late spring period): in January in northern Great Britain (0.02, *Figure 2*, g) and in December in Finland (0.15, *Figure 2*, c), which highlights the warming effects.

Analysing the monthly temperature values, the most record high values occurred after 2000, more specifically, from April to October in the Alps (*Figure 2*, e), in January and from May to July in the Carpathians (*Figure 2*, f), from April to July and in October in the Carpathian Basin (*Figure 2*, d). April, July and September were record warm in the British Isles (*Figure 2*, g–h), as was October in the northern regions and May in the southern parts of the domain. In the northern European regions, December was record warm after 2000 in Finland and in northern Scandinavia, where January, April

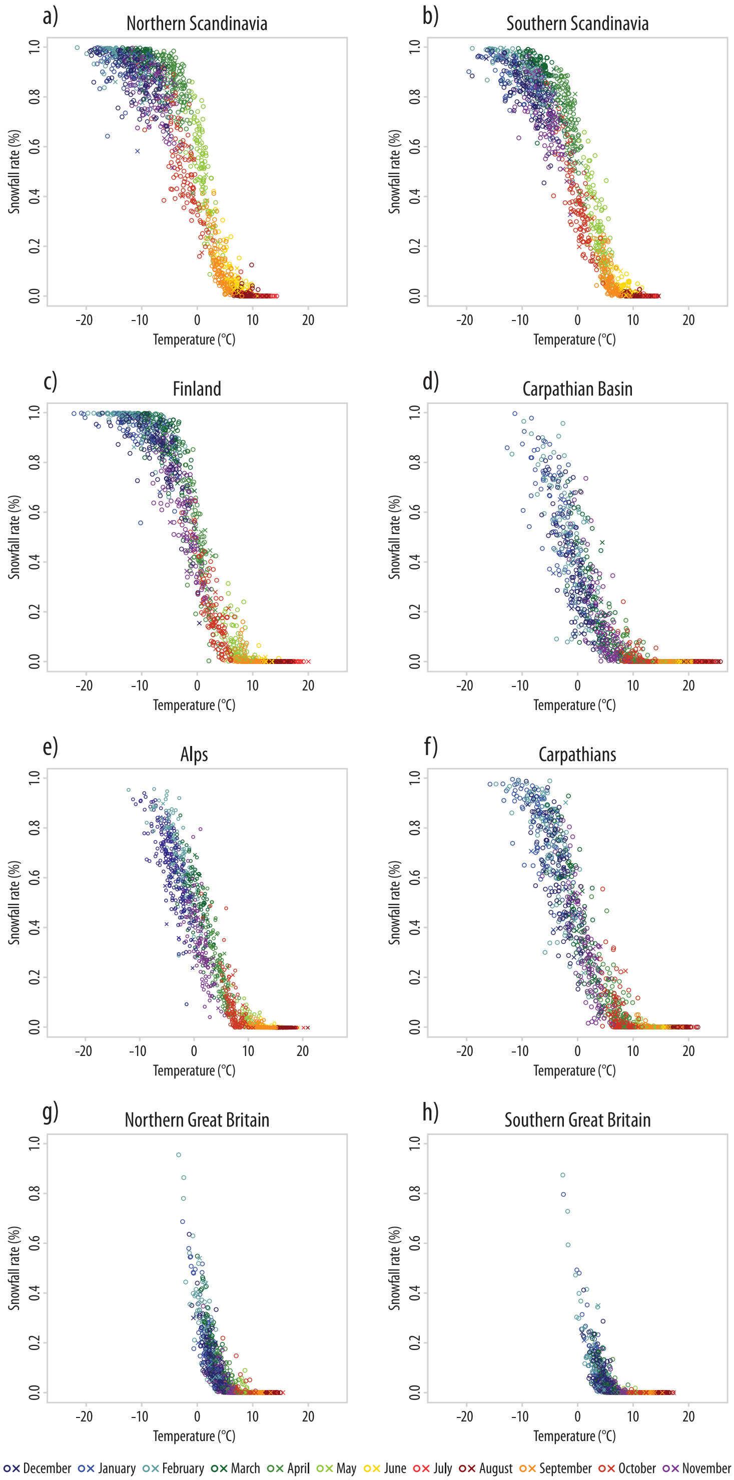

Fig. 2. Scatter plot diagrams of monthly temperature and snowfall ratio values in the selected regions. Each point represents a specific month from a year from the 20th century (1900–2000) or from the 21st century (2001–2010) indicated by 'o' and '×', respectively. Different colours are used for the months as shown at the top.

and November also showed record high values (*Figure 2*, a–c). In southern Scandinavia, the highest temperature values in April and in November occurred in 2002 and 2005, respectively (*Figure 2*, b). The first decade of the 21st century was warmer in several regions compared to the 20th century (WMO 2021), while in the case of snowfall ratio, the minimum record in the northern regions is associated with the start and end of the snow-period. Blahusiaková, A. *et al.* (2020) also found a significant increase in air temperature and a decrease in snowfall fraction and snow depth in Central Europe.

Figure 3 summarises the correlation coefficients between the snowfall ratio and mean temperature. One expects a strong reverse relationship between snow amount

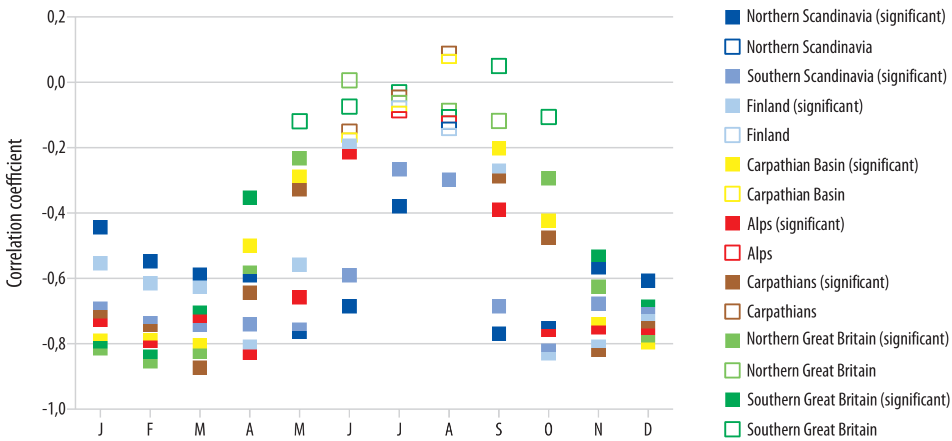

Fig. 3. Correlation coefficients between the time series of monthly snowfall ratio and mean temperature, 1901–2010. Filled and empty symbols represent significant and non-significant coefficients, respectively.

and temperature in winter: the lower the temperature, the higher the snowfall sum. Kim, Y. *et al.* (2013) concluded that overall snow cover in Europe expands by about 30 percent if the mean temperature decreases by 2 °C.

We found that the relationship between temperature and snowfall is significant at 0.05 level from October to May in all the selected regions (except in southern Great Britain, where it is true only from November to April due to the milder climatic conditions – see; *Figure 3*). The strongest relationship (with a negative correlation between –0.6 and –0.9) occurs in March, but it varies among the regions depending on the intra-annual temperature distribution and the mean temperature values themselves. So this spring maximum occurs earlier (in February) as we get closer to the ocean, e.g. in Great Britain, and it shifts to a later time (to April or even May) in the northern regions with colder climatic conditions. The correlation coefficients are close to zero when snow rarely occurs (if at all). Similarly, Henderson, G.R. and Leathers, D.J. (2010) found that temperature and snow cover extent show a significant relationship, especially in Central and Eastern Europe, however, snow coverage generally depends on specific weather conditions in a complex way (Martin, E. and Etchevers, P. 2005). According to Bednorz, E. (2004), the correlation between the annual number of days with a mean temperature below 0 °C during 1960–1993 and the annual number of snow cover days is about 0.46 in the European part of Russia, whereas 0.9 in the north-western parts of Poland and in the Baltic countries.

In the northern areas, the highest negative correlation occurs in autumn, but it is also stronger than –0.7 in most of the spring months (see *Figure 3*). In the Central European regions, the greatest correlation between temperature and the ratio of snow occurs in spring, which can be related to melting, too. The correlation exceeds –0.7 from November to March in the Alps, in the Carpathians and in the Carpathian Basin as well. In Great Britain, both in the northern and southern regions, February shows the strongest correlation, but also greater negative coefficient values occur in January and in March. To conclude: (i) in the colder, northern regions, the strongest relationship between temperature and snowfall ratio was found in autumn when the snow-season starts; (ii) in the Central European, continental areas temperature plays the most important role in snow-melting, therefore, the highest negative correlation between the two variables emerged in spring. Finally, (iii) in the oceanic climate, the ratio of snow is originally less (apart from some extreme years), and it occurs only in winter, so the correlation with temperature was the strongest in winter.

After the monthly analysis, the regional average snowfall sums and the mean temperatures of the time period from October to May are presented for each decade in *Figure 4*. In northern Scandinavia, greater average snowfall sums (360–410 mm) were typical at the end of the 20th century, while smaller amounts of snow (320–330 mm on average) appeared in the first decade of the 21st century and in 1901–1940. Temperature also displays variation, but the 2001–2010 decade was warmer by 0.5 °C on average than the warmest decades (1931–1940 and 1991–2000 with –6.8 °C) in the 20th century. The highest average snowfall amount (414 mm) occurred in 1981–1990 in southern Scandinavia. In the first half of the 20th century, a warmer period emerged, hence the snowfall amount was less in this region also. Meanwhile, the warmest decade was 2001–2010 with a mean temperature of –3.7 °C between October and May (in the 20th century it was never above –4 °C on average). Finland, which is mainly lowland, shows similar tendencies to the Scandinavian regions located more towards West, but with lower snowfall amount values (maximum ~220 mm) due to the somewhat stronger continental effect and the less effective humidity transport of mid-latitude cyclones following a northern path (van Bebber, W.J. 1891). Focusing on temperature, the weather is milder than in northern Scandinavia, but the warm 2001–2010 period (> –2 °C) compared to the earlier decades can be clearly seen in this region as well.

In Central Europe, smaller amounts of snow and higher temperature values are typical because of the continental climate and the greater distance from the Arctic. In the Alps, the greatest average snowfall sums (from October to May), 236 mm and 237 mm, occurred in 1961–1970 and 1971–1980, respectively, when the temperature was only 1.0 °C and 1.2 °C on average, the lowest during the analysed period (*Figure* 4, d). In the first decade of the 21st century, temperature was record high (2.7 °C) compared to the 20th century and snowfall dropped to a lower amount (it was less than 190 mm). Other studies focusing on the Alps also found a decrease in the duration of snow cover, taking into account the second half of the 20th century (e.g. Valt, M. and Cianfarra, P. 2010; Klein, G. *et al.* 2016). This shortening occurred mainly because of the earlier snowmelt (by 5.8 days/decade on average).

In the Carpathians and in the Carpathian Basin, average snowfall (161 mm and 108 mm, respectively) was more substantial in the colder period of 1961–1970 compared to the other decades (*Figure 4*, e–f). The warming trends of the last few decades appear clearly: the average temperature was higher by 0.6 °C in 2001–2010 compared to the warmest decade of the 20th century in both Central European regions. We note that studies highlighting this region showed that snow cover days have been decreased in Austria (Marke, T. *et al.* 2018), Czechia (Potopová, V. *et al.* 2016) and Romania (Birsan, M-V. and Dumitrescu, A. 2014), while only minor changes in snow-related characteristics were detected in Poland (Falarz, M. 2004).

Because of the oceanic climate, the least snowfall occurs in Great Britain among the analysed regions and the mean temperature is the highest in the winter half-year (*Figure 4*, g–h). Similarly to Scandinavia, the minimum amount of snow occurred in the first half of the 20th century and in 2001–2010 here as well. Temperature values show a clear increase from the 1960s, but the changes are smaller compared to the Carpathian regions with strong continental influence instead of the oceanic proximity of the Great Britain regions. Brown, I. (2019) also showed that in the British Isles, the average yearly snow cover duration decreased in 1980–2010 compared to 1960–1990, especially in the northern locations.

According to Kim, Y. *et al.* (2013), a strong positive phase of the NAO (NAO+) indicates warmer and wetter conditions than normal in northern Europe and below-normal tempera-

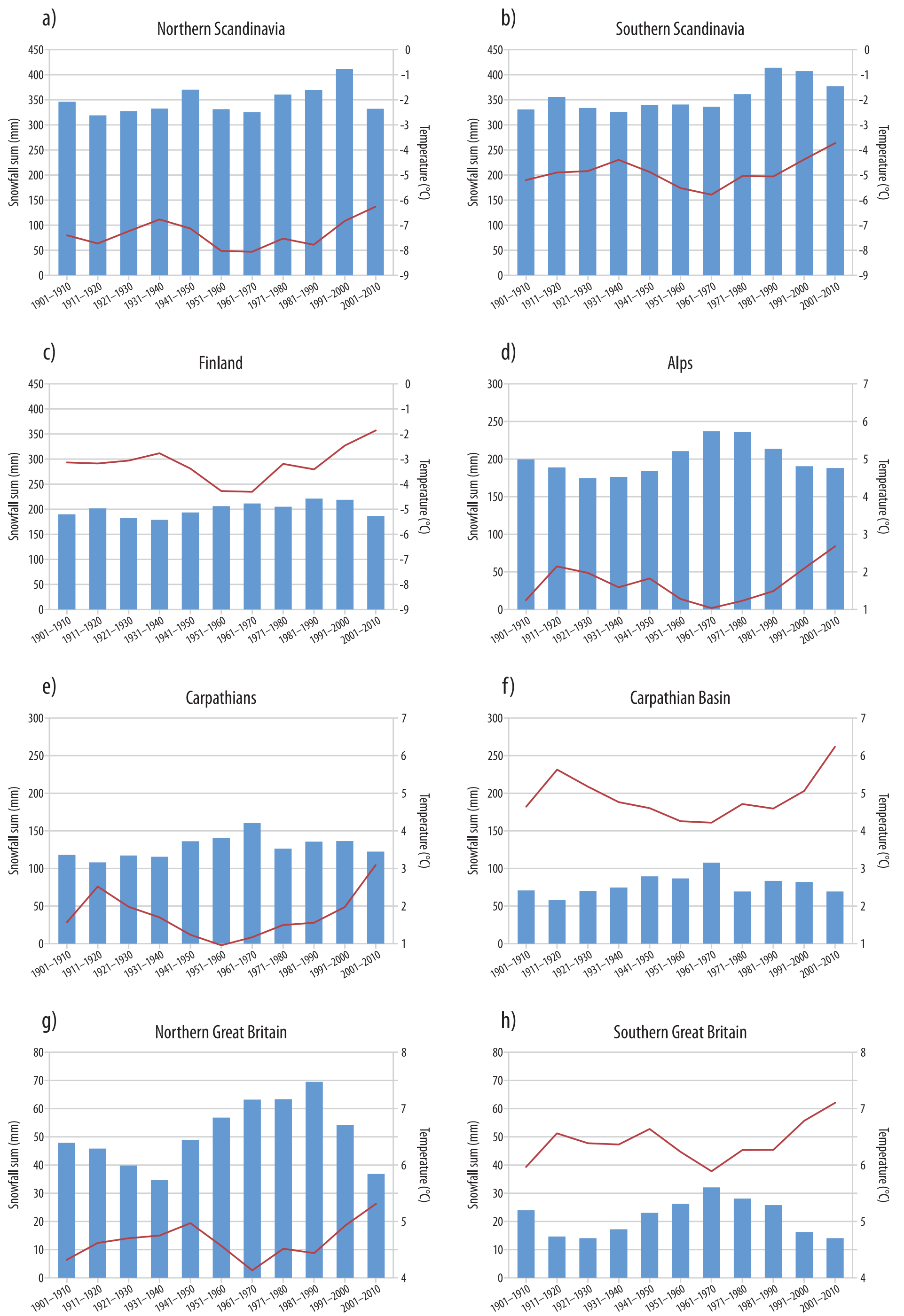

Fig. 4. Long-term changes of average temperature and average snowfall sum from October to May, for each decade in the period 1901–2010.

ture and precipitation in the southern parts of the continent. Strong negative phases of the NAO (NAO–) usually result in opposite patterns. This is why we also investigated the relationship of temperature and snow-related variables with the NAO index for each region.

First, *Figure 5* shows the regional connection between temperature and NAO. For this purpose, the NAO index and temperature values are both divided into three groups: the thresholds are defined by the 33rd and 67th percentiles (i.e. the lower and upper terciles) of the monthly data during the entire period 1900–2010, and then the intervals of the NAO index (NAO-1, NAO-2, NAO-3 phases) are paired with the regional temperature conditions (*Tx*: warm conditions, *Tg*: around mean conditions, *Tn*: cold conditions), thus,resulting in nine groups. The size of the circles is determined by the number of cases that belong to the corresponding group. Since the NAO dominantly appears in winter, we selected January for this part of the analysis.

As one can see, in the case of a positive NAO index, the temperature is usually higher than its 67th percentile (considering the period 1900–2010), especially in southern Scandinavia, in Finland and in southern Great Britain (> 20 cases; see *Figure 5*). When the NAO index does not indicate a specific phase, the regional temperature is roughly equally distributed among the three intervals; thus, no significant anomalies can be detected. In the case of a strong negative NAO index, lower temperature values are more frequent (> 14 cases), whereas positive temperature anomalies are rare, especially in southern Scandinavia, in Finland and in Great Britain (in southern Great Britain only three cases occurred during the 111 years).

Finally, we analysed the connection between snowfall amount (*Sfx*: much snow, *Sfg*: around average snow, *Sfn*: little snow) and the NAO index for January *(Figure 6).* Clearly more snowfall occurs during a strong NAO+ phase (NAO-3) in the northern parts of Europe (especially in southern Scandinavia and Finland, where the number of cases is 22) because of more precipitation and higher temperature values (but still below 0 °C). When the NAO index indicates a NAO-1

Fig. 5. Relationship between the NAO index and temperature values in January for each region. The categories were defined by the lower and upper terciles of the monthly data. The size of the circles is determined by the number of cases within the corresponding group. Tx, Tg, Tn = for explanation see the text.

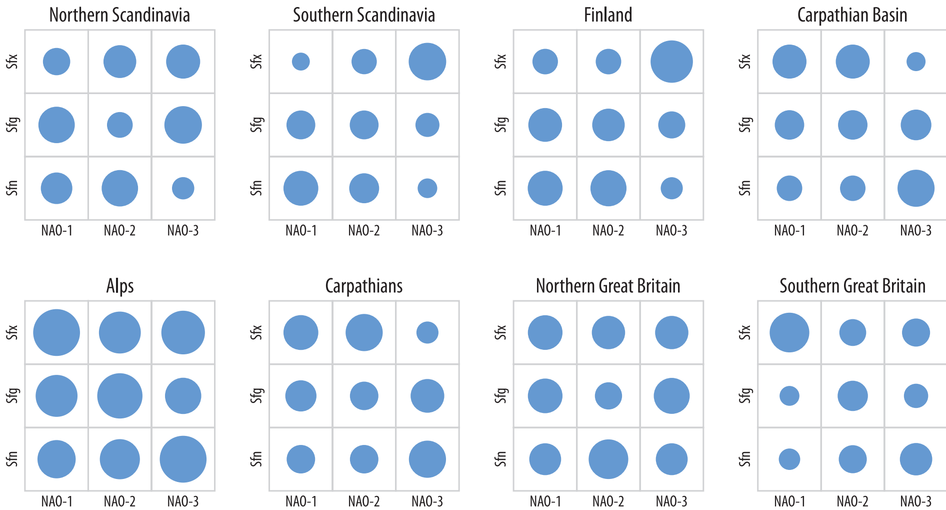

Fig. 6. Relationship between the NAO index and snowfall values in January for each region. The categories were defined by the lower and upper terciles of the monthly data. The size of the circles is determined by the number of cases within the corresponding group. Sfx, Sfg, Sfn = for explanation see the text.

case, the snowfall amount is below normal in the Scandinavian regions (< 42 mm) and in Finland (< 32 mm). This is explained by the differences in large-scale circulation patterns during NAO+ and NAO–, namely, eastern European blocking (resulting in less precipitation and lower temperature) is more likely to occur during NAO– (which is NAO-1), when the polar jet is meandering with higher amplitude and the zonal flow is less strong compared to NAO+ (which implies NAO-3) with a less meandering polar jet and strong zonal flow from the West towards Scandinavia (and northern Europe in general), resulting in more precipitation and higher temperature but still below freezing in winter in the North (Trigo, R. *et al.* 2002).

A NAO+ phase indicates drier climatic conditions in Central Europe, so less snowfall is likely to occur in the Carpathian Basin, in the Carpathians and in the Alps. In Romania, all the investigated snow-related parameters display a strong negative correlation with the NAO index in winter, which is due to the fact that positive temperature and negative precipitation anomalies in Romania are associated with a high NAO index (Bojariu, R. and Paliu, D. 2001). On the contrary, when the NAO index shows a negative phase, the snowfall sum is above normal in the Carpathian Basin (> 26 mm), in the Carpathians (> 36 mm) and in southern Great Britain (> 6 mm), as more precipitation is related to the NAO.

Bednorz, E. (2004) calculated the correlation coefficients between snow cover in Eastern Europe and the NAO index and found a strong correlation in winter, which is statistically significant West of 30° E. Henderson, G.R. and Leathers, D.J. (2010) also concluded that there is a strong association (r = –0.591) between large snow-covered areas and the negative phase of the NAO in Europe, based on NOAA (National Oceanic and Atmospheric Administration) satellite products.

Conclusions

Snow plays an important role in many processes and conditions (e.g. surface energy flux, catchment hydrology, soil moisture, freshwater availability, tourism), therefore, it is important to analyse its characteristics and changes. Relationships between snow-related meteorological variables, the temperature in eight European regions and the NAO index are investigated in this study for 1900–2010. The ERA-20C dataset was used for the calculations, and in order to take into account the different climatic types, mountainous and/or plain subregions with continental (Alps, Carpathian region), oceanic (Great Britain) and polar climates (Scandinavia, Finland) were selected for the evaluation. Temperature and snow-related variables were analysed on monthly, yearly and decadal scales, too. To investigate the relationship between the selected variables and the NAO index, categories were defined by the lower and upper terciles of monthly data.

On the basis of the presented analysis the following main conclusions can be drawn.

(i) Snowfall shows a strong relationship with temperature; the ratio of snowfall can reach 1 in the colder, northern regions in winter, while it is about 0.6 in Central Europe with a continental climate, even in the coldest months.

(ii) Correlation coefficients between the snowfall ratio and mean temperature are significant from October to May in all regions. The strongest relationship occurs in March, but it varies among the regions depending on the temperature. In the vicinity of the ocean (in Great Britain), this spring maximum occurs earlier, while in the northern regions, it shifts to April or even May.

(iii) The strongest relationship between temperature and snowfall occurred in autumn in the colder, northern regions; in spring in the Central European, continental areas; and in winter in the oceanic climate.

(iv) Snowfall amount was smaller in the first decades of the 20th and in the 21st century as well, compared to the middle of the 20th century, but temperature clearly shows the highest values after 2000.

(v) The effect of the NAO appears in snow characteristics, especially in the winter months because it affects both temperature values and precipitation amount. The connection is stronger in Scandinavia, in Finland, and in Great Britain than in the continental Central European regions. This can be explained by the large-scale circulation characteristics during different NAO phases with more substantial consequences for regional climatic conditions closer to the northern action centre of the NAO, i.e. the Icelandic low pressure centre.

Temperature clearly rose in the period 1900–2010, and according to climate model simulations, this trend will continue in the next decades even if the most optimistic scenario is taken into account (IPCC 2013). This will certainly affect snow-related characteristics, but the changes may not be linear. Therefore, our ultimate aim is to expand this study with further analyses for the future conditions on the basis of regional climate model outputs.

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Natural and anthropogenic impacts reflected by paleoclimate proxy parameters in a lake-forest system in Bukovina, Romania

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Abstract

The research area is located in the Eastern Carpathians, Romania. This region is rich in various formations and indicates significant potential for paleo-environmental reconstruction. The present research was carried out on sediment cores collected at lake Bolătău-Feredeu, Feredeului Mountains (Eastern Carpathians, Romania). Preliminary examination of the sediment confirmed the possibility for data analysis with high temporal resolution. The aim of the research was to clarify and supplement the findings of previous research at this site, to explore the relationships between proxy parameters and to elucidate the cause for the changes. Core dating was carried out using ^{210}Pb and radiocarbon isotopes and indicated that sediment cores span the past 500 years. The research uses a wide range of methodologies, including organic geochemistry with calculated n-alkane indices (P_{hw} and P_{wax}). Based on these proxies, the changes of woody and herbaceous coverage in the catchment can be estimated. Moreover, element concentration, weathering indices and particle size distribution assist to detect climate changes in the catchment area. The data and conclusions yielded by the analysis were compared with the regional modelled temperature profile, based on which five periods were separated. In addition to natural and anthropogenic events, the main factor among the natural processes is the change in annual temperature. Based on the obtained data, several parameters were found to be suitable for monitoring past temperature changes.

Keywords: deforestation, landscape change, weathering index, n-alkanes, temperature reconstruction, paleoclimate

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Introduction

Research on paleoclimate and paleo-environmental changes ranks among the most hotly debated topics due to the fast pace at which environmental conditions are currently changing. The earliest scientific approach to use lake sediment as an environmental archive dates back to the early 19th century (e.g. Lyell, C. 1830). Over time, however, paleo-environmental research has become an increasingly complex and multidisciplinary scientific field supported by a wide range of methodologies and techniques for investi-

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gating lake sediments. Numerous tools connected to various fields of science (such as physics, geology, climatology, mathematics, botany and others) have become available for lake sediment research (Last, W.M. and Smol, J.P. 2001.)

The Romanian Carpathians seemingly abound in areas with significant potential for paleoenvironmental research, therefore several studies based on lake sediments have been carried out to date (e.g. Wohlfarth, B.G. *et al.* 2001; Magyari, E.K. *et al.* 2009; Kłapyta, P. *et al.* 2016; Haliuc, A. *et al.* 2019). The study site selected for this analysis is located in Bukovina region, Romania, where historical records documented substantial landscape changes throughout the past centuries, including mainly deforestation and subsequent land cover / land use shifts (Barbu, I. *et al.* 2016). Lake Bolătău-Feredeu is regarded as one of the Bukovinian Millenial lakes and is suitable for high-resolution analysis, based on the findings of previous studies at this site and in the neighbouring area (Mîndrescu, M. *et al.* 2013, 2016; Florescu, G. *et al.* 2017; Karlik, M. *et al.* 2018, 2021).

The aim of this work is to analyse the geochemical and particle size parameters of lacustrine sediments and interpret the data in relation to/as a response to climatic and vegetation changes. We focus on correlations between each parameter with special regard to temperature-induced changes. The lipid biomarker distribution, especially long-chain n-alkanes, in recent sediments is a useful tool to detect natural and anthropogenic changes in the vegetation of lakes and catchment areas (Meyers, P.A. 2003; Eglinton, T.I. and Eglinton, G. 2008; Karlik, M. *et al.* 2018). Elemental analysis is among fundamental methods employed in sedimentology, with XRF measurements becoming widespread in the last 50 years (Engstrom, D.R. and Wright, H.E. Jr. 1984; Couture, R.A. and Dymek, R.F. 1996). Elemental composition data reflect the organic, vegetation, inorganic and/or climate changes occurring in the lake-catchment system, whereas particle size distribution data are essential for interpreting elemental analytical data. This type of complex data analysis creates an opportunity to explore hitherto undiscovered processes, relationships and help to detect high impact effects (Das, B.K. and Haake, B.G. 2003; Jin, Z. *et al.* 2006).

Materials and methods

Study site

Lake Bolătău-Feredeu (47°37′20.74′′N, 25°25′54.43′′E) is located in the south-western sector of Feredeului Mountains (Eastern Carpathians, Romania), in the vicinity of Obcina Feredeului peak (1,364 m a.s.l.) and pertains to Sadova river catchment *(Figure 1).* Sadova stream is a tributary of River Moldova. The lake formed in the upper area of Sadova catchment, at ca. 1,137 m a.s.l., subsequent to a landslide event which dammed the deep, narrow valley head of Holohoșca stream (Mîndrescu, M. *et al.* 2013). The lake surface is only 0.3 ha with an average 2 m depth in 2010, while the catchment area is ~30 ha. The vegetation cover of the catchment is composed of various plant species, among which herbaceous associations account for 6 ha and *Picea abies*-dominated forests for 24 ha (Mîndrescu, M. *et al.* 2010). The bedrock consists predominantly of sandstone, and the soil profile depth increases towards the lake. The slope gradients within the catchment range between ~18° (eastward), ~24° (northward) and ~25° (southward), whereas the outflow of lake Bolătău-Feredeu flows to the West.

Core collection

The sediment cores were retrieved in April 2013 using both a Russian corer (core code: LB-R-01) and a gravity corer (core code: LB-G-01) from the frozen surface of the lake. The corer parameters were identical (d = 6.5+/-0,1 cm; S = 33.2 +/-0.6 cm^2). Two additional gravity cores (core codes: LB-G-02

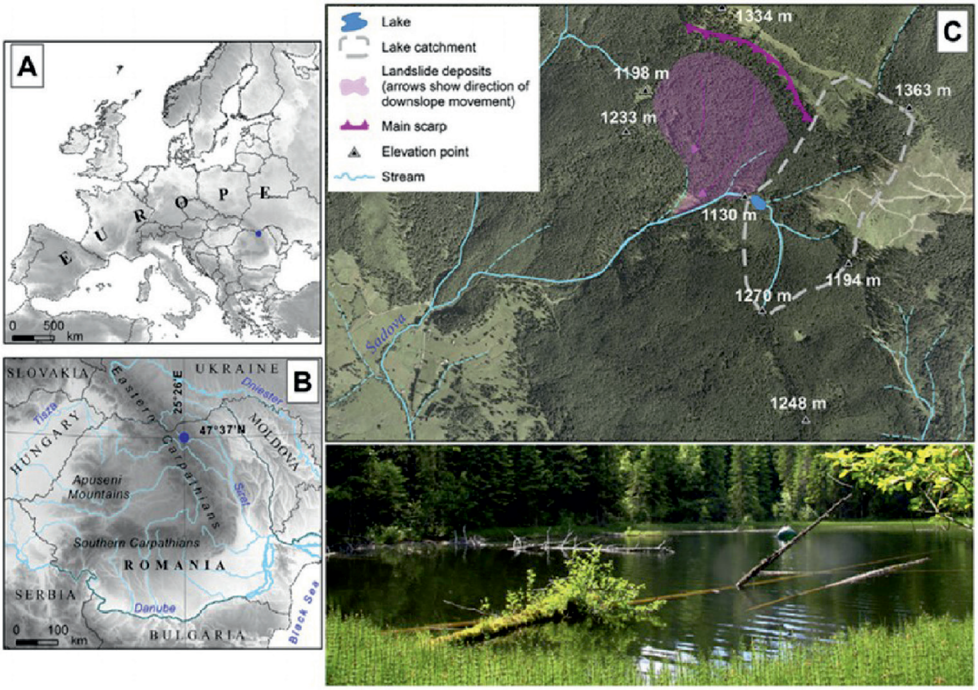

Fig. 1. Location of research area at continental scale (A); in the Eastern Carpathian region (B); and a closer view of Lake Bolătău-Feredeu (C). The grey dashed line shows the catchment boundary. A site photo is displayed below the map (Karlik, M. *et al.* 2018).

and LB-G-03) were extracted using a floating platform in November 2013. The cores extracted in April were visually inspected on-site, described, photographed and sectioned at 1 cm intervals into pre-labelled plastic bags (Mîndrescu, M. *et al.* 2016).

Chronology

An initial sediment chronology was established for the Bolătău-Feredeu sequence based on 8 AMS radiocarbon dates from terrestrial macrofossils and validated for the recent section by the double peaks of the ^{137}Cs flux (i.e. mid-1960s: global fallout maximum; 1986: Chernobyl event) (Mîndrescu, M. *et al.* 2016). The sediment chronology of the top 24 cm has been significantly improved using by ^{210}Pb chronology (Bihari, Á. *et al.* 2018). The ^{210}Pb ages for the top 20 cm (with an uncertainty of the estimated ages below 30%) and all ^{14}C dates were included in the Bayesian age-depth model using the P_Sequence function of the OxCal v.4.2 (Bronk Ramsey, C. 2009) software *(Figure 2).* The latter was also employed for the calibration of ^{14}C dates to calendar years in conjunction with the Northern Hemisphere IntCal13 (Reimer, P.J. *et al.* 2013; dataset: Karlik, M. *et al.* 2018).

Particle size distribution analysis

Particle size distribution was determined using a Fritsch Analysette 22 Microtech Plus laser diffraction particle size analyser, which measures in the range of 0.08 μm – 2.0 mm. Samples were treated for carbonate and organic matter removal according to USDA NRCS method

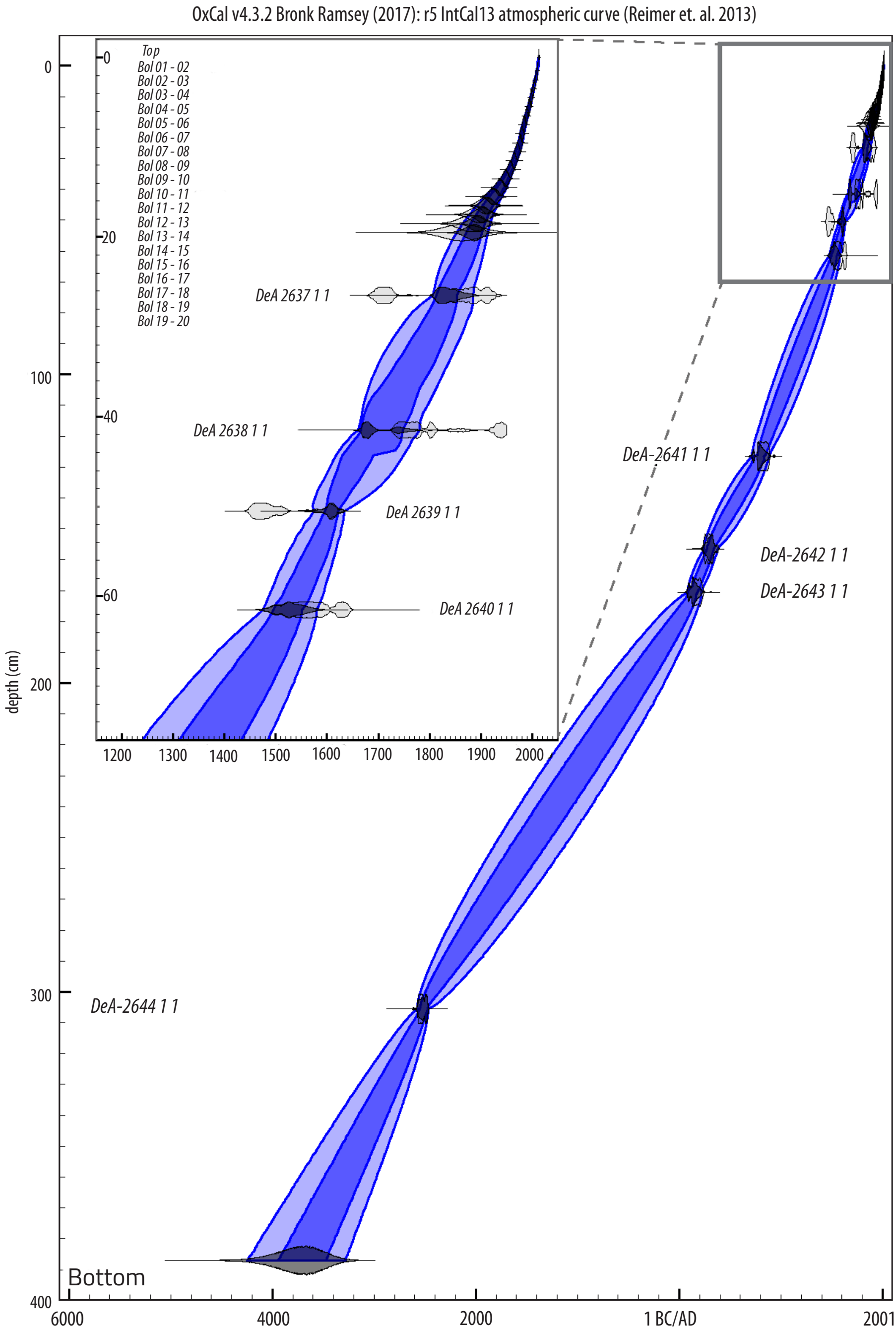

Fig. 2. Sediment chronology of the Bolătău-Feredeu sequence. Light (blue) shading shows the 95 percent (68%) confidence range of the Bayesian model. Original and modelled probability density functions of the radiometric ages are plotted by light and dark blue, respectively. The uppermost 70 cm is enlarged, offering a more detailed view of the section on which the current study is focused (Karlik, M. *et al.* 2018).

(Burt, R. 2004). Three aliquots (ca. 1 g) were taken from each treated sample. Five minutes of ultrasonic treatment and sodium-pyrophosphate (50 g/l) were applied to the samples in order to allow a complete dispersion of the specimens. Refractive index and the imaginary part were assumed to be 1.54 and 0.01 (Eshel, G. *et al.* 2004; Varga, Gy. *et al.* 2019). The percentages of sand (2,000–50 μm), silt (50–2 μm) and clay fractions (below 2 μm) were reported according to a modified United States Department of Agriculture (USDA) texture classification scheme (Konert, M. and Vandenberghe, J. 1997).

Geochemical analysis

XRF is widely regarded as a very versatile and fairly accurate method for elemental analysis. This method is able to detect elements in the mass range from fluorine to uranium in solid and liquid samples. The types of XRF equipment are very diversified and the detection limits and any other measured parameters highly depend on the accepted excitation voltage, measuring time, detection settings etc. XRF is generally used for soil and sediments analyses and is a widespread technique in earth and environmental analytics (Schramm, R. 2012).

The samples were measured using a RIGAKU Supermini wavelength dispersive X-Ray fluorescence spectrometer with Pd X-ray tube 50 kV excitation voltage and 40 anodes current. The EZScan measuring method was applied for 40 minutes on each sample to determine elements from fluorine to uranium *(Table 1).*

Organic geochemical analysis

The ~78 cm long LB-G-02 core was cut into 12 non-uniform samples. Non-uniform sampling steps were decided based on the pilot sampling, which suggested variable organic content. Samples were dried at 40 °C and subsequently ground, and ~20 g samples were filled into stainless steel cells. Extraction was carried out in an Accelerated Solvent Extractor (ASE350) at 75 °C and 100 bar, using 5:2 chloroform: methanol as solvent. The samples were run twice to ensure sufficient extraction. The extract was fractionated via column chromatography into saturated hydrocarbon (HC), aromatic HC, and resin fraction. The dominant fraction was resin. Saturated HC fraction ranged from 1.1 to 5.3 percent of the extracted total organics (Karlik, M. *et al.* 2018).

The entire saturated HC fraction was analysed by gas-chromatography using a Fisons 8000 GC with Flame Ionisation Detector using the following parameters: injector temperature: 310 °C split: 1:10, DB-TPH 30 x 0.32 x 0.25 column, detector temperature: 310 °C. The oven was kept at 60 °C for 1 min, then heated up to 150 °C (20 °C/min), then up to 330 °C (6 °C/min) for 5 min. To avoid the potential bias due to the variable amount of saturated HC subsamples, the changes in the alkane composition were evaluated using well-known indices calculated as the ratio between summed peak areas of certain alkane groups (Karlik, M. *et al.* 2018) *(Table 2).*

Results

Weathering indices curves (CIA, CIW, PIA, V) show similarity to each other throughout the entire examined time interval *(Figure 3).* From 1500 A.D. to 1776 A.D. the weathering index values fluctuated around the same level. The stable period is interrupted by a negative peak around 1820 A.D. The second time frame (between 1845 A.D. and 2010 A.D.) starts with a positive peak. After a short stable period (~55 years), a significant positive peak can be observed in all charts (1902 A.D. – 1948 A.D.) followed by a rapid decline upwards. In the last 55 years the values have been increasing.

The uppermost 52 cm (~500 years) yielded enough material for particle size analysis. Three fractions have been inferred based on particle size distribution: clay fraction < 2 μm,

Table 1. Calculations of the weathering indices

Index	Calculation	Reference
CIA	$[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$	Nesbitt, H.W. and Young, G.M. 1982
CIW	$[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O)] \times 100$	Harnois, L.1988
PIA	$[(Al_2O_3 - K_2O)/(Al_2O + CaO^* + Na_2O - K_2O)] \times 100$	Fedo, C.M. *et al.* 1995
V	$(Al_2O_3 + K_2O)/(MgO + CaO + Na_2O)$	Vogt, T. 1927

Notes: CIA = Chemical Index of Alteration is interpreted as a measure of the extent of conversion of feldspars to clays; CIW = Chemical Index of Weathering is identical to the CIA, except that it eliminates K content from the equation; PIA = Plagioclase Index of Alteration is used to monitor the plagioclase weathering.; V = Vogt's Residual Index reflect the degradation of clay minerals.

Table 2. Calculations of the n-alkane indices

Index	Calculation	Reference
P_{wax}	$(C_{27} + C_{29} + C_{31})/(C_{23} + C_{25} + C_{27} + C_{29} + C_{31})$	Zeng, Y. *et al.* 2007
P_{hw}	$2 \times C_{31}/(C_{27} + C_{29})$	Zhu, L. *et al.* 2008

Notes: P_{wax} = reflects the relative proportion of waxy n-alkanes; $P_{hw:}$ = reflect the herbaceous proportion in the total terraneous plants.

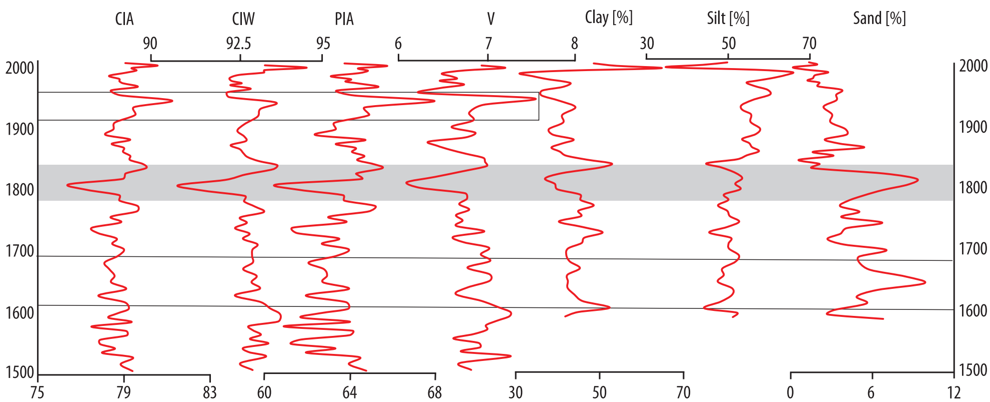

Fig. 3. Weathering indices and particle size distribution data. CIA = Chemical Index of Alteration; CIW = Chemical Index of Weathering; PIA = Plagioclase Index of Alteration; V = Vogt's Residual Index.

silt fraction from 2 to 50 μm, and sand fraction from 50 to 2,000 μm. The clay and the silt fractions accounted for more than 90 percent of the composition (see *Figure 3*).

The proportion of the clay fraction ranged between a maximum of 65.4 percent and a minimum value of 31.5 percent, thus, covering a wide range of approximately 34 percent. The data set can be divided into three main intervals. The first interval (from 1592 A.D. to 1802 A.D.) is characterised by a fluctuation around ~45 percent, with a standard deviation of 3 percent. The dominant trend is not visible in this period, whereas four peaks can be observed in 1607 A.D., 1676 A.D. (small), 1731 A.D. and 1776 A.D. Between 1607 and 1730 A.D. the values are relatively low. The second interval spans from 1802 A.D. to 1845 A.D. Within this short period, both a negative and a positive peak have been detected. The third interval starts in 1854 A.D. and lasts until 2010 A.D. Between

1984 A.D. and 1994 A.D. the values show a declining trend with four peaks. (1985 A.D., 1912 A.D., 1938 A.D. and 1977 A.D.). The end of the period (from 1994 A.D. to 2010 A.D.) indicates a significant signal of current changes (see *Figure 3*).

Silt fraction values commonly vary inversely compared to clay fraction values. In the first interval (from 1592 A.D. to 1802 A.D.) values fluctuate around ~50 percent with a standard deviation of 2 percent. A dominant trend has not been detected. However, six significant peaks can be separated (1592 A.D., 1629 A.D., 1694 A.D., 1749 A.D., 1802 A.D. and 1820 A.D.). In the second time frame (from 1802 A.D. to 1845 A.D.) the silt fraction decreases continuously. The third interval spans from 1854 A.D. to 2010 A.D. Between 1984 A.D. and 1994 A.D. the values show an increasing trend, whereas the uppermost part (from 1994 A.D. to 2010 A.D.) has been disturbed as previously mentioned (see *Figure 3*).

The percentage of the sand fraction is generally less than 10 percent throughout the entire sediment sequence under investigation. The data set can be divided into two main parts. Between 1592 A.D. and 1820 A.D. the sand fraction values show high variability. From 1592 A.D. onwards, after a short decreasing period, three peaks have been determined at 1618 A.D., 1650 A.D. (the highest) and 1705 A.D., followed by ca. 70 years. Of relatively low stable values. The ensuing period covering ~62 years started in 1775 A.D. with a 3.7 percent sand fraction value, showed an increase up to a maximum value of 9.3 percent in 1820 A.D., and ended in 1883 A.D. at 1.6 percent. The last time frame lasted between 1883 A.D. and 2010 A.D. After a 20-year increase, a declining trend followed without major fluctuations (see *Figure 3*).

LOI (Loss-on-Ignition) values range between 16 and 27 percent in the core. From 1500 A.D. to 1767 A.D., the values have not shown any significant changes. Following this stable period, the largest shift can be observed from 16.5 percent (1776 A.D.) to 26.7 percent (1811 A.D.), ensued by a subsequent drop to 16.3 percent (1838 A.D.). An increasing trend has been detected up to 1902 A.D., followed by a stabilisation at around the previous level (from 1500 A.D. to 1776 A.D.) *(Figure 4)*.

The P_{hw} index ranges from 0.23 to 0.84 with a median of 0.47. This index can be used to study the relative abundance of woody

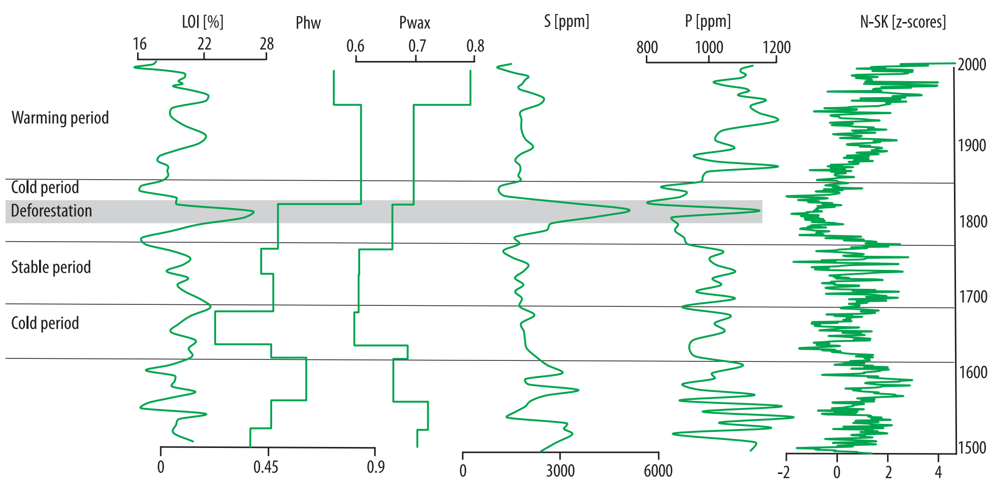

Fig. 4. Temperature and potential organic material proxies: LOI, P_{hw}, P_{wax} (published in: Karlik, M. *et al.* 2018); S, P, N-SK [z-score temperature proxy] (Büntgen, U. *et al.* 2013).

(versus herbaceous) plants reflected by long-chain alkanes (Zhu, L. *et al.* 2008). The high values of P_{hw} indicate an increased contribution of herbaceous plants to the sedimentary n-alkane composition compared to woody plants. P_{hw} shows an increasing trend from 1500 A.D. to 1662 A.D. ensued by relatively higher values peaking at 0.61 (from 1562 A.D. to 1618 A.D.). Subsequent to the peak, P_{hw} drops to the lowest recorded level (0.23) between 1635 A.D. and 1679 A.D. and then it is stabilised around 0.47. A remarkable shift can be observed at 1820 A.D., where P_{hw} is increased by a factor of ~1.7. Less elevated values (0.72) were determined for the most recent sediments, however, these are still well above the values obtained for the sediment below 1820 A.D. (Karlik, M. *el al.* 2018). (see *Figure 4*).

The P_{wax} index ranges between 0.68 and 0.80 with a 0.73 median. P_{wax} reflects the relative proportion of waxy hydrocarbons derived from emergent macrophytes and terrestrial plants to total hydrocarbons (Zheng, Y. *et al.* 2007). Therefore, higher P_{wax} values suggest a larger input from vascular plants. The inferred terrestrial contribution fluctuates along the Bolătău-Feredeu sediment sequence. The P_{wax} is 0.73 in the lowermost sample and exhibits some small fluctuations upwards, dropping to its lowest value at 1635 A.D. Low values were also recorded in the two upper samples, therefore suggesting a diminished terrestrial contribution to the sedimentary organic material during a prolonged period of time. The P_{wax} index recovers at the depth of 1761 A.D. and gradually increases upwards, reaching the maximum value in the topmost sample (Karlik, M. *et al.* 2018) (see *Figure 4*).

Sulfur is regarded as one of the most significant all-round proxies for lacustrine sediments and varies throughout the sediment sequence between ~1,110 ppm and ~5,080 ppm, reflecting the bacterial productivity and pyrite formation (Gransch, J.A. and Postuma, J. 1974; Raiswell, R. and Berner, R.A. 1985), as well as the organic matter content (Werne, J.P. *et al.* 2003). From 1500 A.D. to 1620 A.D. the sulfur content of the sediment changed considerably, whereas, during the following 150 years, the concentration of sulfur remains stable at around 1,800 ppm. The highest peak was recorded between 1785 A.D. and 1838 A.D. showing an increase by three orders of magnitude. Subsequently, the sulfur content dropped to the previous level until present day (see *Figure 4*).

The phosphorus content originates in the organic matter of the sediment (Lu, J.J. *et al.* 2005) and is involved in many biological processes, reflecting various factors such as lake productivity and terrestrial organic input (Engstrom, D.R. and Wright, H.E. Jr. 1984). The phosphorus content varies between ~820 ppm and ~1,250 ppm during the analysed time frame of ~500 years. From 1500 A.D. to 1620 A.D., the values drop reaching a minimum of 920 ppm in 1592 A.D. In the following four decades, the decreasing trend is interrupted by a local peak. After 1618 A.D. a sudden decline in phosphorus content has been determined ensued by a short minimum period (~20 years), subsequent to which the P concentration remains at lower levels compared to the previous period. From 1761 A.D. the value decreases, however, at 1820 A.D. a remarkable peak has been detected, whereas at 1829 A.D. the P concentration is the lowest recorded in the core. The phosphorus content shows an upward trend up to 1938 A.D. ensued by a downward trend until 2010 A.D. (see *Figure* 4).

N-SK [z-score] data set is a high resolution modelled paleotemperature proxy to the Carpathian region published by Büntgen, U. *et al.* (2013). From 1500 A.D. to 1620 A.D., the values show a non-continuous increasing trend and a relapse dated around 1560 A.D. Subsequent to 1620 A.D. the value drops to a minimum between 1630 A.D. and 1650 A.D. From 1680 A.D. to 1760 A.D. the standard deviation of the data is higher than before, with values varying greatly. The ensuing main period starts with a rapid decline from 1760 A.D. to 1800 A.D., whereas during the following 200 years. an increasing trend can be observed (see *Figure 4*).

Discussion

Weathering processes in the catchment of Lake Bolătău-Feredeu

Changes in the weathering conditions have been studied using four different weathering indices and particle size distribution data (see *Figure 3*). From 1500 A.D. to 1776 A.D. the inferred weathering conditions were relatively constant based on the particle size values of clay and silt fractions. The sand fraction peak detected around 1550 A.D. has not been explained according to the classical interpretation, which would point to a shift in weathering conditions due to rainfall effect etc. In this case, the weathering indices calculated based on element concentrations do not show a signal that would confirm the weathering condition changes theory.

From 1776 A.D. to 1838 A.D. all weathering indexes and particle size fractions showed rapid and significant changes. This effect is concentrated within a relatively short time frame with a sudden decline occurring in just 20 years, indicating a significant shift in the lake-catchment area system, which has been explained by the findings of Karlik, M. *et al.* (2018) regarding extensive deforestation in the region.

From 1838 A.D. to the present the weathering index values are more scattered compared to the earliest period (1500 A.D. to 1776 A.D.), thus suggesting that the catchment-lake system was more disturbed likely due to greater anthropogenic impact. The time frame spanning from 1925 A.D to 1948 A.D. deserves special attention as it overlaps with World War II.

Environmental changes in the lake-catchment system

The modelled temperature dataset of the east Carpathian region (Büntgen, U. *et al*. 2013) was compared to the organic and inorganic proxies, which resulted in the following reconstruction of environmental changes in the lake-catchment system.

Spread of herbaceous species in the catchment (~1500 A.D. to 1620 A.D.)

This period is characterised by large variations in values. The most informative indices were the n-alkane proxy parameters (P_{hw} and P_{wax}). The phosphorus content recorded a high fluctuation, whereas the LOI% and the S content show similar shapes. P_{hw} increased from 0.4 to 0.61, while P_{wax} decreased from 0.75 to 0.7. Unfortunately, particle size distribution data are not available for this period. Low fluctuations in sulfur content and LOI% suggest the lack of high impact events, which would have significantly altered the geographical structure of the catchment. However, the values indicate a change in the vegetation of the catchment as the n-alkane proxy parameters suggest that the closed forest of the area receded and herbaceous vegetation settled in the vacant spots. The phosphorus content shows a disturbed signal and has a similar shape to the N-SK record with a 30-year slip. This parameter is linked to lake water temperature (Kim, L.H. *et al.* 2003.) and biological productivity (Wildung, R.E. *et al.* 1977), therefore the connection between P content and the N-SK record is plausible in this source.

The effect of a cold period on the lake-catchment system (1620 A.D. to 1700 A.D.)

This section of the sediment sequence coincides with a well-documented cold period in Central Europe (Dobrovolny, P. *et al.* 2010). The N-SK temperature proxy indicates the interval with the lowest temperature at around 1639 A.D. The low phosphorus concentration corresponding to this time period correlates well with the minimum N-SK index, whereas P_{hw} and P_{wax} drop to their minimum values. Moreover, the contribution of the sand fraction recorded one of its highest peaks at 1650 A.D. However, the weathering indices have not changed to a significant extent, therefore related processes are negligible. The change in temperature is responsible for the shift of the primary biosphere in the catchment area, with herbaceous species responding more sensitively to the environmental condition changes compared to woody species. The variations detected in the n-alkane proxies and the phosphorus content (with the latter at a significantly higher resolution) indicate a fast cooling period in the area of Bolătău-Feredeu lake-catchment. The shape of the P content signal is very similar to the shape of the modelled temperature during the time frame when the minimum temperature was recorded in the catchment (from 1629 A.D. to 1650 A.D.). Herbaceous species, and especially the grass vegetation greatly influence the particle size distribution of the terrestrial input. From the proportion of the sand fraction, it can be deduced that the herbaceous cover had declined between 1620 A.D. and 1650 A.D.

A seemingly stable period in the lake-catchment system (1700 A.D. to 1780 A.D.)

This time frame spanning ca. 70 years, marks a period of relative stability in the 18th century. Based on the available data, the apparent stability could be attributed in part to the sampling frequency. However, a more probable explanation is the slow response of this complex system to rapid, short-term shifts lacking any explicit trend. Whereas the modelled temperature shows significant changes, among the weathering indices only PIA (which is bound to the clay and silt fraction) reflects these variations. The sulfur content and, to a greater degree, the organic matter content (LOI%) both show a decrease. The phosphorus content follows the trend of the N-SK temperature proxy, albeit the resolution of the P curve is higher than N-SK. P_{hw} drops to a minimum level in the second part of the period.

Anthropogenic impact on the lake-catchment system during a cold period (from 1780 A.D. to 1860 A.D.)

Deforestation has been documented in Bukovina (Florescu, G. *et al.* 2017) in the area where the catchment area is located (Karlik, M. *et al.* 2018). The multi-proxy analysis supports a better understanding of the historical evolution of anthropogenic impact in this catchment and allows for comparisons with other areas. According to the N-SK temperature proxy this period was especially cold. The phosphorus content shows a similar trend with the exception of a peak detected between 1811 A.D. and 1829 A.D. During this period, all proxies displayed well marked trends. The maximum P value was reached in the 1820s. The highest LOI% value is recorded during this period, suggesting high organic material input in the lake-catchment system. Moreover, a large sulfur peak (pointing to an anoxic zone) was detected, thus indicating high organic content. All weathering indices recorded unprecedented minimum values, with the clay fraction peak conforming to the trend of the weathering indices. Conversely, the sand and silt fractions show marked peaks. The n-alkane proxy parameters (P_{hw} and P_{wax}) indicate significant changes; however, as the sample at this depth covers a large time interval, only the change itself was considered. Based on the examination of all parameters the deforestation started around ~1811 A.D. and went on for a decade. The effect of forest removal coupled with the major disturbance undergone by the soil modified the total lake – catchment system. The high organic input to the lake originating in the catchment most likely destabilised the lake balance. Subsequent to 1829 A.D. a new vegetation composition began to form.

Modern landscape changes in the catchment (1860 A.D. to 2010 A.D.)

The deforestation documented during the early 19th century marked the onset of change in the Bolătău-Feredeu lake-catchment system. Some of the parameters recorded unprecedented levels or were evolved according to new trends. The silt and clay fraction balance was constantly shifting in the direction of the silt, with the exception of the last

20 years when high fluctuation became prevalent, whereas the sand fraction stabilised at a lower level. Based on these data, it can be asserted that continuous transformation is taking place in the catchment. The fluctuation of the weathering indices was not consistent, which could be linked at least in part to human activity. The human impact was confirmed by the peaks recorded by weathering indices during World War II. LOI% and the sulfur content showed systemic repetition with coinciding peaks of these two parameters. The phosphorus content is comparable to the temperature model throughout this period, with the exception of the last 50 years when the P content trend deviates from N-SK. Thus, it can be argued that P content can be used to monitor the temperature. Although during this time frame the n-alkanes proxies were measured only in two samples, they are still effective parameters, suggesting that organic productivity in the catchment is much higher than before. In the first sample covering the period subsequent to deforestation in the catchment the herbaceous contribution is much higher than the woody content, which is a typical finding. However, the second sample which represents the end of the 20th century, shows the next step in afforestation, a decrease in herbaceous plants and an increase in woody vegetation.

Conclusions

In this study, a multi-proxy analysis was carried out, comprising both organic and non-organic proxies, in order to highlight the importance as well as the disadvantages of n-alkane biomarkers, and the connections between proxies and temperature. Based on the data, we have concluded that the phosphorus concentration and the P_{hw} n-alkane proxy are the most promising temperature proxies at this study site and should be further studied in terms of their potential for past temperature reconstruction. Analysis of indices from multiple sources is essential for avoiding misinterpretation of data and allows for a more in-depth understanding of the paleoenvironment as a biological and inorganic system. Our study provided sufficient solid data to reconstruct the paleoclimate and vegetation changes in the catchment area.

The data interpretation suggests that between ~1500 A.D. and 1620 A.D. herbaceous species replaced the closed forest vegetation in the catchment area based on n-alkane distribution, corroborated by LOI, sulfur and phosphorus variations.

The effect of the well-documented cold period between 1620 A.D. and 1700 A.D. can be detected in the Bolătău-Feredeu lake-catchment system. Based on P_{hw} and P_{wax}, we inferred that bio-production in the catchment area decreased drastically, which is further reflected by the sand fraction peak and low phosphorous content. Phosphorous data suggests that the coldest period occurred between ~1629 A.D. and 1650 A.D.

An apparent stable period was documented between1700 A.D. and 1780 A.D. with only a slight decrease of herbaceous contribution, presumably caused by the undisturbed growth of the woody species. However, rapid changes may influence herbaceous vegetation without significantly impacting woody plants, thus resulting in decreasing herbaceous contribution.

The signal of the cold period (1780 A.D. to 1860 A.D.) can be observed in the N-SK data and the phosphorus content. Earlier studies documented an anthropogenic deforestation event in the area (Karlik, M. *et al.* 2018) based on organic proxies, albeit the exact date has not been determined. The non-organic datasets, especially the phosphorus and sulfur contents, the sand fraction distribution and the calculated weathering indices, helped to accurately understand the course of the event. Therefore, during this cold period the forest removal started around 1811 A.D. and finished around 1820 A.D. In this short period a large amount of organic matter was delivered into the lake from the catchment area. This significant deforestation was further reflected in the changing weathering conditions.

The time period spanning from 1860 A.D. to 2010 A.D. differs from the earlier periods in that human activity in the area has become an additional factor in the lake-catchment system. However, the human impact in the area is somewhat limited, as the Bolătău-Feredeu catchment is located in a relatively remote area, nearly entirely forested, under conservation status (NATURA 2000 framework). The anthropogenic effect was confirmed by several parameters, such as LOI%, the S content and the weathering indices. The vegetation showed various stages of natural forestation during this period: first, the herbaceous contribution increased in the catchment area, then it was displaced by woody vegetation.

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Green infrastructure-based hydrological modelling, a comparison between different urban districts, through the case of Szeged, Hungary

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Abstract

Because of the climate uncertainties caused by climate change and the growing urban areas, today's cities face new environmental challenges. The impervious artificial elements change the urban water cycle. Urban districts with inadequate water infrastructure and treatment can be a major source of environmental risks, like urban flash floods. Modern cities need to be prepared for the changing environment in a sustainable way, which can be realised with the help of green infrastructure. The primary role of the green infrastructure is mitigation, such as surface runoff reduction and retainment. The aim of our research is to examine urban district scale data about the role of green infrastructure in urban water management. Hydrological models can provide adequate data about the surface runoff, infiltration and the mitigating effect of vegetation (interception and evaporation). We compared two significantly different urban districts (downtown and housing estate area), based on land cover and vegetation data. The analysis of the districts of Szeged (Hungary) suggests that the vegetation can significantly contribute to the reduction of surface runoff. Differences between these urban districts can be quantified, thus, these data can serve as a basis for urban water management planning processes.

Keywords: green infrastructure, i-Tree Hydro, nature-based solutions, sustainability, water management, urban hydrology

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Introduction

The hydrological parameters of urban areas are undergoing significant artificial changes, which can be traced back to a variety of reasons (Fletcher, T.D. *et al.* 2013). The pavement materials and sewer systems change the properties of surface and groundwater. As a result of preferred impervious surfaces, the amount of surface runoff increases, in contrast to the storage and the residence time (Rodriguez, F. *et al.* 2008; Mejía, A.I. and Moglen, G.E. 2010; Kjeldsen, T.R. *et al.* 2013; Samouei, S. and Özger, M. 2020). Examining these processes is timely, as urban spatial and population growth is a fundamental trend in the 21st century (UN 2013; Wilby, R.L. 2019).

The flood hydrograph of the predominantly artificially paved areas changes drastically, for which reason is short travel time and intense flood waves can be expected (Shuster, W.D. *et al.* 2005; Lu, W. and Qin, X. 2020). Weather extremes that are intensifying as a result of climate change, such as heavy rainfall events, urban flash floods and droughts, are also having an impact on urban areas (van de Ven, F.H.M. 1990; Schmitt, T.G. *et al.* 2004; Jha. A.K. *et al.* 2012).

Each part of the city may have significantly different land cover, so for example, the proportion of vegetation largely determines the efficiency of mitigation (*Figure 1*). The study of the various hydrological processes ongoing within districts characterised by different

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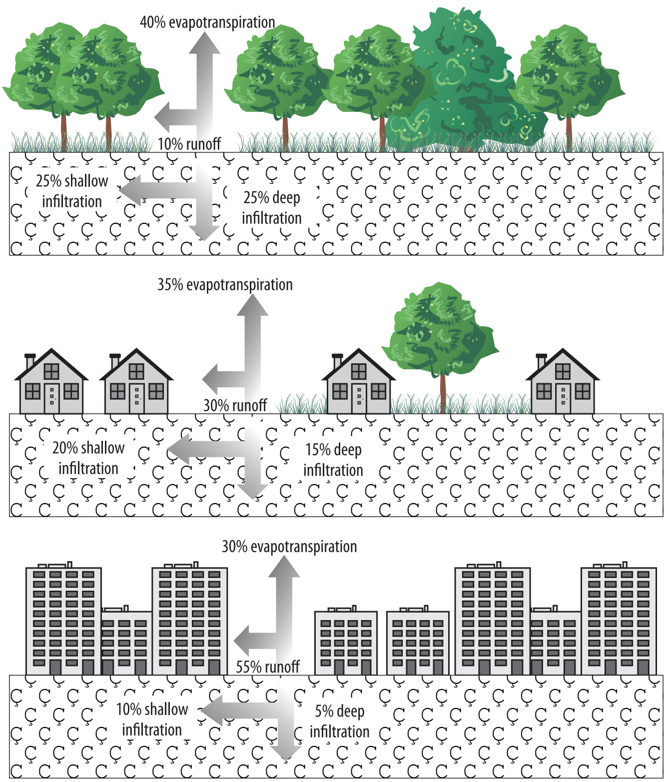

Fig. 1. Hydrological processes of different urban land cover (based on FISRWG 1998)

land cover structures is especially important. In order to install a drainage system with a high enough capacity to meet the demands of its city, knowledge about the expected volume of district level runoff, evaporation and infiltration are paramount (Thorndahl, S. *et al.* 2006; Li, C. *et al.* 2018). In addition to the artificial geometric elements (buildings, surface infrastructure), the different land cover and surface morphology of the districts are shaped by the urban vegetation (Romnée, A. *et al.* 2015; Salvadore, E. *et al.* 2015).

Urban green spaces have multiple positive social and ecological effects on a city and its residents (Kolcsár, R.A. *et al.* 2021). Among the elements of green infrastructure – due to their size – the trees should be highlighted, which can also have a significant impact on hydrological processes through interception (Xiao, Q. and McPherson, E.G. 2002; Holder, C.D. and Gibbes, C. 2016; Berland, A. *et al.* 2017; Huang, J.Y. *et al.* 2017; Kuehler, E. *et al.* 2017). The damping effects of urban trees and other green space elements are getting increasingly recognised and, thus, used to reduce the negative impact of urbanisation on the water cycle (Brears, R.C. 2018; Chatzimentor, A. *et al.* 2020). With these natural tools used in the place of grey infrastructure, urban water management can be made more sustainable and cost-effective, as well as a more liveable environment for the citizens. By combining green infrastructure with traditional elements, complex solutions can be created which have the potential to reduce extreme and unwanted impacts (Liu, C.M. *et al.* 2015; Berland, A. *et al.* 2017; Prudencio, L. and Null, S.E. 2018).

Knowledge of district level processes is also essential because most sustainable urban water management systems also focus on tackling problems at the local level. In addition to sustainable systems such as Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), newer initiatives (Sponge cities) are building on the need to address water-related problems on local levels (Dietz, M.E. 2007; Fletcher, T.D. *et al.* 2015; Liu, C.M. *et al.* 2015; Palla, A. and Gnecco, I. 2015; Mak, C. *et al.* 2017). As a part of the sustainable urban water management systems, in addition to the importance of green infrastructure, it is necessary to emphasise the role of blue infrastructure. Blue infrastructural elements can be basically defined as the natural or semi-natural elements of the water network, which can also be found in urban environments (Haase, D. 2015; Brears, R.C. 2018). These natural infrastructural elements can be applied at the system level – the so-called nature-based solution (NBS) – which is outstandingly popular in today's urban planning (Frantzeskaki, N. 2019).

The main goal in our research was to use hydrological modelling to examine districts with different land cover and to compare the hydrological processes taking place in their area, with a special focus on the role of vegetation in reducing runoff. In urban areas, due to the complexity and diversity of the environment, it is important to use a model that prioritises vegetation not just as a land cover class (Jayasooriya, V.M. and Ng, A.W.M. 2014; Pappalardo, V. *et al.* 2017; Coville, R. *et al.* 2020). In addition, it is important that the extent of surface runoff is handled accurately and exactly by the model. Based on these considerations and our previous research, the USDA Forest Service i-Tree Hydro (version 5) model was chosen (Nowak, D.J. *et al.* 2018).

Study sites and data

The study sites are located in Szeged, which is the central city of the Southern Great Plain Region of Hungary (168,000 inhabitants) (KSH 2013). The area is characterised by high sunshine duration and relatively low rainfall (the region is one of the most arid areas in the country). Consequently, the area is heavily exposed to drought during the summer, which can be interrupted by intense rainfall (Bartholy, J. *et al.* 2014; Sábitz, J. *et al.* 2014; Mezősi, G. *et al.* 2016). Because of climate change, a more extreme distribution of summer precipitation is predicted (Balázs, B. *et al.* 2009). The annual precipitation of 2015 – which was the base year of the modelling – was 450 mm, (slightly below the annual average) in Szeged.

The area of Szeged was significantly transformed by the "big flood" in 1897, as a result of which a new radio-centric plan was formed. This design has significantly influenced the future urban planning processes (Unger, J. and Gál, T. 2017).

One of our study sites is located in the strongly built-up downtown (further on in this document: Site1), while the other is located in the outer, housing estate part of the city (further on in this document: Site2), which is a typical cityscape in larger Hungarian cities (*Figure 2, Photo 1*). Study sites with distinct building geometry and green space coverage provide a good basis for detecting and quantifying the various hydrological properties that are present within the city. The selection of the study sites was based on the system of Local Climate Zones (LCZ) in Szeged (Unger, J. *et al.* 2014). In order to delineate these areas, a number of aspects are taken into account, such as land cover and surface geometry, which also indicate the expected hydrological conditions of the area. Being similar in size was one of the primary factors of the study site selection. Due to the alignment to the road network and buildings, however, there are still differences between these areas regarding their size. In order to avoid bias due to spatial differences, the data for the larger study site (Site2) were projected onto the size of the smaller sample area (Site1) (*Figure 2*).

Site1 is located in the downtown region, hence it is dominantly characterised by impervious area at the expense of green areas (LCZ 3) (Unger, J. *et al.* 2014). A significant part of these green areas are alleys, but two larger urban parks are also present on the study site. The total area of the study site is 60.7 ha. The rate of impervious area is 61 percent (81%, if the impervious surfaces under the tree canopy are included), and the tree canopy coverage is 31 percent of the area, while the herbaceous cover is around 7 percent (*Figure 3* and *5*). The annual precipitation is 450 mm, which means 273,268 m^3 of rainfall fell on Site1.

Site2 is located in the north-eastern part of Szeged (LCZ 5), which can be characterised by midrise buildings and larger open spaces

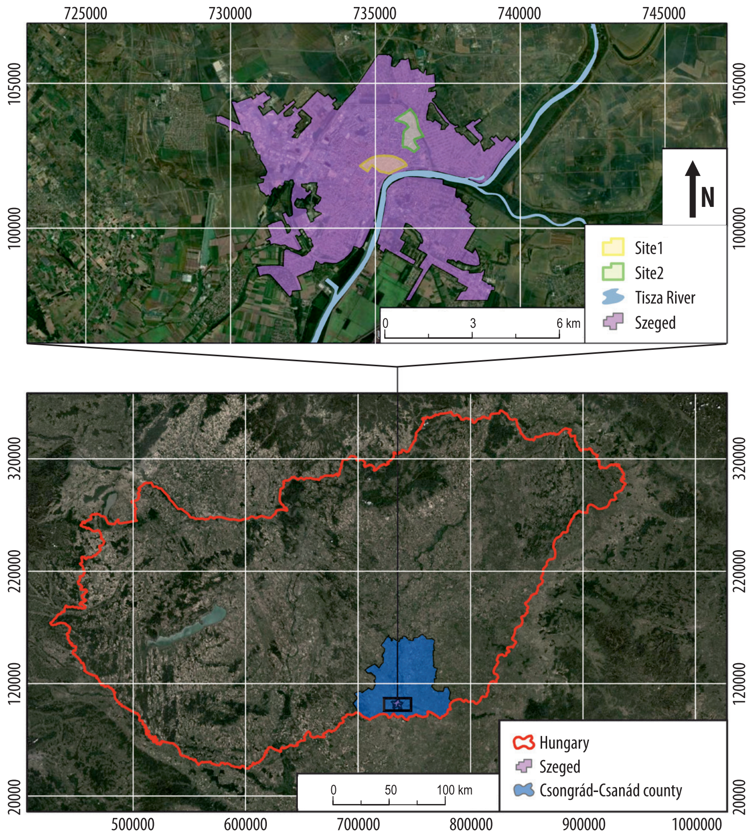

Fig. 2. The spatial location of Szeged and the orientation of the study sites within the city

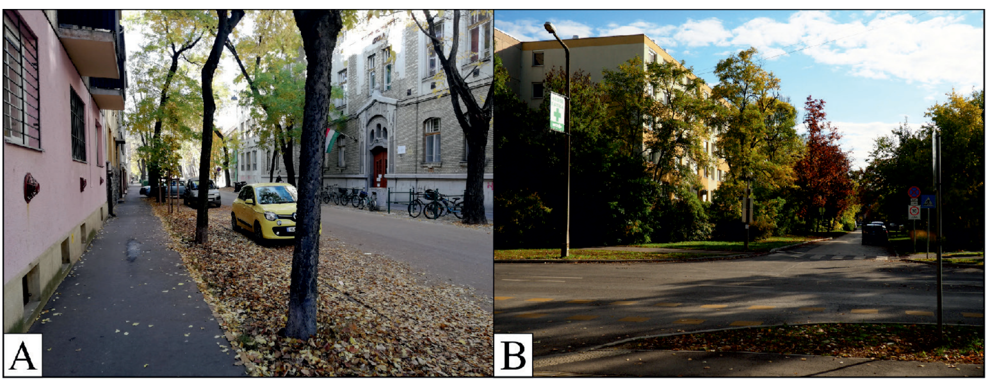

Photo 1. The spectacle in the study sites: Site1 (A), and Site2 (B). (Photo taken by the authors)

Fig. 3. Land cover proportion in Site1

(Unger, J. *et al.* 2014). The total area of Site2 is 65.3 ha. The open spaces are covered with herbaceous and woody vegetation. The proportion of the impervious area is 41 percent (63%, if the impervious surfaces under the tree canopy are included). The tree canopy covers 43 percent of the area, while the herbaceous coverage is considerably more (14%), than in the case of Site1 (*Figure* 4 and 5). In 2015 approximately 294,013 m^3 of rainfall fell on Site2.

These data show notable differences between the study sites in land cover, which also predicts differences in the hydrological processes (*Figure* 5). Site2 is a typical housing estate area. Since housing estate areas are present in virtually every city in the post-socialist countries, this study may potentially provide useful information not only for Szeged but also for most cities in Central and Eastern Europe.

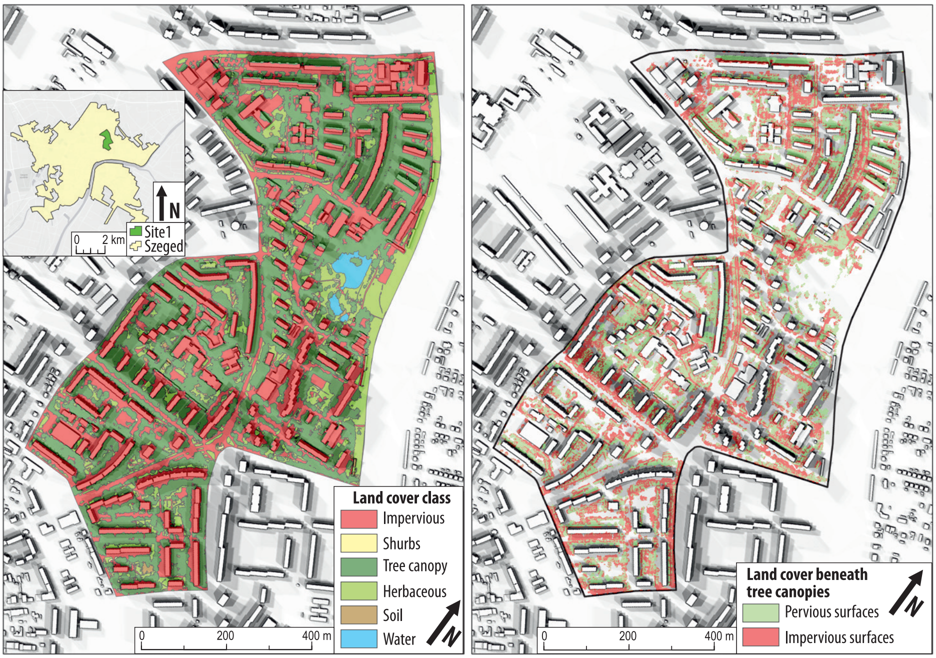

Fig. 4. Land cover proportion in Site2

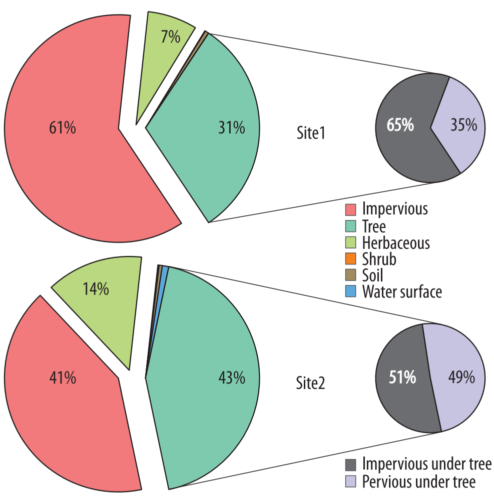

Fig. 5. The land cover proportion of the study sites and the cover beneath under tree canopies

Methods

For the modelling of the hydrological processes, the USDA Forest Service i-Tree Hydro model (in the following: Hydro) was used. Unlike any other similar models, Hydro has the advantage to focus on vegetation in the urban environment. It can be used for a more accurate investigation of the relationships between precipitation and vegetation. The results can provide data on surface runoff (and its distribution on different surfaces), vegetation processes (interception, evaporation) and infiltration (Wang, J. *et al.* 2008; Hirabayashi, S. and Endreny, T.A. 2016). Since i-Tree Hydro was optimised to study areas within the United States, its adaptation to European cities had serious limitations.

The model calculates the outputs based on three main groups of input data: meteorological, land cover, and soil data (Wang, J. *et al.* 2008; Hirabayashi, S. and Endreny, T.A. 2016). The basic data of the model are from 2015. The main parameters of meteorological data include liquid and solid precipitation, wind speed, air temperature, dew point and net radiation. The inputs come from comprehensive databases and have undergone multiple processing (i-Tree 2016). The meteorological data is provided by the Department of Climatology and Landscape Ecology of Szeged and the Szeged synoptic station.

One of the most important databases in the model contains the land cover categories of the study sites. To this end, it is necessary to classify land cover into six classes: impervious areas, trees, shrub vegetation, herbaceous vegetation, soil and water surface. Furthermore, it is necessary to define the land cover beneath the tree canopy according to impervious and pervious categories (i-Tree 2016). In order to define the land cover categories, eCognition 9.1. software was used through performing segment-based multi-resolution classification. The designation of the categories was divided into two stages. In the first stage, the traditional land cover categories were specified. To create the basic categories, a 4-band Ultra Cam X orthophoto (2015) with a geometric resolution of 0.4 m was used. In addition to the orthophoto, a digital surface model (DSM) from 2015, a normalised digital surface model (nDSM) and a digital elevation model (DEM) were also utilised as additional data (Lechner Knowledge Center, 2015). An NDVI vegetation index map derived from the orthophoto was used to refine the vegetation categories.

In the first step, multi-resolution segmentation was used on the orthophoto and the other additional data (DSM, NDVI etc.) to create the basis of the classification. In the next step, with the help of the NDVI, the data was separated into two main classes: vegetation and non-vegetation classes. After this step, the water, soil, and impervious categories were delineated with the use of different limit values and manual classification. We also used a building database of Szeged to filter out buildings (Department of Climatology and Landscape Ecology of the University of Szeged). For better differentiation within the vegetation category, we used DSM and nDSM data. With the help of these, the three different vegetation types (trees, shrubs, herbaceous vegetation) were delineated based on their height. In the next step, the categories beneath the tree canopy were classified. A 3-band orthophoto from 2011 with a geometric resolution of 0.1 m (Department of Geoinformatics, Physical and Environmental Geography of the University of Szeged) was used to categorise the surface under the tree canopy. In this step, only the surfaces under the tree canopies were used. For this delineation, we relied on manual classification in eCognition. The result of these two classification processes was a high-precision land cover category map, completed by a high-precision sub-canopy database (*Figure 6*).

For the third input category, it is necessary to provide pedological data, which were derived from the data of a field survey (Fejes, I. 2014). Regarding the physical soil type, there are only minimal differences between the two study sites, meaning that based on the data, the soil of both sites can be defined as sandy clay loam. Differences occurred in

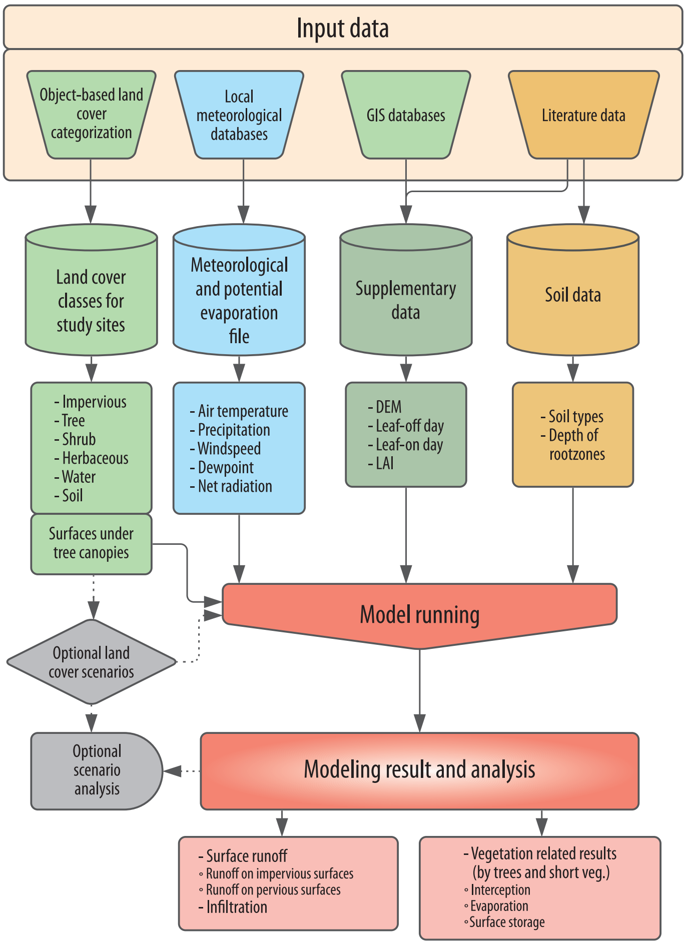

Fig. 6. The structure of the assessment and the modelling results

the depth of the root zone (Site1 50 cm, Site2 100 cm). Besides that, there are some other necessary soil inputs that need to be added to the model (surface hydraulic conductivity, initial soil saturation condition), and in the advanced options, more attributes can be added (e.g. transmissivity at saturation, pervious/impervious depression storage, transmissivity at saturation, soil macropore percentage etc.). The soil data affects the volume of runoff and infiltration, so specifying them accurately is paramount.

The most important output data is the total runoff, which consists of three components: the runoff of impervious as well as pervious surfaces supplemented by the baseflow (Wang, J. *et al.* 2008). Infiltration can also be concluded from this data. Taking into account the land cover data and the soil data, the model also calculates the volume of infiltrated precipitation (using the Green-Ampt infiltration equations). The role of vegetation can be shown by interception, evaporation, and surface storage. These processes can be divided into trees and short vegetation (which includes herbaceous and shrub vegetation) (Shuttleworth, W.J. 1992; Wang, J. *et al.* 2008; Hirabayashi, S. and Endreny, T.A. 2016) (see *Figure 6*).

Results

Runoff-related results

The total runoff was estimated to be 140,595 m^3 in Site1 (51% of the total precipitation) and 120,643 m^3 (44% of the total precipitation) in Site2. These results imply a relationship between total runoff and the land cover structure. The total runoff of the study sites per month shows a similar rate (mostly lower in Site2, with the exception of October and November) (*Figure 7*).

By looking at the subcategories of the runoff of the study sites, significant differences can be detected. The runoff of Site1 is determined by runoff on the impervious surfaces each month. The runoff of the impervious surfaces during the year shows a broadly uniform picture, with the exception of the months with low precipitation. The propor-

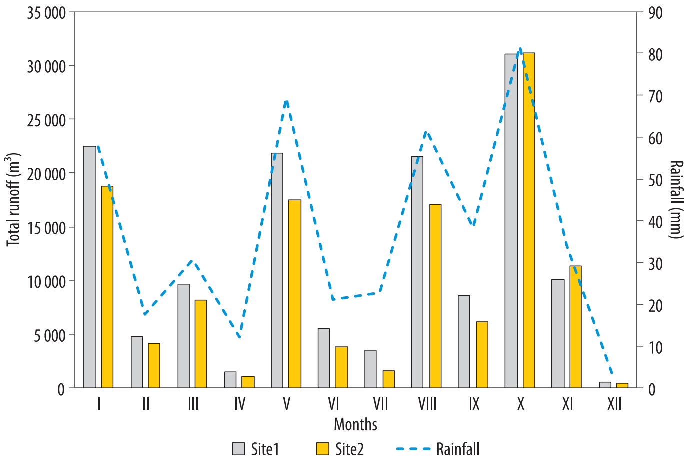

Fig. 7. Total runoff per month in study sites

runoff vast majority of it is flowing on an impervious surface. Infiltration is only 29 percent of the precipitation. A large proportion of the rainfall is being drained away in the downtown area, and only a small proportion of it infiltrates into the soil. In the housing estate area (Site2), the volume of runoff is lower compared to Site1, and a larger part of it flows on pervious surface (*Table 1*). The infiltration rate is 35 percent, meaning tion of the baseflow increased in December and April compared to the other components of the total runoff (*Figure 8*).

In the case of Site2, due to the different land cover structures (higher proportion of pervious surfaces), different runoff ratios are observable. In this case as well – similarly to Site1 – months with low rainfall are the exceptions. During these months, the ratio of the baseflow relative to the other components of the total runoff is higher than in the case of the other months. These months are respectively April, July and December (*Figure 9*).

The differences between the two areas are also reflected in the total volume of runoff throughout the year. Site1 has a higher runoff rate due to lower vegetation cover, lower pervious surface ratio and, thus, less efficient infiltration than Site2. In Site2, there is 7 percent less runoff during the year, which means approximately 20,000 m^3 difference.

In the runoff of pervious and impervious surfaces, an opposite ratio can be observed between the two study sites, which is also due to the differences in land cover. Infiltration is also higher due to the higher proportion of pervious surfaces Site2. Due to its high building coverage, sparse vegetation and, thus, infiltration rate, Site1 in the downtown has significantly more surface

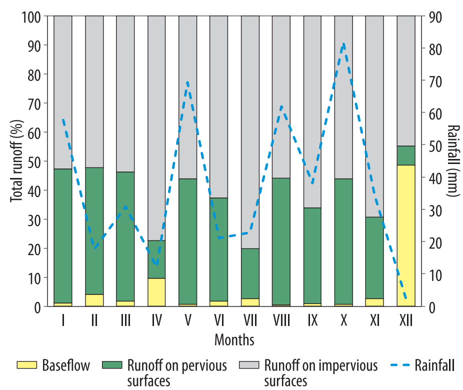

Fig. 8. Runoff subcategories at Site1 per month

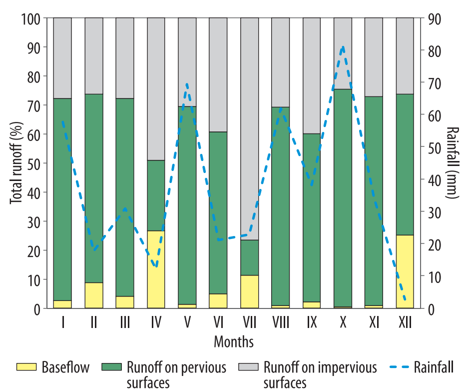

Fig. 9. Runoff subcategories at Site2 per month

Table 1. The runoff-related results by study sites

Processes, m^3	Site1	Site2	Site2 original
Total runoff	140,595	120,643	129,802
Baseflow	1,936	2,622	2,821
Runoff on pervious surfaces	57,304	82,435	88,693
Runoff on impervious surfaces	81,355	35,586	38,287
Infiltration	78,416	94,703	101,892
Precipitation	273,268	273,268	294,013

a larger volume of precipitation infiltrates in this case (*Figure 10*). According to the preliminary assumptions, the hydrological conditions in Site2 are more favourable from the point of view of water management. In Site1, water management development is also hampered by the fact that the densely built-up urban structure is hard to modify, so there is little chance that large-scale changes can be made in the area.

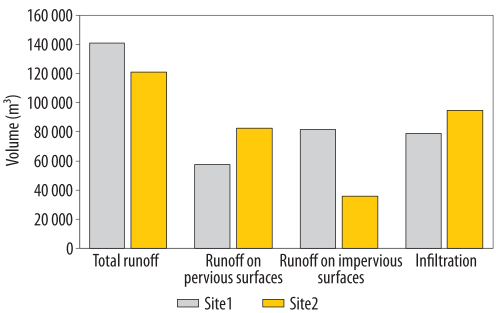

Fig. 10. Summarised runoff-related processes by study sites

Vegetation-related results

The role of vegetation in hydrological processes was investigated through two vegetation categories. One is the short vegetation (which includes herbaceous and shrub vegetation), and the other is the trees. Due to their size, as well as their structural and spatial proportions in the study sites, trees play a key role in modifying hydrological processes. The proportion of trees is significantly higher in Site2 than in Site1, which predicts higher interception and evaporation values.

Due to the higher tree canopy coverage, a larger volume of precipitation fell on the tree canopy in the case of Site2, with almost 35,000 m^3. The volume of interception for Site1 is 10,502 m^3 (3.8% of the total precipitation) and 14,759 m^3 (5.4% of the total precipitation) for Site2. It is observable that the larger extent of the tree canopy cover makes a higher amount of interception possible. Consequently, housing estates located in more open areas have a fundamentally higher green infrastructural value than downtown areas (*Figure 11*). Evaporation shows similar proportions. According to the calculation method of the model, captured rainwater completely evaporates from the surface of the vegetation.

Due to the ratio of short vegetation's structural properties (less surface area to retain precipitation), less water is absorbed, resulting in milder evaporation. In the case of Site2, the interception of short vegetation was 2,020 m^3 (0.7% of the precipitation of

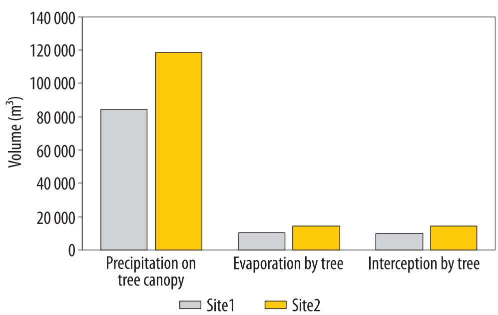

Fig. 11. Tree-related processes by study sites

the total area), while in the case of Site1 it was only 1,030 m³ (0.4% of the precipitation of the total area). Based on these, it can be seen that the interception of the study sites is fundamentally influenced by the trees, while the short vegetation – due to their smaller surface area – has a less important role in the process. Due to the difference between the study sites, vegetation's contribution to rainwater retention is much higher in the housing estate area than in the denser, downtown study site (*Figure 12)*.

The monthly volume of interception is primary based on precipitation, the length of vegetation period (between 200 and 215 days – Rötzer, T. and Chmielewski, F.M. 2001), however, also influences its change. Comparing months with high precipitation in different seasons (e.g. January, May, August and October), clearly visible differences can be detected. In January and August, while the amount of precipitation was almost the same (58–62 mm), interception differed by almost twice as much (*Figure 13* and *14*). In August, due to the active vegetation period, the vegetation was able to retain precipitation at a much higher rate than in January with almost the same volume of precipitation. Similar trends are observed between October and May with the former having higher precipitation associated with a lower interception rate compared to the latter.

Interception efficiency (the proportion of withheld rainwater relative to the total fallen precipitation) is higher the more arid a month

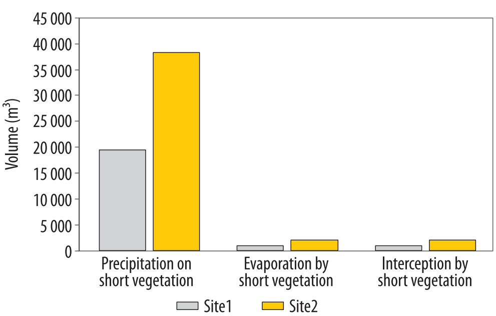

Fig. 12. Short vegetation-related processes by study sites

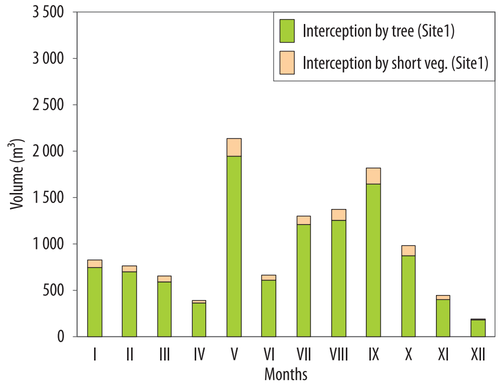

Fig. 13. Interception at Site1

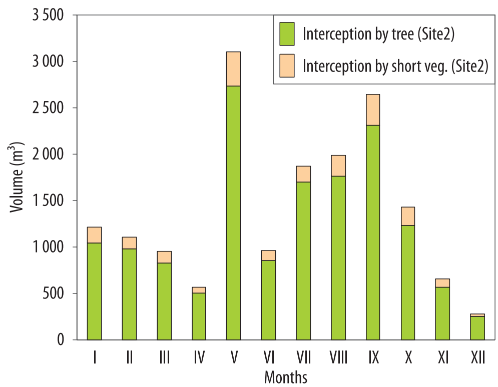

Fig. 14. Interception at Site2

is (*Figure 15*). This phenomenon is caused by the fact that in the case of lower precipitation volume and intensity, the storage capacity of the tree canopy does not reach its maximum, while in the case of a large volume of precipitation, the canopy becomes saturated. The leaf storage maximum values are the highest in the vegetation period (*Figure 16*). When the tree canopy reaches the maximum storage capacity, excess precipitation will not be stored, thus, worsening the precipitation-interception ratio (see *Figure 15* and *16*).

By looking at the interception efficiency, it can be seen that these values are mostly high-

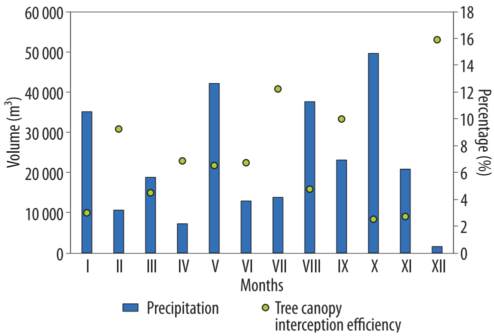

Fig. 15. Tree canopy interception efficiency at Site2

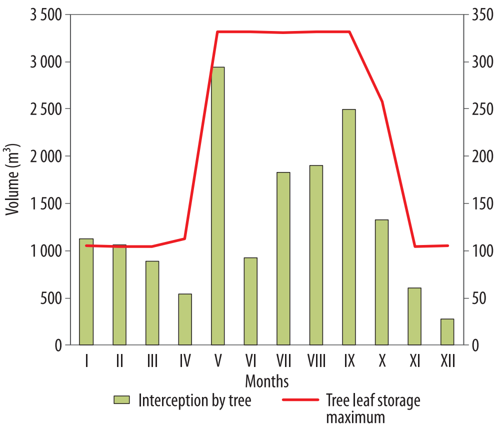

Fig. 16. Tree canopy interception and leaf storage maximum at Site2

er during the vegetation period (additionally in December as well, when the precipitation is minimal), resulting in the volume of intercepted water by the vegetation in a larger proportion during the vegetation period (see *Figure 15*).

Discussion

Results showed notable differences in the hydrological processes between the study sites meeting the preliminary expectations of the study. Runoff and infiltration are greatly influenced by the differences in the ratio of the various land cover types, as noticed in other researches (Shuster, W.D. *et al.* 2005; Li, C. *et al.* 2018; Zhang, N. *et al.* 2018).

In the city centre (Site1) – characterised by a higher ratio of impervious areas – the surface runoff is higher than in the open, housing estate part of the city. This is caused by the higher proportion of impervious surfaces, such as lower infiltration rate and lower vegetation cover, similarly to the results of Li, C. *et al.* 2018. The difference is 7 percent, which means nearly 20,000 m³ of rainwater per year. The infiltration is higher in Site2 due to the higher ratio of pervious surfaces (Brun, S.E. and Band, L.E. 2000; Jacobson, C.R. 2011). In Site1 the infiltration is only 29 percent of the precipitation in contrast with Site2 where the infiltration is 35 percent of the precipitation.

In the study site with high vegetation coverage (Site2), trees contributed to the lower value of surface runoff through interception. Tree canopy induced total runoff reduction has an important role in support of urban water management systems by making the surface flooding and sewerage network overloading events less frequent in this area. Among the vegetation elements, trees contribute the most to the reduction of runoff. This is caused by their size and structural parameters (Berland, A. *et al.* 2017), as well as by their ratio within the study site. The interception efficiency of vegetation is the highest during the vegetation period, but the influence of the time distribution and amount of precipitation are not negligible either. In Site2 the interception of short vegetation is 2,020 m³ while the interception of the trees is 14,759 m³, in opposition to Site1, where the interception of short vegetation is 1,030 m³ while the interception of the trees is 10,502 m³. Due to the difference between these sites, vegetation's contribution to precipitation retention is higher in the housing estate area than in the downtown study site (Li, C. *et al.* 2018).

There are not many available studies with i-Tree Hydro in urban areas, furthermore, these studies investigated significantly larger study areas than ours. A research in Bogotá

(Colombia) investigated a study area of 33.26 km^2, and in another assessment in Luohe (China) a 75.2 km^2 study area was chosen. In contrast with these the study areas in our assessment are 0.65 km^2 and 0.6 km^2 (Bautista, D. and Peña-Guzmán, C. 2019; Song, P. *et al.* 2020). In the assessment of Song, P. *et al.* (2020), scenario analysis was used. They ascertained the increased proportion of green spaces could reduce the surface runoff. This is in line with our findings that the study site with a larger green cover has better water management properties. They highlighted that the vegetation, as part of the green infrastructure, has positive effects on runoff reduction, but on its own, the vegetation/green spaces do not have enough capacity to avoid urban flooding. Based on our assessment, we can also conclude that vegetation decreases surface runoff; however, with the increase of permeable surfaces, the efficiency of runoff mitigation can be further enhanced. Song, P. *et al.* (2020) divided the interception efficiency investigation of trees into two groups. Leaf-on period during the year means the vegetation period, while the leaf-off period means the phase when the vegetation is in a bare state. Song, P. *et al.* (2020) stated that the interception efficiency is higher in the vegetation period, which coincides with our results. Bautista, D. and Peña-Guzmán, C. (2019) also highlighted the necessity for permeable surfaces. In their assessment, the increment of permeable surfaces under tree canopies had a significant improvement in surface runoff reduction. This fact is of key importance because in the case of the study sites of Szeged, the impervious surfaces beneath tree canopies have a high proportion, which needed further investigation.

The study sites of Szeged have different characteristics, and therefore need different management and green infrastructure developments. The SC1 is characterised by impervious areas and dense building coverage. There are many old buildings and a narrow road network between them. This structure fundamentally determines and limits development opportunities. The buildings cannot be demolished, nor can geometric structures be changed. Therefore, developments are limited to a smaller scale. Smaller-scale green infrastructure and sustainable water management tools have various forms. One of the obvious solutions is the raingardens which can be applied in narrow spaces and can reduce the local surface runoff. They also have a temporary storage capacity. The other feasible improvement is to increase the proportion of the permeable / pervious surfaces. With the permeable concrete or asphalt, parking areas can be made more sustainable, especially if they are supplemented by underground stormwater tanks. In the SC2 the urban planners have more opportunities due to larger open spaces. In this study site, the buildings are at a greater distance from each other, and the proportion of impervious surfaces is lower than in the SC1. Within the study site, a storm basin lake already exists. In addition to the solutions listed at the SC1 – which can also be implemented here – swales and infiltration trenches can increase the infiltration and reduce the surface runoff within SC2.

The i-Tree Hydro model is an appropriate tool to evaluate the role of vegetation in the urban water cycle and water management options. There are only a few tools that build on vegetation in such detail. Nevertheless, its spread is hampered by a few factors. First of all, the model was developed in the US and is therefore optimised for US databases, international use is relatively complicated (and therefore rare). Obtaining and compiling the necessary data is encounter difficulties, especially the meteorological and discharge data within cities. The data supply in Hungary limits the possibilities of model calibration and validation, so we must rely on data from any available international literature (e.g. Bautista, D. and Peña-Guzmán, C. 2019; Song, P. *et al.* 2020). These problems are not completely solved in other researches either, where the calibration or validation was possible, the studies were conducted on a larger area, where more data sources were available (Bautista, D. and Peña-Guzmán, C. 2019; Song, P. *et al.* 2020). More detailed data about the vegetation and its seasonal variability (LAI) can could further strengthen our results.

Conclusions

The i-Tree Hydro model utilised in the present research is suitable for modelling the role of vegetation in the urban environment. In this study, two urban districts with different vegetation cover and geometric structures were compared in order to get a comprehensive picture of their differences regarding their hydrological processes. The district-level data provided by the model can be used in urban planning processes. With this information, the runoff of the areas, as well as the vegetation contribution to its reduction were quantified. Studies in this topic might contribute to making nature-based solutions more popular among urban planners and spreading this concept to reach a wider range of professionals and decision-makers.

Data from different districts and their comparison with the processes of the whole urban area can give a comprehensive picture of the processes in the city, but it can also be extended to cities with similar climate and spatial structures. This research may provide a good basis for urban planning in Central-European cities. This assessment has highlighted the advantages and disadvantages of the model and has emphasised some problem that needs to be solved. We have investigated different study sites within Szeged, similar of which can be most likely found be in other Central-European cities. This research has also focused on which types of green infrastructure elements can be feasible in these districts. Hopefully, the modelling can provide a basis for a similar endeavour of urban planners in other cities. While the data and the results might be different in many cities, this method and the main points can nevertheless be used in other cities as well. Future studies in this topic should aim to complete a runoff analysis based on green infrastructure for the entire administrative area of Szeged. Further investigation in connection with the model is planned. Assessment for the whole administrative area of Szeged could give a comprehensive picture about the city-scale usability of the model on a city level and could highlight the differences between the different scales. Another possibility is to create a scenario analysis between different land cover cases. Furthermore, longer time scale investigations may provide more accurate results. Working with hourly resolution output data is a way to analyse the effects of rapid meteorological events, which makes the assessment more current, based on the future climate predictions.

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Vertical differentiation of pedogenic iron forms – a key of hydromorphic soil profile development

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Abstract

This paper focuses on the vertical distribution and characterisation of pedogenic iron forms in a Gleysol-Histosol transect developed in a marshy area in the Danube-Tisza Interfluve, Hungary. Four soil profiles were investigated along a series of increasing waterlogging and spatial and temporal patterns of hydromorphic pedofeatures (characteristics of pedogenic iron forms) were recorded. Frequent and wide-range redox potential (Eh) changes caused the emergence of many types of redoximorphic iron features, including mottles, plaques and nodules. The forms of these features depended on the micro-environments determined by the vertical position in the soil profile and the presence of plant roots. The greatest iron enrichment occurred in the zone of most intensive and widest-range redox fluctuations. Increasing water saturation resulted the extension of gleyic pattern due to the existence of permanent reduction. Most of the features also showed annual variations during the varying periods of water saturation and aeration.

Keywords: pedogenic iron forms, redoximorphic pedofeatures, hydric soil formation, gleysation, soil colour

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Introduction

The development of hydric soils is determined by longer or shorter periods of water saturation. As water is the weathering reactive agent as well as the transporting phase of solutes and colloidal components through soil profiles (Chadwick, O.A. and Chorover, J. 2001), waterlogging plays an intensifying role in the development of hydric soils (Lin, H. *et al.* 2012). As a result, weathering of primary minerals of the parent material and, thereafter, the precipitation of pedogenic iron minerals take place in environmental time scale and are often supported by mineral-rich groundwater in the case of hydric soils (Thompson, C.A. *et al.* 1992; Amon, J.P. *et al.* 2002; Katsikopoulos, D. *et al.* 2009).

The altering of water-saturated (reductive) and aerated (oxidative) periods provides a platform for specific soil-forming processes that produce redoximorphic features in the soil profiles (Cornell, R.M. and Schwertmann, U. 2003). Ever-changing Eh (redox potential) promotes the transformation and redistribution of redox-sensitive soil components, with particular regard to iron compounds. Permanently water-saturated soil horizons exhibit strongly reducing conditions which results the absence of iron

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(light grey colour) or the presence of ferrous components (green colour). Water table fluctuations lead to redox changes followed by the appearance of reddish to yellowish brown colour in the soil profile due to the enrichment of different Fe oxy-hydroxides (Golden, D.C. *et al.* 1997; Cornu, S. *et al.* 2009; Lindbo, D.L. *et al.* 2010). Newly formed iron minerals can appear as mottles, cutans or nodules. The first signs of these redoximorphic features can develop in a few years or less (Amon, J.P. *et al.* 2005). The spatial and temporal distribution of iron forms along the soil profiles is determined mainly by the intensity of waterlogging and redox fluctuations (Imbellone, P.A. *et al.* 2009).

This paper focuses on the vertical distribution and characterisation of iron compounds in a Gleysol-Histosol transect developed in a marshy area in the Danube-Tisza Interfluve, Hungary.

Our aims are to (1) reveal the forms and distribution patterns of pedogenic Fe compounds found in the studied hydric soil profiles, (2) find the relationship between the specific redoximorphic features and the degree of waterlogging, and, (3) detect how these Fe compounds indicate the soil environment in which they were formed.

Materials and methods

Study area

The study area is located in the Danube–Tisza Interfluve, Central Hungary (N 47° 12′ 23,37″ E 19° 40′ 54,87″). The nearly flat plain is covered by sedimentary, coarse calcareous quartz sands of Pleistocene age (Dövényi, Z. 2010; Kalmár, J. *et al.* 2012). The study area lies on an approx. 8 ha marshy meadow in the former floodplain of the stream Gerje.

The primary surface consisted of a succession of low ridges of sand dunes and shallow troughs along the stream. Peat formation took place in the depressions. A layer of calcareous sand material from the adjacent hills was deposited on the surface via an extremely heavy flash flood event in 1963 (Surányi, D. 1965 – L. Pultzer pers. commun.). Since then, there has been no sediment deposition again. As part of waste-water management in the 1970s (Baranyai, Zs. *et al.* 2014) the Gerje stream bed was settled and regularly dredged. As a result, the groundwater level has dropped to an average of approx. 30 cm below the surface but still shows a wide-range seasonal fluctuation. The meadow is flooded on average 5–9 months of the year. The topsoil is almost permanently water-saturated, exceeding field capacity. The groundwater level is often above the soil surface in the early spring and gradually decreases during the summer, reaching its minimum in the late autumn and winter.

In the present work, we investigated four hydromorphic soil profiles (M1–M4) assigned along a transect of increasing duration of water saturation *(Figure 1).* M1 profile is the least affected by water. The upper 20 cm is always aerated but also moist due to capillary rise. M4 profile is constantly under water. M2 and M3 profiles form a transition between the former two, with altering water cover, water saturation and aeration, following the annual fluctuations of the groundwater level. The vegetation pattern follows hydric characteristics, with alternating wet meadow, sedge and reed along the transect.

Samples were collected from each diagnostic soil horizon. Where possible, nodules and Fe-rich root channel infillings were collected as well. Samples for laboratory measurements were taken by Edelman auger, immediately put into Falcon type high purity polyethylene tubes and stored at 4 °C until being measured. Field studies were planned and performed based on the inscriptions of the World Reference Base for Soil Resources – WRB (Schoeneberger, P.J. 2012; IUSS Working Group WRB, 2014).

Field observations

Distribution of carbonate, Fe^{2+} and Mn^{2+} content was detected via simple chemical tests by

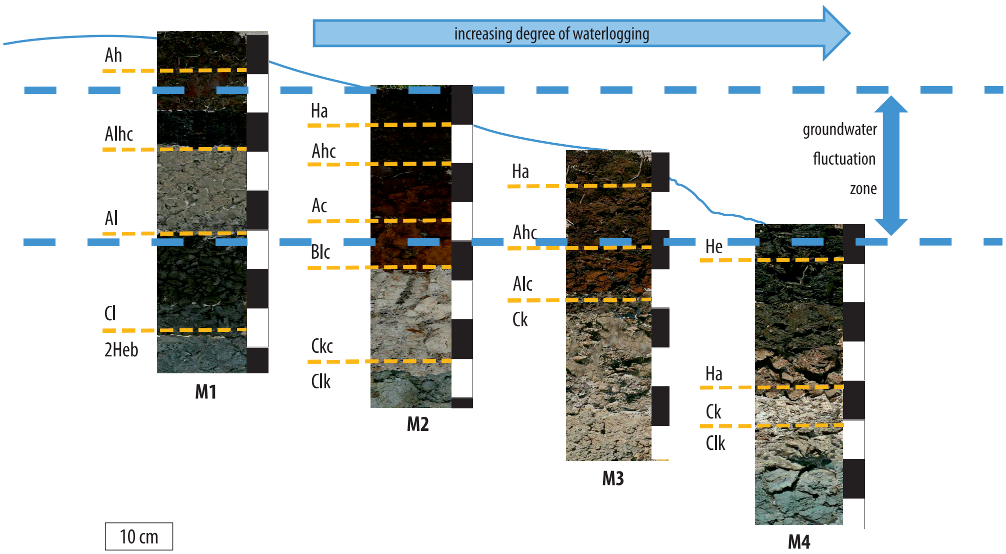

Fig. 1. Position of the studied soil profiles along the transect of different depths of waterlogging

10 percent hydrochloric acid, α, α-dipyridyl dye (Childs, C.W. 1981), and 10 percent hydrogen peroxide, respectively. The presence of Fe(III) compounds was inferred from their characteristic reddish-brown hue. Soil colour was determined by Munsell colour chart.

Redox potential (Eh) and pH in the rooting zone (in 20 and 40 cm depth) and in the permanently water-saturated zone (in 100–120 cm depth) were being monitored in the area during the vegetation period in earlier studies (Szalai, Z. *et al.* 2010, 2012, 2021).

Morphological study

Stereomicroscopic studies were carried out and photos of redoximorphic features were taken by ToupLite software. Spatial distribution of the major chemical elements of the Fe nodules was studied by point analyses by a JEOL Superprobe JCXA-733-type electron micro-probe equipped with an INCA Energy 200 energy-dispersive spectrometer. An acceleration voltage of 20 kV, a probe current of 3 nA, and a count time between 10 and 60 s were used for the analyses. The diameter of the electron beam used for the micro-chemical analyses was 1 μm. The fabric of the Fe nodules was studied by analysing the backscattered electron images of the polished surfaces.

Analytical overview

For the measurements, samples were air-dried, cleaned from plant residues and mollusc shells and sieved through 2 mm sieve (van Reeuwijk, L.P. 2002). The total Ca (and Mg) carbonate content was determined using Scheibler's gas volumetric method (Rowel, D.L. 1994).

Selective chemical extractions were applied to determine the free Fe and Mn contents. Free (CBD) Fe and Mn phase was extracted by dithionite-citrate-bicarbonate solution according to Holmgren's procedure (Holmgren, G.G.S. 1967). The samples and reagents were placed in centrifuge tubes, were shaken for 16 hours and, centrifuged at a speed of 4,000 rpm for 20 minutes. The residues of the extractions were twice again washed with the reagents due to the great amount of extractable Fe present in the samples. The solutions were diluted and then dissolved Fe and Mn content was measured by atomic absorption spectroscopy, using Perkin Elmer AS300 Fl-AAS, at 248.3 nm (for Fe) and 279.5 nm (for Mn) wavelength.

Results

Toposequence of the hydromorphic soil profiles

The toposequence of soil profiles toward the increasing degree of waterlogging is Calcaric Mollic Gleysol (Endoarenic, Epiloamic, Hyperhumic), Calcaric Calcic Histic Gleysol (Endoarenic, Epiloamic), Calcaric Histic Gleysol (Endoarenic, Epiloamic), and Fibric Eutric Histosol (Calcaric, Mineralic), referred to as M1, M2, M3 and M4, respectively, in the text.

The uppermost 10 cm of M1 formed a hyperhumic mollic horizon *(Table 1)*, followed by the Alc horizon (10–35 cm) also characterised by SOM (soil organic matter) and Fe oxy-hydroxide enrichment (> 50% mottles). The C horizon was slightly mottled. The depth of the buried Histosol (H2eb) was about 80 cm.

The uppermost 10 cm of M2 was a histic horizon (Ha). The uppermost mineral horizon (Alhc) of M2 (10–35 cm) was characterised by SOM enrichment, a clay loam/silty clay texture, and Fe oxy-hydroxide accumulation. A reddish colour dominated the soil matrix between 10 cm and 45 cm due to a high amount of free Fe oxy-hydroxide minerals. Fe oxy-hydroxide masses, Fe mottles, and Fe plaques (rusty root channels) appeared in the upper 20 cm. While mottles and Fe plaques were dominant in the Ah horizons, the amount of Fe nodules increased to a depth of 45 cm. Root density (with dominant species being *Carex riparia* and *Carex vulpina*) was the highest between 35–45 cm. A zone of fine-grain carbonate accumulation was found at the depth of 45–70 cm, containing numerous irregularly shaped carbonate nodules of varying sizes. The gleyic pattern appeared below 70 cm in a sandy-loam-textured horizon.

The uppermost 10 cm of the M3 formed a histic horizon (Ha) followed by two organic-rich A horizons (Ahc and Ac) with continuously decreasing SOM content and common Fe plaques and many coarse black and reddish mottles. The extent and distribution of red and black mottles could make it impossible to determine the colour of the soil matrix. Below 50 cm powdery lime enrichment was present (Ckc) with few fine Fe mottles.

The uppermost 40 cm of the M4 profile was extremely rich in SOM, arranged in two histic horizons (He and Ha). Below 40 cm disperse powdery lime was present (Ckc) with Gleyic pattern starting from 50 cm (Clk).

Field observations

The α, α-dipyridyl dye and hydrogen peroxide tests showed permanently positive results in the topsoils (*Table 2*). The amount of Fe(II) increased with the duration of water saturation. With the lowering of the groundwater table, the abundance of reduced phases decreased.

Annual changes of soil colour could be observed (*Table 3*). The reddish colour appeared and became dominant during the summer via extended precipitation of Fe oxy-hydroxides in the zone of decreasing groundwater level (M1-M3). In some cases, soil colour in this depth of M1 and M2 was indeterminate because of the great variety of different hues *(Photo 1).* In the upper 35 cm of M1 profile darkening was observed. Gleyic pattern appeared in many different hues in the permanently water-saturated zone. In profile M4 reddish hue was missing, most likely due to mostly reduced Fe forms.

Morphology of iron plaques, coatings and nodules

Fe plaques and Fe nodules often occurred in a combined way *(Photo 2)* in the upper 20 cm of the studied soil profiles. Single Fe nodules found in 35–45 cm depth were built up of mineral particles of the soil matrix stuck together by finer Fe precipitations.

*Table 1. Soil morphological description**

Profile	Horizon	Depth, cm	Description	Redoximorphic features
M1	Ah	0–10	Loam; strongly calcareous; many fine roots; clear, smooth boundary	Few very fine Fe mottles; Fe plaque
	Alhc	10–35	Loam; common coarse mottles; moderately calcareous; few fine and medium roots; clear, smooth boundary	Common coarse mottles; Fe plaque
	Al	35–45	Sandy loam; strongly calcareous; clear, smooth boundary	
	Cl	45–75	Sandy loam; strongly calcareous; very few fine channels; very few fine roots; abrupt, smooth boundary	Few very fine Fe mottles
M2	Ha	0–10	Sandy loam; common fine roots; strongly calcareous; clear, smooth boundary	Few very fine Fe mottles; very few fine Fe concretions
	Ahc	10–20	Sandy loam; strongly calcareous; few fine and medium roots; clear, smooth boundary	Many coarse black and reddish mottles; common very fine Fe mottles; few fine Fe concretions
	Ac	20–35	Silty clay; strongly calcareous; very few fine roots; few shell residues; clear, smooth boundary	Common fine irregular Fe nodules
	Blc	35–45	Loam; moderately calcareous; common fine roots; clear, smooth boundary	Many coarse yellowish red mottles; common fine irregular Fe nodules; few fine greenish mottles
	Ckc	45–70	Clay loam; strongly calcareous; common medium hard carbonate concretions; clear, smooth boundary	Few Fe oxide infillings
	Clk	70–120	Sandy loam; strongly calcareous; disperse powdery lime	Gleyic pattern
M3	Ha	0–10	Strongly calcareous; many fine and medium roots; clear, smooth boundary	Fe plaque
	Ahc	10–25	Extremely calcareous; many fine roots; clear, smooth boundary	Fe plaque, many fine Fe mottles
	Alc	25–50	Strongly calcareous; few fine roots; clear, smooth boundary	Many coarse black and reddish mottles
	Ck	50–70	Extremely calcareous; disperse powdery lime; clear, smooth boundary	Few fine Fe mottles
M4	He	0–10	Strongly calcareous; many medium roots; clear, smooth boundary	Few very fine Fe mottles
	Ha	10–40	Extremely calcareous; many medium roots; clear, smooth boundary	
	Ck	40–50	Extremely calcareous; disperse powdery lime; clear, smooth boundary	Very fine Fe mottles, coarse Fe precipitations
	Clk	50–70	Extremely calcareous; disperse powdery lime	Gleyic pattern

*Based on Jahn, R. *et al.* 2006.

Table 2. Seasonal changes of Fe(II) and Mn(II) content of the soil horizons during the year 2013, detected by α, α-dipyridyl dye and hydrogen peroxide, respectively

Soil profile	Horizon	Depth, cm	May		July		August		September		October	
			Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn
M1	Ah	0–10	***	nd	*	**	*	***	*	*	**	*
	Alhc	10–35	**		*	*	*	*	–	*	**	*
	Al	35–45	***		**	*	**	–	–	–	**	–
	Cl	45–75	*		*	*	–	*	–	–	*	–
	2Heb	75–100	***		**	–	***	**	**	–	**	–
M2	Ha	0–10	***	nd	***	**	***	***	nd	nd	***	**
	Ahc	10–20	*		*	***	*	***	*	**	–	*
	Ac	20–35	**		*	**	*	***	–	*	–	*
	Blc	35–45	**		*	*	–	***	–	**	–	–
	Ckc	45–70	***		*	–	–	**	**	*	**	–
	Clk	70–120	***		**	*	**	*	***	*	***	–
M3	Ha	0–10	nd	nd	***	*	*	**	***	***	***	**
	Ahc	10–25			*	*	–	**	–	**	–	*
	Alc	25–50			*	*	–	**	–	***	–	*
	Ck	50–70			***	–	**	–	**	*	**	*
M4	He	0–10	nd	nd	***	*	***	**	***	*	***	*
	Ha	10–40			***	*		***		**	–	*
	Ck	40–50			**	–		*		–	–	–
	Clk	50–70			***	–		nd		–	*	–

Notes: ***strong, **medium, *slight reaction; – : no reaction; nd: no data.

Fe and Mn distribution of Fe plaques and Fe nodules did not show a clear pattern *(Figure 2)* and a regular structure could not be detected.

The structure of different kinds of Fe precipitations seemed to be different depending on their location. Fe plaques were built up of finer Fe precipitants of a rather homogenous distribution. Their colour showed differences: a darker reddish hue was located by the plant roots and a lighter orange hue was observed at a distance (see *Photo 2*).

Chemistry

Free Fe and Mn distribution showed a notable pattern in the soil profiles *(Table 4)*. Fe and Mn enrichment was observed in the topsoils with SOM accumulation and they reached the maximum amount in the zone of groundwater level oscillation. In the studied soils (M1-M3) Fe amounts of the intensive Eh changes increased with increasing degree of waterlogging, while Mn reached its maximum in the buried H2eb and Alhc horizon of M1 and Ahc horizon of M2. Permanently reduced horizons were low in free Fe and Mn. The molar ratio of Fe and Mn was imbalanced by the great amount of Fe.

Different amounts of $CaCO_3$ was detected in all horizons except for the H2eb in M1. Permanently water-saturated horizons contained great carbonate accumulation in the form of powdery lime and nodules of different sizes. pH varied between 7.2 and 8.1 showing maxima under 50 cm of M3 and M4.

Discussion

Redoximorphic features were represented by different forms of Fe and Mn compounds

Table 3. Colour of the bulk soil and its annual changes based on the Munsell colour chart

Profile	Horizon	Depth, cm	Munsell colour (moist)			
			May	August	September	October
M1	Ah	0–10	10YR 2/1 10YR 2/2	7.5YR 2.5/2	10YR 2/2	7.5YR 2.5/1
	Alhc	10–35	10YR 2/2 7.5YR 5/8	7.5YR 5/8	2.5Y 2.5/1	7.5YR 2.5/1
	Al	35–45	7.5YR 2.5/1	indet.	indet.	N 2.5/
	Cl	45–75	2.5YR 4/2	2.5YR 5/3	2.5Y 5/2	2.5Y 5/3
	2Heb	75–100	10YR 2/1 2.5Y 4/2	10YR 2/1	5Y 2.5/1	10YR 2/1
M2	Ha	0–10	7.5YR 3/2	10YR 2/1	7.5YR 2.5/2	10YR 2/2
	Ahc	10–20	7.5YR 3/4	7.5YR 3/2	7.5YR 3/2	10YR 3/2
	Ac	20–35	7.5YR 3/4 7.5YR 5/6	indet.	7.5YR 4/6 7.5YR 5/8	10YR 2/2 7.5YR 5/8
	Blc	35–45	7.5YR 5/6	indet.	10YR 8/2	10YR 4/1
	Ckc	45–70	10YR 7/1	10YR 7/1	10YR 7/2	10YR 8/3
	Clk	70–120	10GY 5/1	5G 7/2	5GY 6/1	10GY 5/1
M3	Ha	0–10	10YR 2/1	5Y 2.5/1	10YR 2/2	10YR 2/2
	Ahc	10–25	10YR 3/4	7.5Y 3/3	7.5YR 3/3	10YR 3/2
	Alc	25–50	10YR 3/3	7.5YR 5/8	7.5YR 4/4 7.5YR 5/8	10YR 2/1 10YR 4/2
	Ck	50–70	10Y 8/1	2.5Y 6/2	2.5Y 7/2	2.5Y 6/2
M4	He	0–10	nd	10YR 2/1	10YR 2/1 2.5Y 2.5/1	2.5Y 2.5/1
	Ha	10–40	nd	10YR 2/2	2.5Y 2.5/1 7.5Y 5/2	2.5Y 2.5/1
	Ck	40–50	nd	2.5Y 7/2	5GY 7/1	10YR 5/2
	Clk	50–70	nd	nd	5G 5/2	2.5Y 7/1

Notes: indet. = indeterminate, nd = no data.

in the studied soil profiles *(Table 5)*. The distribution of these features showed a vertical and a horizontal pattern following the main characteristics of groundwater fluctuations. In this environment, the conditions often resulted Fe(II)/Fe(III) oxidation state transition, causing Fe enrichment also in micro- and macro-scale.

Fe mottles represented the first signs of hydromorphism and were commonly found in the studied soils. Their prevalence and volume increased with the effect of waterlogging. In some cases (in M1 and M2), soil colour was indeterminate due to multi-colouration. Annual soil colour changes were driven by Eh and the corresponding species and forms of Fe. The effect of Fe oxyhydroxides on soil colour have been extensively investigated and detailed in previous studies (Schwertmann, U. 1993; Cornell, R.M. and Schwertmann, U. 2003; Ibáñez-Asensio, S. *et al.* 2013; Martín-García, J.M. *et al.* 2016; Cuadros, J. *et al.* 2020; Samus, M.G. *et al.* 2021). Accordingly, yellowish and reddish hue is due to Fe(III) minerals, such as goethite, lepidocrocite, jarosite and hematite (the first two are typical of hydromorphic soils). Greenish or greyish colour is usually attributed to the presence of Fe(II) compounds under hydric conditions.

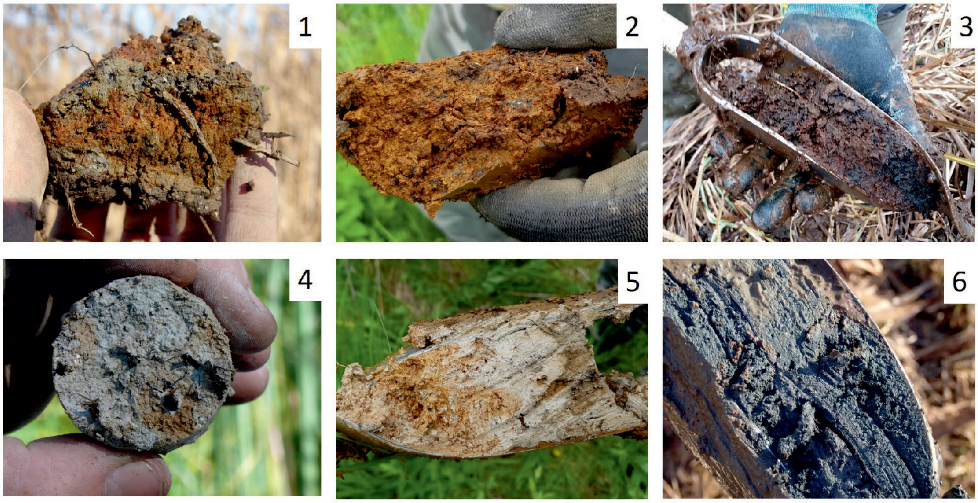

Photo 1. Field photos of collected soil samples: 1 = M2 20–35 cm; 2 = M2 35–45 cm; 3 = M3 10–25 cm; 4 = M2 50–70 cm in May; 5 = M2 50–70 cm in August; 6 = M4 50–70 cm.

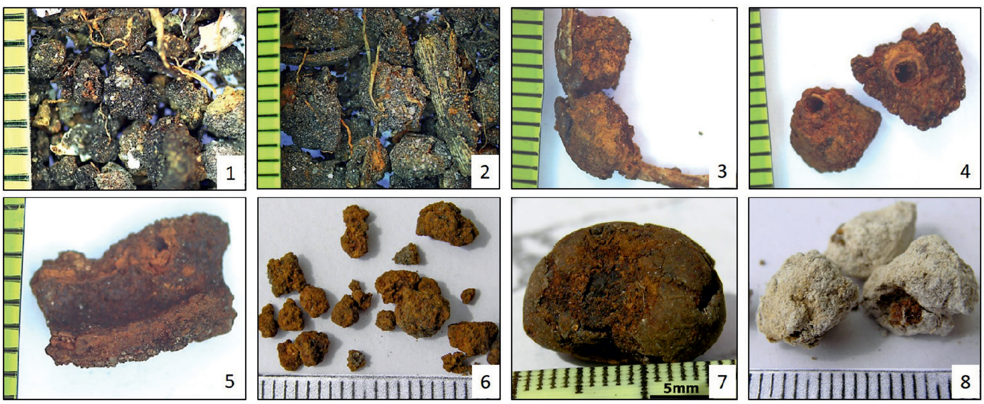

Photo 2. Stereomicroscopic photos of redoximorphic features. 1 = M3 topsoil (0–8 cm) with Fe mottles; 2 = M4 topsoil (0–5 cm) with Fe mottles; 3 and 4 = combined Fe plaque and Fe nodule from M2 35–50 cm; 5 = Fe plaque from M1 22–42 cm; 6 = 2–5 mm Fe nodules from M2 10–25 cm; 7 = 15 mm Fe nodule from M2 35–45 cm; 8 = carbonate concretions with Fe impregnation from M2 50–70 cm.

Fe oxy-hydroxide enrichment is often associated to plant root environment, forming Fe plaques. Fe plaques were often combined with Fe nodules, but these formations showed similar fine structures. Dark red-brown colour (located close to the plant roots) referred to short-range ordered ferrihydrite, while a lighter hue of orange assumed the presence of more crystalline goethite (Driessen, P. *et al.* 2001).

Waterlogging-induced Fe nodules in the bulk soil of M2 and M3 were built up of mineral particles cemented by Fe precipitation. The irregular shape and the incorporation

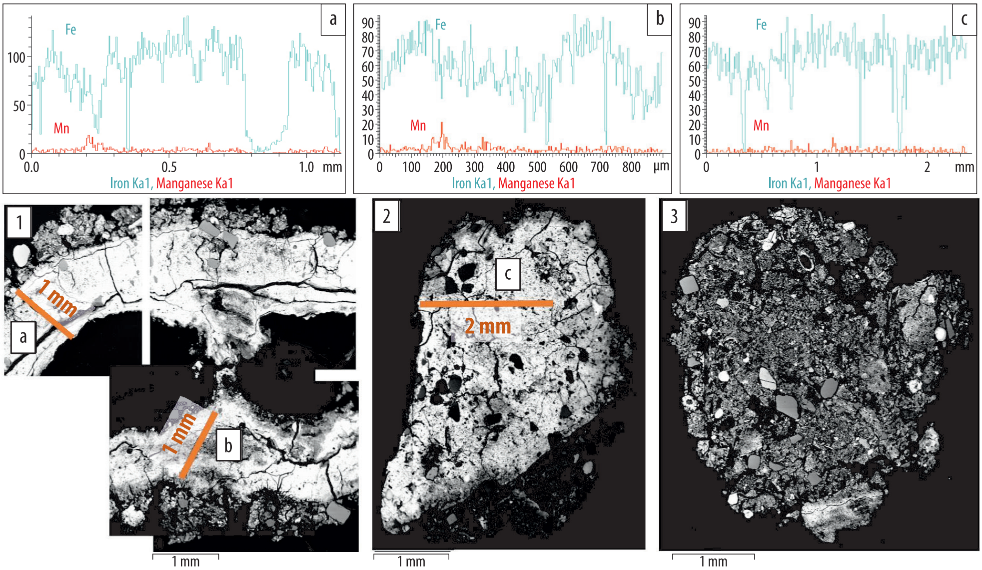

Fig. 2. SEM images of the polished surface of Fe plaque (1) and Fe nodules connected to Fe plaque (2) and standing alone in the bulk soil (3). Orange lines (a, b, c) mark the location of the recorded Fe and Mn Kα 1 spectra (a, b, c). The horizontal axes of the spectra are of the same size as the orange lines.

Table 4. Some chemical characteristics of the soil profiles

Profile	Horizon	Depth, cm	Fe, ppm	RSD%	Mn, ppm	RSD%	Fe/Mn, n/n	$CaCO_3$%, m/m%	pH(dw)
M1	Ah	0–10	76.08	2.17	4.84	1.50	15	28.2	7.7
	Alhc	10–35	156.30	1.88	5.93	0.36	26	9.5	7.4
	Al	35–45	80.00	2.00	1.21	4.00	65	21.3	7.4
	Cl	45–75	4.27	5.69	0.15	19.71	29	15.8	7.6
	H2eb	75–100	22.17	5.83	6.48	3.16	3	0.0	7.2
M2	Ha	0–10	119.76	2.37	4.09	0.37	29	22.5	7.7
	Ahc	10–20	219.83	4.05	5.22	0.45	41	36.7	7.2
	Ac	20–35	222.53	0.43	4.45	1.64	49	13.3	7.2
	Blc	35–45	245.73	1.57	3.51	3.24	69	10.8	7.6
	Ckc	45–70	39.36	1.10	3.95	1.19	10	68.4	7.0
	Clk	70–120	10.36	2.80	1.41	0.43	7	20.8	7.2
M3	Ha	0–10	227.47	2.78	2.92	–	77	24.2	7.8
	Ahc	10–25	267.44	1.72	3.45	–	76	28.2	7.7
	Alc	25–50	350.55	1.76	3.99	3.40	86	14.1	7.7
	Ck	50–70	97.58	0.89	1.98	2.58	49	54.2	8.1
M4	He	0–10	no data					20.5	7.6
	Ha	10–40						33.3	7.6
	Ck	40–50						54.6	7.9
	Clk	50–70						no data	8.0

Table 5. Summary of redoximorphic features found and soil environments under hydric conditions

Hydromophy	Redoximorphic features	Environment
Increasing duration of water saturation ↓	Fe mottles[1]	Periodic water saturation
	Fe plaques[2]	Locally varying Eh (root environment)
	Fe enrichment, changing colour	Eh varying around Fe(II)/Fe(III) oxidation state transition
	Fe nodules[3]	Periodically changing Eh (fluctuating groundwater)
	Gleysation, lack of Fe(III)	Permanently reduced (water-saturated)

Definitions: [1]Mottles = spots or blotches of different colours or shades of colour interspersed with the dominant colour of the soil; [2]Plaques = films of poorly crystalline Fe oxides deposited on the surface of plant roots; [3]Nodules = discrete bodies without an internal organisation. Gradual transitions exist with mottles (Hansel, C.M. *et al.* 2001; Jahn, R. *et al.* 2006).

of soil matrix material in these Fe nodules reflect dynamically varying Eh (Stoops, G. *et al.* 2010; Sipos, P. *et al.* 2011; Szendrei, G. *et al.* 2012; Gasparatos, D. *et al.* 2019).

SOM content of the topsoils seemed to result Fe(II) and Mn enrichment which pointed out the relevance of interactions between Fe, Mn and organic compounds. Complex forming and co-precipitation of these components may be a significant driver of Fe, Mn and carbon redistribution (Sodano, M. *et al.* 2017; Huang, X. *et al.* 2018, 2020; Tangen, B.A. and Bansal, S. 2020; Kocsis, T. *et al.* 2020; Bi, Y. *et al.* 2021; Papp, O. *et al.* 2021). The co-occurrence of Fe(II) and Fe(III) reflects locally and intensively changing conditions.

Gleysation appears below 70 cm in M2 and M3, and below 40 cm in M4 due to the presence of poorly crystalline Fe(II) compounds (so-called green rust / fougérite minerals), which cannot be examined successfully by routine procedures (Bourrié, G. *et al.* 1999; Feder, F. *et al.* 2005; Mills, S.J. *et al.* 2012).

Conclusions

Redistribution of iron along the soil profile acts as a key process in the development of hydromorphic soils. The first signs of these alterations can occur in a few years. The aim of this paper was to characterise the redoximorphic features of pedogenic iron forms in four hydromorphic soil profiles along a sequence of increasing duration of water saturation. Fluctuating groundwater table causes changing Eh environments resulting special conditions for the formation of redoximorphic features, such as iron mottles and nodules. Changes in soil colour and iron forms can be observed in a few months and may have an annual pattern following the groundwater fluctuations. Plant roots control Eh locally resulting the formation of special features similar to the ones originated from waterlogging. The longer the waterlogging persists in the given depth of the soil profile, the more reductomorphic features appear. Gleyic pattern was linked to permanently reductive conditions, although Fe could also be reduced by SOM in topsoil environments. Increasing degree of waterlogging resulted the extension of gleysation. Spatial and temporal patterns of water saturation established the hydromorphic properties of hydromorphic soil profiles. Groundwater level fluctuations followed by Eh oscillations may cause changes in soil colour due to iron oxidation state changes and mineralogical alterations. Seasonally changing soil colour and redoximorphic iron features may also be of interest for soil description and soil classification, giving a different result depending on the date of the investigation.

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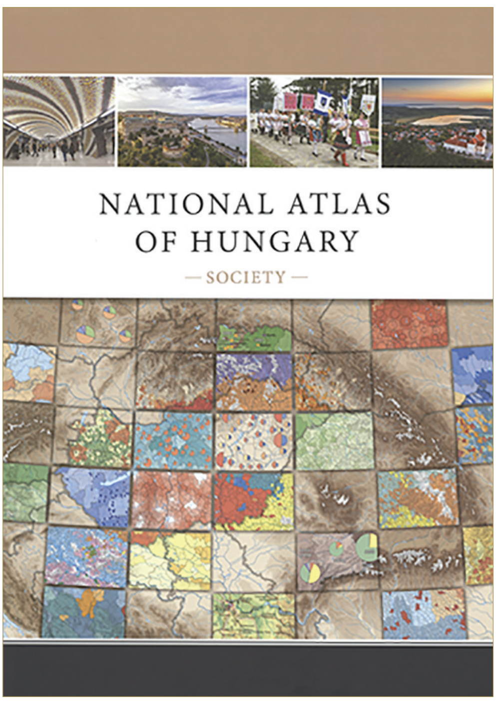
BOOK REVIEW SECTION

Kocsis, K., Kovács, Z., Nemerkényi, Zs., Gercsák, G., Kincses, Á. and Tóth, G. (eds.): National Atlas of Hungary Vol. 3: Society. Budapest, Research Centre for Astronomy and Earth Sciences, Geographical Institute, 2021. 191 p.

It seems that cartography as a science and cartographic practice (map making) have exceeded their climax of the later 20th century. Map use and the ability to compile maps methodologically correctly have obviously been in decline in recent decades, although better technical means than ever are at hands and map-making is open to a much wider range of people than ever before. That is exactly what this atlas volume reminds us, not because it is an example of the decline, but exactly for it is an example for just the opposite: the power of maps , the communicative value of cartographic representation, which can convey at one glance what would have to be explained by a text of innumerable pages. And the question arises, why today only such a small number of geographers utilizes this potential.

This Volume 3 "Society" of the English version of the new four-volume National Atlas of Hungary is a jewel of cartography, and particularly atlas cartography. It would take too much space to repeat here what was already said on the atlas series and its editors and authors in my review of its Volume 2 "Natural Environment" in the Hungarian Geographical Bulletin, Volume 68, Number 1, 2019, pp. 93–96, and readers are kindly asked to consult that review for information on the whole atlas series. In the following, just some essential aspects of the recently published volume are to be highlighted.



Like the previous atlas volume, this volume is divided into chapters easily traceable by colours. Their number is 12. An appendix with names of authors, bibliography and sources completes the volume.

Chapter I (Hungary at a glance, 3 pages) comprises a map of Hungary's administrative division into counties and districts, also representing the eight statistical regions. As in this English version in general, foreign countries and their places are named by their English exonyms (in case they exist), with their Hungarian names in the second position, when the share of the Hungarian minority exceeds 10 percent. A geographical map of the Carpatho-Pannonian area in the 1: 1.8 million scale embracing the Croatian coast of the Adriatic in the Southwest, Cracow in the North and Bucharest in the Southeast impresses by its relief representation. The English exonym principle rules, but endonyms are – except in minor cases like *Königsboden* or *Burzenland* in Transylvania – only presented in their national language and in an official minority language version when the minority has a share of more than 10 percent.

Chapter II (History of population, 6 pages) starts with the Hungarian conquest of the Carpathian Basin but recognizes that a Slavic population was already present and more or less assimilated like other groups arriving together with the Hungarians and later. Very obvious are the effects of the Austrian colonization policy of the 18th century in the south-eastern Carpathian Basin.

Chapter III (Population number, population density, 10 pages) has also a diachronic perspective looking partly back to 1869 and shows that the whole Carpathian Basin has suffered from population decline since 1990 at the latest and depopulation of non-touristic rural areas is significant. Most interesting and innovative is the map of the Carpathian Basin on components of population change between 2001 and 2018 (natural increase/decrease, migration gain/loss), where apart from metropolitan areas southern

Transylvania, Transcarpathia, Ukrainian Bukovina and western parts of eastern Slovakia stand out by migration gain (and natural increase) – very likely due to their Roma population. All these maps show that it is very well possible to combine thematic representation by areal colours with relief representation by hill shading – so important for an adequate interpretation of all these demographic issues.

With the table of main data of vital statistics in Chapter IV (Natural change of population, 12 pages) it is not immediately recognizable that it refers just to the territory of modern Hungary taking into account that the atlas embraces very frequently the entire Carpathian Basin. High fertility rates as well as infant mortality are obviously very indicative for the distribution of Roma population. Most striking is the exceptional rate of suicides in the Great Hungarian Plain and the historical stability of this fact. The text alludes at isolated farmsteads ('tanyas') as an explanation.

Chapter V (Migration, 14 pages) shows that Hungary as well as the rest of the Carpathian Basin are much less affected than Austria or even Slovenia by immigration in recent decades. This can certainly be attributed to the socio-economic gradient, but also to migration policies. The vast majority of immigrants to Hungary appears to be ethnic Hungarians from parts of the former Hungarian Kingdom that remained outside Hungary after the 1920 Treaty of Paris, mainly from Romania with its still sizeable Hungarian minority. Hungarian emigration, on the other hand, is strong to Western Europe with Germany as a main destination. The chapter also reminds us of the exodus of Hungarians after the crackdown of the Hungarian uprising in 1956 as well as the influx of ethnic Hungarians from Yugoslavia and Romania towards the end of the Communist period, when national polarization culminated in Yugoslavia and a tough Communist dictatorship persisted in Romania up to the last moment. It also shows the growth of Chinese immigration in the 2010s. Internal migration – as in most other countries – goes in Hungary at the expense of rural and periphery areas and favours larger centres, although much less their cores (most of which have a negative migration balance) than their suburban zones. Budapest is the best example for this kind of development. If internal migration is taken as an indicator for attractivity in socio-economic terms, the Budapest agglomeration and Northern Transdanubia clearly rank highest. Commuting to abroad is most significant along the Austrian border, where better income in Austria and lower living costs in Hungary are the determining factors.

Chapter VI (Population structures, 44 pages) is the central section of the atlas not only by size, and it is subdivided into several subsections. Age structures are very much coinciding with socio-economic structures leaving older people behind in disadvantaged and periphery areas. Hungary seems to be almost an island of unmarried couples, in the wider region only comparable with Slovakia and eastern Slovenia, obviously due to many divorces.

The ethnic section extends (of course) over the entire Carpathian Basin including even city plans showing the concentration of Hungarians in the old urban cores of Cluj-Napoca and Târgu Mureş in Transylvania. For ethnic and language maps, it is always a question whether the areal method, usually preferred due to its visual impact, is the best choice, since it is insensitive of population density. But this atlas mitigates this negative aspect by excepting compact uninhabited areas from thematic representation. Anyway, instead of "ethnic map", "map of ethnic consciousness" or "map of ethnic affiliation" would be terms better corresponding to current scientific approaches towards ethnicity. With the distribution of Roma an interesting comparison between self-affiliation and estimates by 'objective criteria' is drawn. The two methods result in rather the same spatial pattern, just in much lower shares according to subjective affiliation. The maps on religion in 1910 and 2011 of the entire Carpathian Basin demonstrate impressively the much higher persistence of reformation in the territories of the Hungarian Kingdom than in the Austrian parts of the Habsburg empire due to a significantly less successful Catholic counter-reformation. Very impressive is the progress of Orthodoxy in what became Romanian and Serbian territories after World War I. Other striking issues are the declining number of Lutherans due to the exodus of Saxons and Landler from Transylvania as well as the small share of religious population in modern Hungary compared to the lands that remained outside Hungary in 1920.

In the sections on educational structure and economic activity the map on literacy in 1910 reveals striking disparities inside the Hungarian Kingdom with mountain regions standing out by illiteracy. Within modern Hungary, the Budapest metropolitan area and Northern Transdanubia – the socio-economically best developed parts of the country – are obviously in the best position, also in educational terms. A very interesting topic is the comparison between the educational level of employees and unemployed population. It shows, first of all, the relative size of both population groups, and secondly, the importance of education for finding employment. A diagram demonstrates impressively the decline of the primary and the secondary sectors of the economy in favour of the tertiary sector by employment between 1920 and 2016. The Communist period favoured industrialization at the expense of primary employment but caused (compared to Western Europe) a delay in tertiarisation.

Social stratification is significant in Hungary, and the Northeast as well as Southern Transdanubia on the one hand and the Budapest metropolitan area as well as Northern Transdanubia on the other are clearly the poles in this respect. Here, just like in other sections of the atlas, maps of the Carpathian Basin based on data attributed to administrative units are hardly comparable to Romania, because Romania is the only country represented by (small) municipalities, while all the others are shown by higher-ranking administrative units. This, however, is a problem that cannot be solved, since the next level of administrative units in Romania, i.e., counties ('judeţe'), is already much larger than Hungarian, Slovakian or Serbian districts.

Chapter VII (History of settlement, 6 pages) starts with a map of settlements, in fact, administrative, ecclesiastical and economic centres at the end of the 11th century, when the Hungarian Kingdom established its power over the Carpathian Basin. The chapter also reflects the Ottoman period, when central parts of the Carpathian Basin were under Ottoman rule and Transylvania (plus "Partes") was under Ottoman supremacy leaving in the former some remarkable architectonical traces (e.g. in Pécs, Buda, Eger, Temesvár). An interesting map series demonstrates recolonization of the southern Pannonian Basin after the Ottoman wars by the example of Csanád County. The Great Hungarian Plain stands out by its low settlement density due to natural conditions and the 'tanya' system of isolated farmsteads already before the Ottoman period and not only due to destruction by Ottoman wars and the flight of inhabitants.

In Chapter VIII (Settlement system, 8 pages) a large-scale map of populated places in the Carpathian Basin according to their number of inhabitants and legal status in 2018 demonstrates again the exceptional concentration on larger populated places in the Great Hungarian Plain down to Belgrade.

In Chapter IX (Urban settlements, 12 pages) a most instructive map shows population change of urban settlements in the Carpathian Basin between 1990 and 2018, i.e., in the post-Communist period. It shows that just a few centres essentially grew, i.e., Budapest, but only its suburban zone, Vienna, Graz, suburban Bratislava, suburban Zagreb, Belgrade, Novi Sad, suburban Bucharest, while most others declined in population number. It is also interesting to see that the Hungarian system of regional centres has not become more accentuated in the era since World War II but has diversified towards polycentrism. Formerly less important centres, like Nyíregyháza, Kecskemét, Győr or Békéscsaba, have caught up, while the earlier 'stakeholders' Debrecen, Szeged and Pécs could not advance essentially.

Chapter X (Budapest and its region, 12 pages) on Hungary's dominant urban centre highlights the typical processes of metropolitan development like gentrification and suburbanization.

Chapter XI (Rural areas, 10 pages) addresses demographic developments, village and settlement types, functions and service facilities of villages as well as the significant reduction of small rural outskirts in the Communist period. Accompanying photos contribute especially in this chapter to a better understanding. Exceptional is a map of Hungary's rural landscapes based on rural settlement systems. It shows a hierarchy of large units like Northern Transdanubia or Tiszántúl and their subdivision into smaller ones like Bihar or Csanád. It is a scientific landscape classification applying some traditional names of cultural landscapes in local use, but not necessarily sticking to them. A map representing traditional cultural landscapes and their names in local use would certainly look different in naming as well as in landscape outlines. It is nevertheless questionable, whether a subunit of Northern Transdanubia should bear the same name *Northern Transdanubia* and another subunit of Northern Transdanubia the name *Western Transdanubia* and not *West Northern Transdanubia*.

Chapter XII (Living conditions, quality of life, 26 pages) is a kind of a summary or conclusion of the entire volume, since what else than a 'good life' is the ultimate goal of all societal efforts. It shows that spatial socio-economic disparities in modern Hungary are at least not felt as dramatic but in fact, the Budapest agglomeration and Northern Transdanubia enjoy a privileged position.

Contrary to many other national atlases, this atlas profits from the view on a wider region, in this case the Carpathian Basin, which is of course due to Hungary's image of self as the successor of a much larger historical entity. It nevertheless deserves to be acknowledged that this means much additional work with finding comparable data and classifications for quite a number of countries. The atlas excels by an ideal mixture of cartographically splendid maps, tables, diagrams, concise texts and photos interrelated by a sophisticated numbering and colouring system. This highlight of modern atlas cartography nourishes great expectations to the remaining atlas volumes on "The Hungarian State and its Place in the World" and "Economy".

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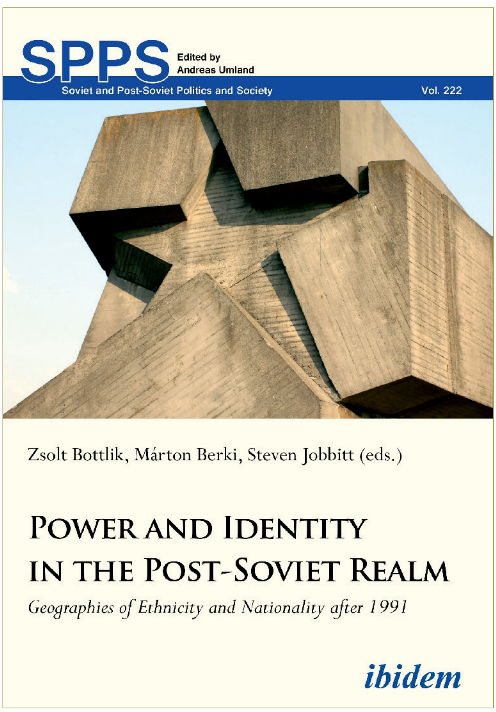
Bottlik, Zs., Berki, M. and Jobbitt, S. (eds.): Power and Identity in the Post-Soviet Realm: Geographies of Ethnicity and Nationality after 1991. Stuttgart, *ibidem*-Verlag, 2021. 311 p.

Zsolt Bottlik, Márton Berki, and Steven Jobbitt have produced a thoughtful and remarkable volume on ethnicity and nationality in the former Soviet republics that emerged as independent states in 1991 – minus the Russian Federation and the three Baltic states, the latter of which quickly joined the European Union. Many studies on ethnicity and nationalism preoccupy themselves with the origin and development of national movements and focus on dominate and competing discourses as articulated by key historical figures, often intellectuals, who expressed their thoughts in writing. They then trace the evolution of a national idea through intrigue and conflict, often war. All too often, such studies express to some degree the Romantic notion that ethnicity and nationality are essential and that language is the essence of such identities. Subsequently, the struggle or national self-determination is seen as a struggle for the right to read, write, and speak one's national language. Unfortunately, such studies rely heavily on the written record of a small group of historical figures, who presumably speak for the masses and represent their presumed historical yearning.



Fortunately, the editors of this volume take a different approach to ethnicity and nationality. They begin from the starting point that social identities are a product of a complex set of historical, geographical, and socio-economic factors. For the post-Soviet states in particular, geopolitics, namely competing empires, which, by attempting to integrate these territories in their respective empires with specific policies, shaped the identities of these territories' inhabitants. Of course, the Russian Empire and its successor the Soviet Union was the common denominator for these eleven states, and indeed the latter drew the political boundaries for all of these states. However, the other empires that played roles depended on location and affected differing groups of these states that can be grouped into subregions. The first subregion is located to the southeast where the Russian Empire competed with the Ottoman and Persian Empires, giving rise to the modern South Caucasian states of Azerbaijan, Georgia, and Armenia. The second subregion lies to the southwest. Known as "In-between Europe" or *Zwischeneuropa,* the countries found there on the map today are Belarus, Moldova, and Ukraine. They emerged where the Russian Empire competed with the Habsburg Empire, then with its successor the Austro-Hungarian Empire, as well as the Kingdom of Poland and then the Second Polish Republic. The German and Ottoman Empires also exerted their influences in parts of this subregion at times. The third subregion is found farther to the east in what was "Turkestan", which then became known as "Soviet Central Asia", out of which the Soviets carved today's Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

In examining ethnicity and nationality, the editors and contributing authors not only group the post-Soviet states into subregions but also examine these states temporally. The template for each chapter consists of three historical periods: imperial (with emphasis on the 18^{th} and 19^{th} centuries), Soviet, and post-Soviet. Each is distinct yet remarkable continuity is found through history. For example, both imperial Russia and the Soviet government sought to integrate their territories through socio-economic and cultural, more specifically, language policies. During imperial times, Russification was seen as the primary tool for integration, especially at the end of the 19^{th} century as the winds of modern nationalism blew ever stronger from where they originated in western and then central Europe almost a century before. However, while modern nationalism inspired Russia's imperial leaders to lean evermore heavily on Russification as an integration tool, modern nationalism likewise inspired non-Russian speakers to resist and seek independence. Later, Soviet leaders also used language policy to reassemble the old Russian Empire as the new Soviet Union by recognizing a sort of right of self-determination of many of the minority peoples. Indeed, the number and choice of republics were rooted in the concepts of ethnicity and nationality. Over time, however, the desire to integrate the Soviet state, led Soviet authorities to create the concept of *"homo Sovieticus"*, which in turn led them to policies of Russification. Despite ostensibly rejecting the imperial past, Soviet thinking and practices simply illustrated the old adage that "the more things change, the more they stay the same." Indeed, as the Soviet government attempted to restructure the economically weakening Soviet Union at the end of the 20th century, the non-Russian republics seized the opportunity for independence, in part as a negative reaction to the Russification policies. After independence was achieved, the desire for national homogenization within each of the post-Soviet states made language policy a continuing issue and a source of conflict, witness for example eastern Ukraine where Russian-speaking separatists have created the separatist territories of Donetsk and Luhansk.

These evolutionary characteristics of ethnicity and nationality in the post-Soviet states are hardly revelatory and are not what makes this volume unique. Instead, the great contribution of this volume is founded on the highly detailed spatial analysis of data. In the first chapter, Gábor Demeter describes the means of spatial analysis, which begins with a comparison of the 1897 imperial census with post-Soviet census data collected in the 2000s and 2010s (pp. 8–9). The more recent data, which is collected and mapped at the rayon-level and covers 740 territorial entities, is a much finer spatial resolution than usually applied in studies, especially studies over such vast areas. The 1897 census was composed of only 340 entities. Thus, the spatial alignments are not exact. Moreover, the overall spatial extent of the censuses is not completely coterminous because political boundaries have shifted. For example, the Russian Empire did not include part of today's western Ukraine because it was in Austrian Galicia in 1897. Similarly, the Russian Empire included areas of contemporary Poland and the Baltic states that now are found outside the boundaries of the post-Soviet states. On the one hand, perhaps there is no point in collecting and analyzing the most recent census from Poland and the Baltic states for those areas that once were included in the Russian Empire precisely because they do not currently lie within any of the post-Soviet states. On the other hand, the study could have been enhanced by considering data from the Austrian census in Galicia in 1900. Though it is not a particularly large area, it is in the zone of shifting politically boundaries. Thus, Austrian data and its comparison with recent data could bolster assertions of the effects of shifting boundaries on social and economic processes and expressions of ethnicity and nationality. Because the authors already processed and analysed such large data sets, it hardly can be considered a weakness of their studies that they did not include Austrian census data for Galicia. Nevertheless, such an inclusion could be considered for future study.

The main result of the overall spatial analyses reveals the existence and effects of "phantom boundaries" (p. 3), taken from the translation of the German term *Phantomgrenze* as employed by Béatrice von Hirschhausen, Hannes Gratis, Claudia Kraft, Dietmar Müller, and Thomas Serrier. In short, phantom boundaries are political boundaries that no longer exist, for example, many of the ones of imperial Russia. Nevertheless, they mark previous spatial arrangements of territory and mark dividing lines of previous socio-economic policies and practices of differing states. They not only mark differences in state ideologies but also very concrete differences in levels of economic development, including differing transportation systems with differing degrees of density and cardinal orientations. Because the locations of previous but no-longer-existing political boundaries are already known, the point of the spatial analyses is to reveal a deeper point. By comparing census data from 1897 and the early 2000s, it is possible to determine how responsible these phantom boundaries are for current social divisions and conflicts. In short, the editors and contributing authors of this volume argue that phantom boundaries go a long way in explaining today's conflicts in the post-Soviet states. If true, this volume makes a powerful contribution to the scientific literature.

The vastness of the study area provides the editors and contributing authors many opportunities to prove their argument and in many nuanced ways. The ethnic and linguistic diversity of the Russian Empire, especially on its territorial edges was great and continued through the Soviet period and continues to exist in the post-Soviet period. Moreover, the Russian Empire's and Soviet Union's external boundaries pushed up against and resisted the external boundaries of a variety of differing other states (e.g. Austro-Hungarian and Ottoman Empires). This overall situation has left a series of zones where varying policies and practices of differing state ideologies imposed on a variety of ethnicities and nationalities can be analysed and assembled into a typology of case studies. Indeed, the volume is structured accordingly. Specifically, the volume is comprised of three sections, each with four chapters. The first section, entitled "Formation of National Identity", contains chapters that discuss broader concepts and illustrates the overall picture. This is particularly true of Gábor Demeter's chapter entitled "The Historical Roots of Regional Inequalities and Their Relationship with Present-Day Peripheries and Conflict Zones in the Post-Soviet Realm (1897–2010)". The next three chapters explore different facets of the broader issues. Margit Kőszegi more examines "The Faces of Russian Nationalism". Zsolt Bottlik concentrates on "Geopolitics and Language in the European Post-Soviet Realm", and Géza Barta, Tamás Illés, and Zsolt Bottlik focus on "Russian and Soviet Censuses in Ethnic-National Context."

The second and third sections of the book delve into the case studies. The second section concerns itself with "Local Identities under Russian Rule", and the third section are cases falling under the rubric of "'Constructed' (Soviet) Ethnicities". The four chapters of the second section are devoted to the nomadic Turkic-speakers and the agrarian Iranian peoples. A common denominator for the section is that the creation of monolithic groups "can also be considered a Russian construct, since the relative cohesion among both smaller and larger groups scattered over this vast area [former Turkestani territories] was itself very much a reflection of the changing attitudes of Russian power" (p. viii). It means that integration extended far beyond Russification policies, which in many ways took a backseat to more prominent issues. Islam was the most obvious as it was the "enemy" religion, but integration involved more than the suppression and reorientation of religious beliefs. State power can act so profoundly that it has the ability to construct nationalities through (re-)organization and (re-)classification. Margit Kőszegi's and Zsolt Bottlik's chapter "The Layers of Post-Soviet Central Asian 'Nations'" illustrates such power and its processes. Not only were Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan constructed by the Soviets, the "titular" nations of these nation-states were themselves constructed by Russian imperial then Soviet policies. Though groups with these names already existed, they were not homogenous nations as understood by European definitions. Instead, they were only a few among a constellation of numerous groups with complex and overlapping sets of social relations. Russian imperial authorities then Soviet ones privileged these five and then slowly amalgamated the others to them over many decades. They sought to completely reorganize these peoples' social relations in the process. Though they were not completely successful and actually failed in many ways, their combination of successes and failures resulted in the creation of new nationalities that eventually jettisoned themselves from the Soviet state that they shared with Russians. Similar identities were constructed in the same ways for smaller groups that remain in the Russian Federation today and are analysed in the other chapters of the second section. Margit Kőszegi discusses the evolution of state relations with the "Tatars in Russia and the Post-Soviet Realm". She also authors "In the Net of Power: Small Nations and Ethnicities on the Black Sea Coast." Tamás Illés ends the section with "Living on the Edge: The Origins and Evolution of the Kalmyk Ethno-Religious Enclave along the Southern Russian Frontier."

The third section is comprised of cases falling under the rubric of "'Constructed' (Soviet) Ethnicities". The title of this section is a bit of mystery because all the previous chapters of the volume demonstrated that ethnicities in the study area have been "constructed". Nevertheless, the chapters in this section distinguish themselves from the second section with their own set of common themes. First, they examine groups that were divided from the Russian, then Soviet realm and other realms. The peoples who found themselves on both sides of the Russian Empire's then Soviet Union's boundaries were in "linguistically and culturally similar communities" (p. xiv). Géza Barta provides the first case study of these chapters: "In the Contact Zone of In-Between Europe and the Post-Soviet Realm-Notions of Karelian Spaces". Karelians and part of Karelia are also in Finland. Tamás Illés and Zsolt Bottlik wrote "Rescaling Moldovan Identities." Moldova is part of historic Moldavia, which is largely in Romania and many Moldovans speak a form of Romanian. Margit Kőszegi and Zsolt Bottlik examine "The Post-Soviet Azerbaijani National Identity". Some sources count more Azeris in neighbouring Iran than in Azerbaijan, not to mention many more in other states that neighbour Azerbaijan. And Csaba Baroch addresses "Tajik Identities: Ageless Alternatives to an Unborn Nation". Though the last section of the volume, it is perhaps the most crucial. For if the amalgamation of groups into ethnicities and nationalities discussed in previous chapters may seem more the product of natural forces than they are the product of state power and geopolitics, then these case studies certainly demonstrate the power of state power and geopolitics.

Overall, *Power and Identity in the Post-Soviet Realm* is an excellent contribution to the study of ethnicity and nationality for many reasons. First, it is a comprehensive study that examines identities across a spectrum of circumstances through a series of compelling and convincing case studies. The editors and contributing authors are commended for their choices of cases studies and their success in integrating their case studies into a larger coherent work. Often, such volumes are uneven in their coverage and individual case studies are not well-oriented and well-linked to one another. Second, the volume makes a great contribution by integrating the interplay of internal political geographies with broader geopolitics to explain the evolution, character, and fluidity of ethnicity and nationality. Third, the editors and authors, by building on census data, show that language use does not necessarily reveal identity, at least not essential identity as an individual ultimately may see and define him- or herself. A person's selection of language use on a census questionnaire is often more reflective of geopolitics and socioeconomics than identity. Moreover, census questions often do not capture the complexity of identities, namely that identities are multi-layered. Therefore, the answer to a question about language use often only captures one layer of identity at a specific point in time and may not be the most important one to an individual. Fourth, the editors and contributing authors illustrate the power of geography by showing that the spatial analysis of ethnicity and nationality can reveal crucial aspects of these phenomena that studies without any kind of spatial awareness do not even detect. In sum, the volume's breadth and depth combined with its easy to read but nuanced writing styles make this volume a highly recommended read.

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Fuerst-Bjeliš, B. and Glamuzina, N.: The Historical Geography of Croatia: Territorial Change and Cultural Landscapes. Cham, Springer, 2021. 203 p.

Historical geography has become less fashionable in the past couple of decades compared to a general fascination with the historical changes of geographical conditions, which is not independent of the growing concern for the environmental crisis of our time. Research, however, has partly turned to studying the Earth system and increasingly focused on humans as part of environmental processes rather than towards understanding the changes in the physical geographies of certain areas. This led to a well-expressed shift from historical geography towards environmental history.

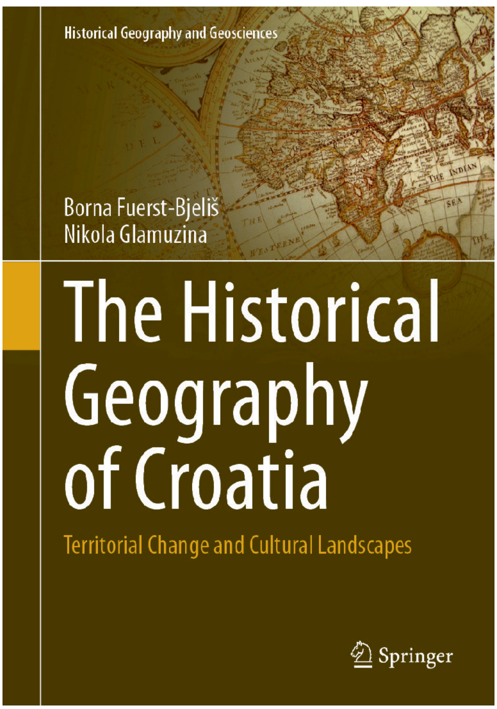
Another paradigm shift that made historical geography less fashionable was the increasing critique of polities as units of enquiries, and shifting focus to smaller, and non-traditional units of analysis such as social and religious groups, different settlement types, etc., which usually proved to be more alien to historical geography.

However, the book of two Croatian geographers, Borna Fuerst-Bjeliš and Nikola Glamuzina, went against both trends in choosing a modern polity, the Republic of Croatia as their unit of analysis, and focusing on the changes of the geographical conditions of this area in the past millennia. The book was originally published in Croatian (in 2015) mainly for educational purposes before it was translated into English in 2021. On the one hand, the translation is a good one, but due to the original, potentially Croatian-Serbian readership, it goes into details which are very difficult to follow without a deep knowledge of the micro-regions of Croatia. The authors also attach explanatory footnotes to discuss different terms unfamiliar for the average reader.

As historical geography has very different research traditions and approaches, it would have been essential to provide a theoretical basis to the analysis of Fuerst-Bjeliš and Nikola Glamuzina in the 10 chapters of their book. According to them, "the nature of the discipline, the historical geography of Croatia can be understood as the geography of Croatia's past. It is primarily the geography of how the space and cultural landscape have been shaped, for every respective period of Croatia's historical-geographical development." (p. 3). However, what the authors mean by cultural landscape remains unclear. While in many subchapters the authors point to changes in population and administration of the different provinces, the analysis of the landscape and vegetation changes in the past millennia is not detailed thoroughly. While at some points the authors discuss the importance of stock breeding, wine growing, olive production as well as, of course, crop production, the impact of the different activities on forest cover, soils, erosion, etc., is only vaguely mentioned in the different chapters of the book. This is difficult to understand, as according to the authors' definition, the historical geography they were to present is the history of the cultural landscape changes in which one can hardly disregard from studying the above listed problems.

Despite the reduced thematic focus there are some remarkable merits of the text. First, it is logically well-structured and easy to read. The recurrence of topics makes comparison easier, such as the maps of similar outcrop. Beside general descriptions, both qualitative and quantitative data are available in the text. Especially well-written are the parts on land ownership-system (including Neolithic, Roman, Medieval, Ottoman etc.), trade, commerce and traffic (the Venetian seashore). The changes of geographical terms (Dalmatia, Slavonia) are also well interpreted.

However, there is certain imbalance within the focus. First there is the territorial aspect: Dalmatia is very professionally written, while in the case of Pannonian Croatia one would expect more, especially if compared to the valuable descriptions and analysis of transformations in Dalmatia. Furthermore, though



the text keeps focusing on cultural landscapes, some elements could have been emphasized better. For instance, there is no map on the changes of land cover and agricultural systems – not even on a small portion of the country.

The fact that in the chapters from the foundation of the Croatian state onwards the work mostly builds on Croatian scholarly literature is no surprise, and the fact that the research results of the last decades are brought to the English-speaking audience is most welcome. However, two tendencies worth to be pointed to in this respect. First, that even while discussing the Roman times, the book predominantly uses Croatian literature, and in most cases not ones written in the past two decades. The other striking omission is scholarship of the neighbouring countries for the last millennium, such as works written in Italian, German, and Hungarian.

One last point before turning to the different chapters of the book, is the usage of maps. Some of the maps significantly contribute to the understanding of the administrative changes, the political units, migratory processes, etc. However, many maps (e.g. Figures 3.1, 5.5, etc.) only represent the actual features within the present boundaries of Croatia that makes it difficult to use. In most cases not only the visualization, but the content of the maps too deserves attention, but some could have been planned better (like the one indicating migration routes or the one that illustrates whole Baranja as part of the medieval Kingdom of Croatia). Original maps, the contemporary and local perceptions of the landscape could also have added more to the general picture. As for cultural elements on landscapes, while routes are indicated professionally, there is no map on castles and fortifications, major churches with data of their (re)construction, mines, etc. These would have been worthy of more attention. The authors also consider the territorial changes of administration as a part of cultural landscape, but while the župa-system is clarified well, one would expect more explanation in the beginning when the boundaries of Croatia and their creation is discussed.

After these general points, in the following sections we aim to draw attention to some specific issues in the different chapters. After the general outline and concept of the book (Chapter 1), that we touched upon above, Chapters 2 to 10 give a chronological overview of the development of the land of Croatia from the Palaeolithic to the 2010s.

The general features of Palaeolithic-Neolithic era are described too long (just like the Ottoman structure and its general internal problems before its collapse in Croatia), in comparison to the shorter description of the local specificities. The maps are lacking excavational sites located outer Croatia, which is confusing (the territorial extent of these archaeological cultures is indicated properly). Since the territorial extent of some cultures is not limited to present-day Croatia it would have been more proper to give the full names of these cultures: the authors use Starčevo culture instead of Starčevo-Körös, or Vučedol culture instead of Vučedol-Zók culture.

After discussing the Palaeolithic and Neolithic settlement processes in the area in Chapter 2, the authors provide a more in-depth analysis of the Roman period, which clearly was a period of fundamental importance in the landscape changes in the past millennia. There is a fascination amongst historians for almost a century on the formation of the landscape of the Mediterranean. Some of the scholars have put the formation of secondary vegetation, the treeless hillslopes and shrubland vegetation to the Roman period in their focus, and attributed it to the intensive timber need of both the military and civil populations. There is virtually no discussion of this in the book (the authors seem to consider the Ottoman period more serious in this respect), and neither of the impact of the Roman agricultural system on the soils in the area, which in the past decades, not independent of the growing importance of geoarchaeology, brought important results in understanding the impact of Romanization all throughout the Mediterranean. There are some misunderstandings and mistakes in this chapter. The Roman *limes* is referred to as a hard border (p. 45), the Ostrogoths as nomadic peoples (p. 49). To illustrate, how important it would have been to use the most recent literature let us point to one further issue. The authors attribute large importance to the plague of 542 A.D. (Justinianic Plague) in the territory of modern Croatia, around which a completely different paradigm has been unfolding in light of more recent research by Lee Mordechai, Timothy Newfield, Adam Izdebski, and others.

Chapter 4 is dedicated to the changes in the post-Roman period, marked by a strong desurbanisation and decline according to the authors. They point to these processes in the territory of the former province of Pannonia, while in the seaside they suggest a stronger continuity in the "Roman cultural landscape". The focus of the chapter is early medieval migration processes, most importantly the arrival of the Slavs. The Balkan migratory processes and the Slavic migration within that have been a large field of debate in the past half a century, where fundamentally different views have been presented, including ones that argue against the actual movement of the Croats to their later medieval settlement area, but argue for their local presence from earlier on, and for their identity transformation in the early medieval period. (For a comprehensive overview of the question, see Latosinszky, C. 2017.) It is also in this part that the Byzantine, the Carolingian, and then Ottonian control over the territory are discussed. The Carolingian influence over the region has recently been subject of an important set of analyses (Dzino, D. *et al.* 2018) which along with other works showed that the region, unlike suggested in the current book, was never under direct influence of Carolingian noble families (pp. 60–61). The authors suggest that the German influence in the tenth century went hand in hand with the development of classical feudalism in the area, which was not even typical in areas north of the Alps in the Holy Roman Empire (p. 59).

Chapter 5 discusses the development in the centuries starting with the political influence of the Árpád dynasty and Hungary over Croatia at the turning of the eleventh century. From that time on, the book refers as Hungarian-Croatian Kingdom to the polity that covers most of what is nowadays Croatia, which is anything but usual in the existing scholarship. This part of the book almost completely disregards the discussion of the changes caused by the Hungarian rule, despite that in the past years, important works discussed the connections of the two polities in the Árpádian period and later (Gál, J. 2021). This part would have also profited from a thorough review by a historian. In that case the Golden Bull of 1222 would not have been dated to 1242 (p. 67), Pécs would not have been included in Lower Slavonia (p.69), and Genoa would not have been interpreted as an important trading hub in the tenth century (p. 77) when it was only a small fishing village.

In presenting the late medieval transformation in the region not only the political changes – i. e. the appearance of the Ottoman Empire in the area – are discussed (Chapter 6), but also the social and religious crisis are mentioned, partly as attributed to the *pataria* and the Cathars in the area (p. 89) which is difficult to digest in this form. The political crisis is also explained in terms difficult to understand. According to the authors the lower levels of the aristocracy lost much of their status due to the strengthening of mid- and high-level aristocracy (sic!) that went along with disappearance of nearly all noble counties which is a complete misunderstanding (p. 89). The first half of the Ottoman presence is explained in a relatively detailed manner. The new political-administrative system is presented in detail, alongside with religious regulations for the Christians who lived under Ottoman rule. Yet, landscape and geography are almost completely omitted from the discussion. Somewhat surprisingly the Ottoman rule is seen as a heyday for the people, compared to the "Habsburg Monarchy and the Republic of Venice, where Slavs had a secondary role and could not rise high in the state rulership apparatus" (p. 93). The land management system under the Ottoman rule is also explained in positive terms contrasted with the "abusive feudal system," which is debatable (p. 101).

The map on migrations (p. 106) during the Ottoman era uses the term Burgenland and Slovakia (instead of present-day Slovakia or Upper Hungary), which are anachronisms, and did not emphasize the Hungarian Kingdom as a refuge area of Croatians and Bosnian Catholics (though the text itself mentions this). (Central Bosnia should have been mentioned on the map as a source area of immigrants not only to Croatia, but to the Hungarian towns of Mohács, Pécs, Baja and even Buda in the 17th century. After 1686 the [re]conquering of Buda, Catholic Bosnians [Croatians] were allowed to settle in Víziváros and Tabán in the close vicinity of the castle of Buda, because they were trusted loyal subjects.) The abundance of Bosnian Catholics is clearly indicated by the family names 'Bosnyák' in Baranja in the *Conscriptio regnicolaris* from 1715 (*Conscriptio regnicolaris*), whereas the frequency of family names 'Horvát' in western Upper Hungary underlines the hypothesis that Croatian elements contributed to the birth of the modern Slovakian nation. Texts mention *šokci* and *bunjevci* as resettled elements, but maps did not illustrate them separately. (The directions on this very map could have been labelled with the linguistic terms, which are described in the text, but foreign readers hardly have any idea on the location of Stokavian, Kajkavian, etc.)

While explaining the formation of dialects in the Ottoman period, little space is dedicated to the landscape changes caused by the completely transformed land ownership, which received disproportionately little attention with some but notable exceptions such as the military frontier areas. In Chapter 7, while explaining the Habsburg and Venetian occupation and the recapture of the territory of present-day Croatia, we recurrently read about cultural landscapes being destroyed, but finally with numeric data. When explaining the eighteenth century, the authors address the Venetian dominance over Dalmatia and emphasize the importance of natural resource exploitation such as mining, timber for shipbuilding. One may wonder the long-term landscape heritage of this period, along again with the transformed landownership explained by the authors on page 134. The re-settling of many areas in the aftermath of the Ottoman occupation is presented in a more balanced way. However, while deeply explaining demographic processes and economic changes, less attention is paid to land-use and landscape changes.

Finally, the reader might appreciate some data and maps using the modern censuses executed in the eighteenth century and later. A map on the social structure based on the first census of Emperor Joseph in the 1780s in the Kingdom of Hungary would have been worth further discussion, even if it did not contain data on Dalmatia. Similarly, peasant landholding size and lifestyle could have been supported by Bićanić's old work (Bićanić, R. 1952). The authors could not know, but in 2020 Hungarian scholars digitized the data on Croatia from the 1786 conscription – which indicates not only the landholding size of smallholders at settlement level, but also the taxes, days spent with 'robot' (work on allodium landsize), and gift to landlord. The census data from 1910 for Croatia without Dalmatia are now available online not only as raw data (*GISta Hungarorum*), but as a series of maps published in an electronic atlas (Demeter, G. 2019). These could have also enriched the topics discussed and the authors' statements. Mariann Nagy in her work on Hungarian agriculture in the late nineteenth century compares the situation in Croatia and Hungary at county level with hundreds of maps based on quantifiable statistical data for Slavonia and Croatia (not for Dalmatia) (Nagy, M. 2017).

While using both the most recent economic literature on the development of Croatia (Stipetić, V. for dynamic GDP calculations for the different regions and pp. 156–158) and old literature, sometimes contradictory statements occur. The former speaks about dynamic development, while the traditional historical works emphasize underdevelopment and backwardness, for which they blame Austro-Hungarian economic policies (the same was true for Hungarian Marxist historians in the 1970s). The truth is that the elder generation did not understand the mechanism of liberal capitalism, thus failed to recognize that during the dualistic period after 1868 most of the investments were realized through private enterprises and not by the state (including the railway sector), unlike in the era of absolutism. In the regular form of capitalism state intervention is of secondary importance, thus supposing exclusive role for the state itself in industrialization is a misconception. Therefore, the criticism towards Austria-Hungary's government for the economic backwardness of Croatia cannot stand fully. It is also worth further emphasis that industrialization in Croatia was largely based on available agrarian surpluses, such as wood and timber – the same role was played by grain (flour) in Hungary, which also fueled the industrialization.

There are also some minor mistakes in the text regarding the modern period. The Salonika railway was not finished by 1874 (p. 152), only the Ottoman parts had been constructed by then. It should also be noted that a railway economically more suitable for Croatia (between Vukovar and Rijeka) was first planned by Lajos Kossuth early in the 1840s, but the Pest-centric approach of count István Széchenyi finally triumphed (p. 151). The original idea was to send grains from Hungary and Slavonia directly to the markets through Fiume/Rijeka, bypassing Budapest. Since the plan was not carried out in this form, Budapest was able to create its enormous milling capacities, the incomes of which served as basis for capital supply for other industrial branches. Though this story highlights the role of politics over economy, in other cases economic interests were of primary importance (of course, these economic interests of the nobility appeared in politics too during the era of railway constructions). More information on banking would have been better, as well as some better maps regarding urban development (Rijeka).

Beside these considerations the book is a worthy contribution on the topic, especially for those, who are not experts of the field, but want to get some initial insight into the problems, topics, and structures.

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and Dénes Sokcsevits[2]

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