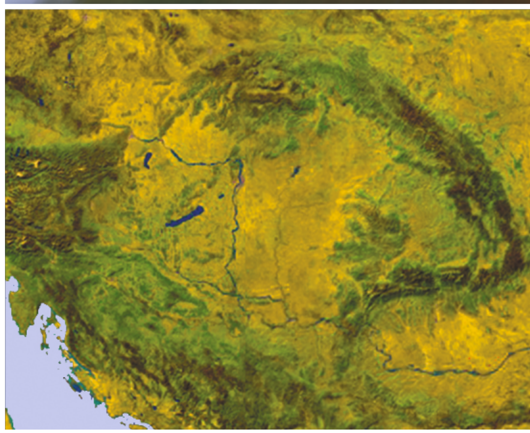
Hungarian Geographical Bulletin



Volume 70 Number 1 2021

Research Centre for Astronomy and Earth Sciences
GEOGRAPHICAL INSTITUTE

HUNGARIAN GEOGRAPHICAL BULLETIN

Quarterly Journal of the
GEOGRAPHICAL INSTITUTE
RESEARCH CENTRE FOR ASTRONOMY AND EARTH SCIENCES

Indexed by Elsevier-GEOBASE®, Elsevier-SCOPUS®,
EBSCO Information Services, CAB Abstracts, Current Geographical Publications,
Scimago Journal & Country Rank, Google Scholar

HUNGARIAN GEOGRAPHICAL BULLETIN 70 2021 (1)

CONTENT

Book review section

DOI: 10.15201/hungeobull.70.1.1 Hungarian Geographical Bulletin **70** 2021 (1) 3–18

Built-up area analysis using Sentinel data in metropolitan areas of Transylvania, Romania

Constantin OŞLOBANU and Mircea ALEXE[1]

Abstract

The anthropic and natural elements have become more closely monitored and analysed through the use of remote sensing and GIS applications. In this regard, the study aims to feature a different approach to produce more and more thematic information, focusing on the development of built-up areas. In this paper, multispectral images and Synthetic Aperture Radar (SAR) images were the basis of a wide range of proximity analyses. These allow the extraction of data about the distribution of built-up space on the areas with potential for economic and social development. Application of interferometric coherence and supervised classifications have been accomplished on various territories, such as metropolitan areas of the most developed region of Romania, more specifically Transylvania. The results indicate accuracy values, which can reach 94 per cent for multispectral datasets and 93 per cent for SAR datasets. The accuracy of resulted data will reveal a variety of city patterns, depending mainly on local features regarding natural and administrative environments. In this way, a comparison will be made between the accuracy of both datasets to provide an analysis of the manner of built-up areas distribution to assess the expansion of the studied metropolitan areas. Therefore, this study aims to apply well-established methods from the remote sensing field to enhance the information and datasets in some areas lacking recent research.

Keywords: backscattering, metropolitan areas, supervised classification, urban footprint, built-up area

Received February 2021, accepted March 2021

Introduction

Current geographic studies attempt to follow as accurately as possible the different natural and anthropogenic phenomena in the world. In this direction, different geographic branches develop techniques for processing and interpreting geographic information, such as satellite data. A good example would be the European Space Agency (ESA) data acquired by the remote sensing satellites, Sentinel-1 and Sentinel-2. European satellite data presents the best performance regarding open-source multispectral images at a spatial resolution of 10 m. ESA occupies an important position, and its data are being studied and analysed by various researchers (Koppel, K. *et al.* 2015; Khalil, R.Z. and Haque, S.U. 2017; Zakeri, H. *et al*. 2017) to approach the results of high-resolution Synthetic Aperture Radar (SAR) platforms. Therefore, extensive studies were accomplished using different types of classifications (e.g., Corbane, C. *et al*. 2017) and exploiting Landsat multispectral images and Sentinel SAR images for the global mapping of human settlements, using Global Human Settlement Layer, which includes global multi-temporal evolution (1975, 1990, 2000 and 2014) of built-up surfaces.

Studying the expansion of the built areas, different methods have been applied. One of these methods is represented by the normalized difference indices: Normalized Difference Built-up Index (NDBI) and Normalized Difference Vegetation Index (NDVI) (Zha, Y. *et al.* 2003). Then the technique evolved, creat-

[1] Faculty of Geography, GeoTomLab, Babeş-Bolyai University, 5–7, Clinicilor Street, 400 006 Cluj-Napoca, Romania. E-mails: mircea.alexe@ubbcluj.ro (corresponding author), constantinoslobanu@yahoo.ro

ing new indices based on either the thermal band (As-Syakur, A.R. *et al.* 2012) or on the analysis of built-up areas on extended surfaces using a group of built-up indices (Li, H. *et al.* 2017) or combining several vegetation, water and built-up indices to reduce confusions (Xu, H. 2010). Afterwards, these validated indices begin to be used in studies for measurements of the built space (Kaimaris, D. and Patias, P. 2016).

Another variant of emphasizing the built-up areas is the one in combination with other land use classes (Yuan, F. *et al.* 2005; Dewan, A.M. and Yamaguchi, Y. 2009). In this category, most of the studies (Sekertekin, A. *et al.* 2017; Forkour, G. *et al.* 2018) generated maps using supervised classification method (Maximum Likelihood Classification, MLC) based on Landsat scenes, then comparing the results with Corine Land Cover (CLC). Apart from using land cover datasets, other digital resources may be used for mapping urban areas, such as high-resolution imaging studies, orthophoto maps, the Google Earth data catalogue or even images acquired by the drones. The approach based on supervised classifications was developed even on large surfaces (Ma, Y. and Xu, R. 2010) or on long-term models of maps (Padmanaban, R. *et al.* 2017) using optical data.

Similar to the trend of the universal scientific literature in the field, the tendencies from Romania approaches the same remote sensing elements for studying space in the extra-atmospheric environment. On this subject, a bunch of research concentrated on the biggest city, the capital of the state, Bucharest. The main trend in the Romanian literature was to analyse urban expansion using supervised classifications from Landsat scenes and then comparing with CLC data and applying buffers every 5 km to observe the evolution of all elements in the territory (Mihai, B. *et al.* 2015), but there were authors who also relied on high-resolution panchromatic and multispectral images, like CORONA and IKONOS imagery (Sandric, I. *et al.* 2007). In the same period, more complex subjects were applied by other authors, such as the Principal Component Analysis (PCA) method on Landsat and SPOT multispectral images or SAR data (Zoran, M. and Weber, C. 2007). Another example is the comparison of Bucharest city with French Guyanese areas, using the fusion of optical data and SAR data with high-resolution (Corbane, C. *et al.* 2008).

The MLC is a supervised method, which assumes that the user identifies by visual analysis, polygons of pixels or groups of pixels, defining the ranges of spectral values that have a correspondent in phenomena or objects in the real environment. Then, the classifier determines according to statistics which pixel is assigned to a certain class that has the highest probability to be normally distributed. Other supervised methods (Lillesand, T.M. and Kiefer, R.W. 1994) use mean vectors, such as Minimum Distance method and classifies pixels to the nearest class based on Euclidean distance or such as Parallelepiped classification based on n-dimensional parallelepiped, where each pixel is assigned to a certain class defined by the standard deviation threshold from the mean of each identified class. The MLC is preferred by some authors for several of regions from Romania, such as the Iași Metropolitan Area (Cîmpianu, C. and Corodescu, E. 2013), the Brașov Metropolitan Area (Vorovencii, I. 2017) or the Constanța Metropolitan Area (Corodescu, E. and Cîmpianu, C. 2014). Also, the use of NDVI or NDBI is appropriately accomplished on small human settlements, such as Lugoj Municipality and surrounding area (Copăcean, L. *et al.* 2015) and for those located in various natural conditions, in the mountainous area or the areas with a temperate marine climate, near the Black Sea lagoons (Huzui, A.E. *et al.* 2012). Besides, optical data is also used to identify agricultural land conversions to Argeş County (Kuemmerle, T. *et al.* 2008).

Various elements of cartographic representation methods have been treated in other research papers, such as cartograms and buffers. (EEA, 2006; Grigorescu, I. *et al.* 2012). It is in regard to cartogram maps with annual surface growth rates of the built-up area at administrative-territorial unit (ATU) level within the Metropolitan Area of Bucharest (Grigorescu, I. *et al.* 2014). For better attainment of this method, this study will use cartogram maps for comparing the built-up area percentages resulted from processing multispectral datasets and also SAR datasets.

Regarding the most important studied area, which is in full economic and social growth, Cluj-Napoca Metropolitan Area, this is more intensively studied through the perspective of the national university center present in this city. Thus, in this area, it encounters various spatial-space studies such as the spatial-temporal expansion of impermeable surfaces using the Landsat data for supervised classifications (Ivan, K. 2015) or the extraction of built-up areas using texture analysis of SAR images combined with unsupervised classification Sentinel images (Holobâcă, I.H. *et al.* 2019).

Other studies (Mucsi, L. *et al.* 2017) are focusing on using more precise instruments (e.g., hyperspectral aerial image) for accurate detection of anthropogenic elements. It has reached a level where SAR images are increasingly exploited in geographic and interdisciplinary studies by using interferometric coherence (Koppel, K. *et al.* 2015). The access to data that provides such SAR information has become insignificant, achieving even semi-automatic and fully automated urban area classification (Urban Footprint Processor, UFP) methods using SAR images with TanDEM X (Esch, T. *et al.* 2013). However, the current trend is to produce the highest degree of accuracy using all types of data made available, of good and very good precision. Sentinel and Landsat satellites are the main providers of such data. Processing these spatial data, standards of accuracy can be achieved with a small number of classes, urban – non-urban and through more complex methods. This type of technique can be performed using advanced computer algorithms such as Symbolic Machine Learning – SML (Pesaresi, M. *et al.* 2016).

This study aims to highlight natural and human influences on the development of different urban settlements. This purpose was achieved using methods such as Maximum Likelihood and coherence backscattering, which can offer a practical comparison between two fields of remote sensing, optical/multispectral and radar. But the main signature lies in the proximity analysis with which it was able to notice under what natural conditions the methods succeeded in identifying properly built-up areas and which of the metropolitan areas managed to create examples of efficient structures for urban sprawl.

Study area and data

Study area

Study areas were represented by 6 metropolitan areas: Baia Mare Metropolitan Area, Brașov Metropolitan Area, Cluj-Napoca Metropolitan Area, Oradea Metropolitan Area, Satu Mare Metropolitan Area and Târgu Mureş Metropolitan Area (*Figure 1*). These metropolitan areas were chosen on the basis of consulting different scientific articles, technical and scientific reports, development strategies, and information from sites managed by metropolitan associations (FZMAUR, 2013).

The completion of the status of every studied territory is proved both in the specialised literature (Mitrică, B. and Grigorescu, I. 2016) and in the legislation of the country (Law no. 351/2001), which is regarding the approval of the National Spatial Plan of Romania. Moreover, the ruling from local public administration describes the principle of functioning as intercommunity development association (Law no. 215/2001). But the current legislation was modified (Law no. 264/2011) and states that the metropolitan area has been defined as an "intercommunity development association established on a partnership agreement between the Romanian Capital City or the first rank cities or the county capitals, and the territorial administrative units from the surrounding area." (*Table 1*).

Overall, these six functional metropolitan areas contain 113 ATU covering 9,228 km^2. These populated areas extend on varied landforms: plain areas, intermountain basins, hill and plateau areas or at the foot of the peaks (*Table 2*).

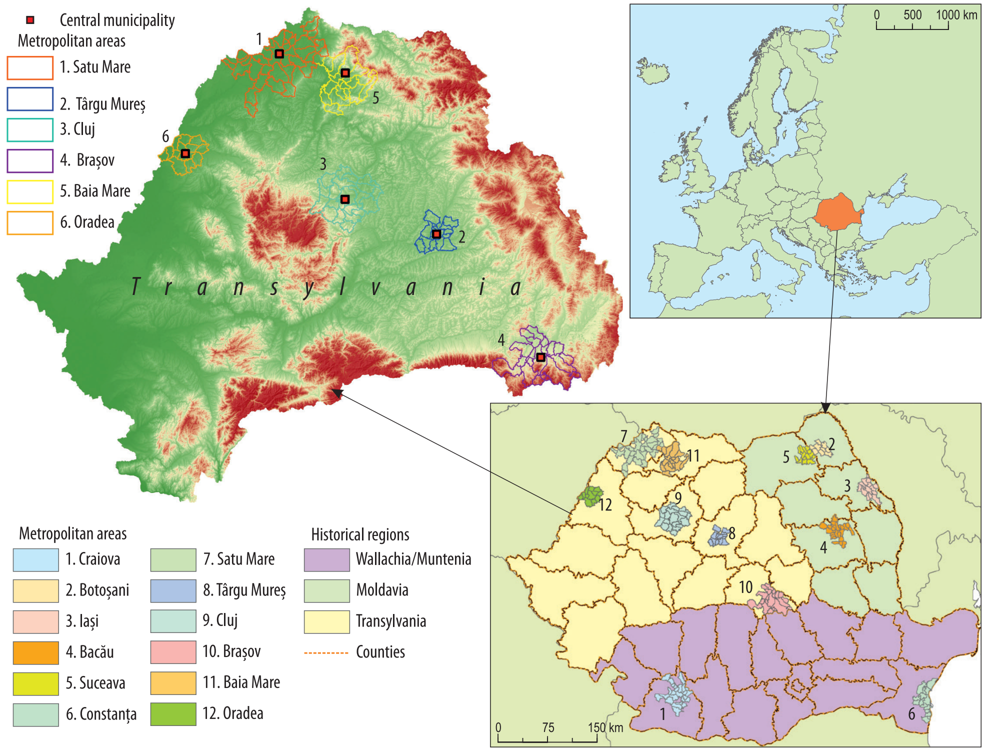


Fig. 1. The location of studied areas: The Romanian metropolitan areas with the three historical regions and metropolitan areas studied in Transylvania overlapping the natural environment.

Table 1. Administrative-territorial units within the metropolitan areas of this study

Metropolitan areas	Associated municipalities	Associated cities
Baia Mare, 19 members	Baia Mare	Baia Sprie, Cavnic, Seini, Şomcuta Mare, Tăuţii-Măgherăuş
Braşov, 18 members	Braşov, Codlea, Săcele	Ghimbav, Predeal, Râşnov, Zărneşti
Cluj-Napoca, 20 members	Cluj-Napoca	–
Oradea, 12 members	Oradea	–
Satu Mare, 30 members	Satu Mare, Carei	Ardud, Livada, Tăşnad
Târgu Mureş, 14 members	Târgu Mureş	Ungheni

Table 2. Main socio-demographic indicators of the case study areas

Metropolitan area	Area, km^2	Average elevation, m	Population, 2018*	Established
Baia Mare	1,400	763	243,611	2012
Braşov	1,694	1,471	477,344	2005
Cluj-Napoca	1,741	745	435,693	2008
Oradea	750	220	277,687	2005
Satu Mare	2,241	401	262,690	2013
Târgu Mureş	657	414	224,021	2006

*National Institution of Statistics (NIS).'

The chosen areas are located in the historical region named Transylvania. It is known that due to the domination of the Hungarian Kingdom and then of the Habsburgs, this region has had a different economic and social development than the Trans-Carpathian regions. For this reason, it can observe a different architecture of buildings, differences in community behaviour and, thus, in the way of territorial organisation.

The Baia Mare Metropolitan Area is developing more in a North–South direction, in an open field of the inside of the Carpathian arch. Major concentrations of the population are in the Lower Someș Plain and the Baia Mare Basin, at the foot of the Igniș-Gutâi-Lăpuș mountain range. The central municipality is located at 47° 39′ 37″N, 23° 34′ 23″E (centroid of the city which was determined from the "Digital Romania" database, more precisely from the point dataset with the localities in Romania), crossed by the Săsar River. The main feature of this city is that it has based on the exploitation and processing of gold and silver ores and of other metals (Cu, Pb, Zn, Al), becoming an important industrial centre during the communist period.

The most developed area of this study is the Brașov Metropolitan Area. This study area presents an asymmetric relief with a lower basin area (Brașov Basin) in the northern part and with a mountainous relief that exceeds 2,000 m in the South. This area turns the natural elements of mountain tourism (Poiana Brașov and Predeal resorts) and the medieval culture to its advantage. The Brașov city is located at 45° 39′ 34″N, 25° 35′ 48″E, in a scenic area with a breezy climate of intra-mountainous basin.

The Cluj-Napoca Metropolitan Area consists of two rows of communes in an approximately circular-concentric direction around the city at 46° 46′ 6″N, 23° 35′ 28″E along the Someșul Mic River in the western part of the Transylvanian Basin. The city has one of the most developed transportation infrastructures in the country, managing to attract numerous industrial and service companies around it, noting the IT component. At the same time, it also holds one of the best performing university centres in the country.

Although it has the lowest number of members, the Oradea Metropolitan Area is one of the most advanced in terms of accessing European funds for urban development. The central municipality is located at 47° 3′ 31″N, 21° 55′ 47″ E and crossed by the Crişul Repede River. The surrounding urban area is located on a low-altitude ground and slightly higher in the eastern part due to the piedmont plains and the penetration of hilly relief. The Oradea city has learned that the absorption of European Union funds is vital for the urban development of the area.

The largest studied area is the Satu Mare Metropolitan Area. This is mostly extended over a low relief stage, a flood plain (Someș Plain) with a few hills in the southern part and with mountainous features in the northeast (Oaș-Gutâi Mountains). It consists of 30 members, most of which support the county capital with a median position in the territory (47° 47′ 9″ N, 22° 52′ 32″E). With the exception of tourism due to thermal and cultural resources, this area has more established for a better using of over 70 per cent of agricultural land of the total area.

Being among the first metropolitan areas established, the Metropolitan Area of Târgu Mureş has the smallest area of the six studied cases and the lowest human resources. The central city, which has the same name, is located at 46° 31′ 51″ N, 24° 32′ 17″ E and is crossed by one of the longest rivers in Romania (Mureș). The area extends into a section of hilly subunits of the Transylvanian Plain and Târnavelor Plateau with the Mureş and Niraj Valley. At the moment, this union of localities tries to forget the socialist period and to develop commercial and recreational components combined with the presence of the machine, chemical and woodworking industry.

Data

A wide range of data from different sources was used for applying the established methodology. The first of these were multispectral images with a spatial resolution of 10 m, being acquired by the satellites of the European Space Agency, Sentinel-2A and Sentinel-2B (Copernicus Open Access Hub – https://scihub.copernicus.eu/). One of these remote sensing data was represented by the scenes with a cloud cover of 0 percent at different dates for every study area, depending on the availability of the chosen criteria. The earliest image was obtained from 21 April 2018 for the metropolitan area of Braşov and the most advanced one – 6 October 2018 for metropolitan areas of Cluj-Napoca and Târgu Mureş (*Table 3*).

The second dataset was the Sentinel-1. For each metropolitan area, one pair of SAR images was downloaded at a difference of 12 days, captured by the Sentinel-1A satellite. Every image is an SLC (Single Look Complex – for radar interferometry applications), incorporating signal phase information and covering a 250 × 250 km global field and a 5 × 20 m spatial resolution (*Table 4*).

Also, demographic data was used for the year of this study – 2018. The information was obtained from the National Institute of Statistics (NIS – http://www.insse.ro). A digital elevation model (DEM) of 25 m spatial resolution was used to position the primary information in a consistent and well-documented whole and for the execution of different maps (location, physical-geographic, cartograms etc.). This DEM was downloaded from the Copernicus database of the European Environment Agency (https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem).

To make different thematic maps, vector data was used (administrative boundaries, localities, etc.), being available in OpenStreetMap (OSM – https://www.openstreetmap.org/) database and in the Google Earth data imagery as well as a series of orthophoto maps were acquired from 2012 and 2015 from the National Agency for Cadastre and Land Registration (ANCPI) to assess the accuracy of the classifications.

Methodology

Multispectral images had to run through a series of atmospheric and radiometric correction pre-processing. Downloaded satellite scenes are Level 1C datasets, and therefore the Bottom-of-Atmosphere (BOA) mode had to be calculated. BOA mode represented the actual reflectance of the areas on the surface

Table 3. Technical details of data sets used in the study – Optical field

Metropolitan area	Acquisition date	Orbit	Pass	Satellite type
Baia Mare	07.05.2018	136	Ascending	Sentinel-2A
Brașov	21.04.2018	50	Descending	Sentinel-2A
Cluj-Napoca	06.10.2018	93	Ascending	Sentinel-2B
Oradea	07.05.2018	136	Descending	Sentinel-2A
Satu Mare	07.05.2018	136	Ascending	Sentinel-2A
Târgu Mureș	06.10.2018	93	Ascending	Sentinel-2B

Table 4. Technical details of data sets used in the study – Radar field

Metropolitan area	Acquisition date	Orbit	Pass	Satellite type
Baia Mare	07.05.2018 – 19.05.2018	29	Descending	Sentinel-1A
Brașov	12.04.2018 – 24.04.2018	51	Ascending	Sentinel-1A
Cluj-Napoca	28.09.2018 – 10.10.2018	29	Descending	Sentinel-1A
Oradea	29.04.2018 – 11.05.2018	80	Descending	Sentinel-1A
Satu Mare	07.05.2018 – 19.05.2018	29	Descending	Sentinel-1A
Târgu Mureș	28.09.2018 – 10.10.2018	29	Descending	Sentinel-1A

and was calculated from the TOA(Top-of-atmosphere) values, which is already included in Level 1C datasets. This pre-processing step was carried out by using Sen2Cor tool within the SNAP software. Both types of images (optical and SAR) were co-registered and were re-projected in the official coordinate reference system of Romania (Stereographic 1970 – Stereographic azimuthal projection line perspective 1970 with secant plan). To complete the maps, satellite datasets were transferred to the ArcGIS software, where the maps were reclassified to obtain quantitative area data. After that, areas were calculated, providing them cartographic features to complete maps editing. Although many other techniques are superior, such as Object-based Image Analysis (OBIA), Deep learning, Support Vector Machine (SVM) etc., these two main methods of the study, MLC and experimental SAR processing, present a combination of reliability.

For SAR data, every image had to go through a number of steps (Ferretti, A. *et al.* 2008) using the Sentinel-1 Toolbox (SNAP):

- Splitting the satellite scene for the study area by first choosing the appropriate longitudinal band, followed by the level of coordinates of the analysed area;
- Apply orbit – improving orbital information;
- Calibration – conversion of digital values into physical values, which refers to the retro-reflected signal;
- Deburst – removing no data values;
- Multi-looking – create square pixels of the same size, using one look in range and three looks in azimuth, reducing the noise of radar images and making a virtual band with signal in decibels (dB) to change the contrast of the image using the histogram; in addition, this step will approximate pixel spacing after being converted from slant range to ground range, resulting a mean ground range pixel size of 10 m;
- Terrain correction – applying the Range-Doppler technique, the image will be overturned because initially it has been acquired by the satellite in the mirror, depending on the pass orbit of the satellite; in this step, the image is associated with the country-specific cartographic projection, Stereographic 70 *(Figure 2).*

Supervised classification represents one of the main techniques being applied to multispectral images. This involves that the user selects pixel samples or pixel groups by visual analysis. The user defines the ranges of spectral values that correspond with phenomena or objects to the real environment. In this study, the probability method named Maximum Likelihood was used (Deng, Y. *et al.* 2012). All processes were performed with the ERDAS Imagine 2016 software. Fifty pixel samples per land cover were taken for training, resulting in a number of four to six classes. These classes can be assigned to a number of general land cover classes: built-up area, agricultural land, vegetation – broad-leaved forests or coniferous forests, industrial waste, water and snow.

After performing these procedures within SNAP Desktop, two final images will be produced for each Sentinel-1 scene (required for the pair of SAR images). The products of the first two stages will be co-registered in a stack, resulting in a product to which the interferometric coherence will be calculated. After this step, this image will have to perform the deburst, multi-looking and terrain correction stages again. For the final image, it will be making a conversion of the Vertical to Vertical (VV) polarisation band (Abdikan, S. *et al.* 2016) from a linear scale to a logarithmic scale. By deriving a signal in decibels (dB), the histogram of the image can be modified.

Furthermore, the mean signal and the difference signal will be calculated, both of them in decibel units, followed by creating an RGB image, where for the red channel, interferometric coherence will be used, for the green channel – the mean and for the blue channel – the difference. These products can be observed in *Figure 3*. The urban footprint of the localities, including the built-up areas, will be achieved by creating a new raster through a conditional expression. This will assign two types of pixel value, 0 and 1, depending on certain thresholds of the average signal in decibels, respectively, accord-

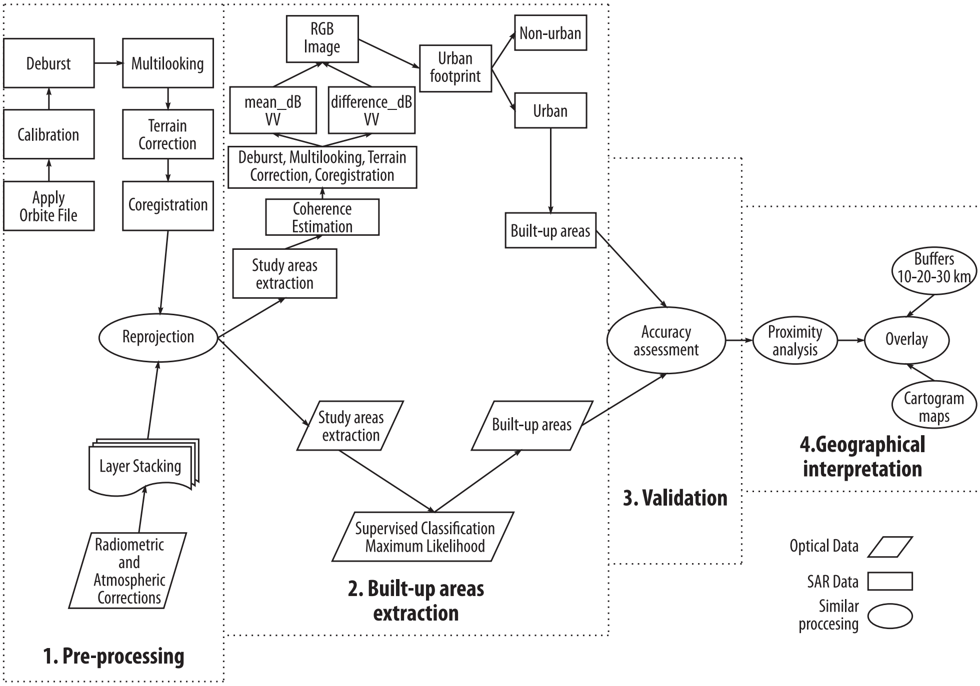


Fig. 2. Methodology flow chart of the study

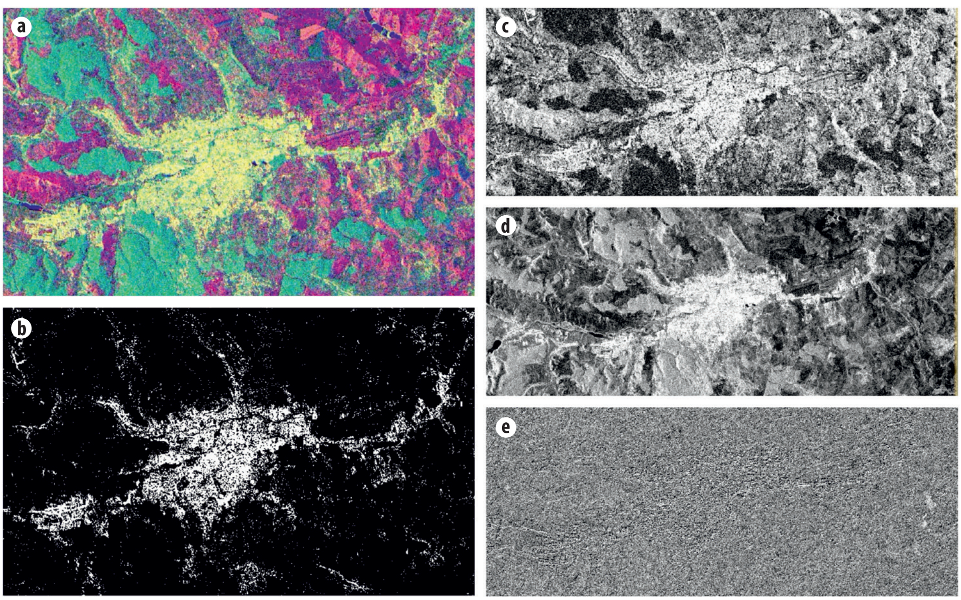


Fig. 3. Final products of pre-processing SAR data sets: a = RGB image; b = urban footprint; c = coherence estimation; d = mean dB; e = difference dB for Cluj-Napoca city

ing to interferometric coherence. The result will be brought to ArcGIS and reclassified to get maps with two classes: urban and non-urban/built-up and unbuilt.

After getting the supervised classifications in the ERDAS Imagine 2016 software, an assessment of the accuracy of classification has performed within the same program, a necessary operation to validate the results. Thus, the software has randomly assigned a number between 200 and 350 points (50 points/class) per classification, depending on the number of detected land cover classes. These points have been transposed to orthophoto maps and georeferenced Google Earth images for validation. For SAR images, the accuracy assessment classification has performed in the ArcGIS software by producing the number of points for two classes. Then, reference values have given and extracted supervised classification values have added to join data in the attribute table to get a matrix of errors *(Figure 4)*. According to the literature (Congalton, R.G. and Green, K. 2009), the minimum number of points taken to validate the classification should be 50 per category.

Also, a proximity analysis was created in this paper, which is referring to the built-up space from the total area of the metropolitan areas. Once the maps of multispectral images and SAR data have been reclassified, the built-up areas and the areas of the ATUs were calculated and were intersected. In addition, it has traced 10-km, 20-km and 30-km buffers for a more in-depth analysis. The distance of 30 km from the central municipality is the maximum limit of the metropolitan areas specified in the specialised legislation in Romania (Law no. 264/2011). Thus, the Romanian legislation has taken economic relations (between the members of the area) more into account than natural barriers. The following 20 km and 10 km buffers become reference thresholds in this study to observe whether metropolitan areas have been properly established and to monitor the degree of development of the built-up areas.

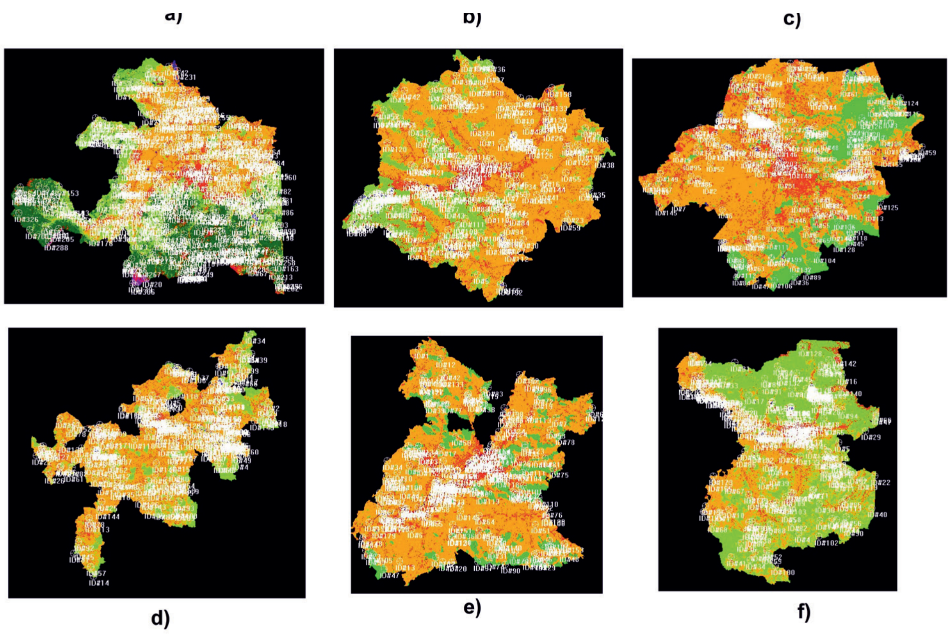


Fig. 4. Distribution of reference points on supervised classifications data in the six metropolitan areas (MA): a = Brașov MA; b = Cluj-Napoca MA; c = Oradea MA; d = Satu Mare MA; e = Târgu Mureș MA; f = Baia Mare MA

Results

Most classifications have been able to identify at least four classes of land cover to which some classes were added depending on positioning in a certain landscape or due to the existence of other natural or anthropic factors. This is the case of the Oradea Metropolitan Area, where the industrial waste (ashes and slag) of the Central Heating and Power Station was identified in the northwest part of the city. For the Brașov Metropolitan Area, there is a distinction of vegetation, broad-leaved forests and coniferous forests, plus snow from the highest peaks of the Bucegi Mountains or the Piatra Craiului Mountains. The appearance of the snow class may be due to the acquisition date of the optical image – 21 April 2018, in a mountainous area, between 2,000 m and the maximum altitude (2,462 m). Also, some small confusions were observed in these high areas where the recently deforested land was considered as built-up space. In all cases, in addition to the residential space and the most visible buildings, the communication network of localities could be well observed (*Table 5*).

Regarding the accuracy of the classification, all the cases managed to exceed 80 per cent. According to the literature (Congalton, R.G. 1991), if this value exceeds 80 per cent, there is a high concordance between the classified data and the reference data. The highest values were achieved for Oradea Metropolitan Area, which is the smallest area (see *Table 5*). For the other larger areas, the values fluctuate from 80 to 87 per cent. This may be due to some identified confusions: relatively recently deforested land was considered a built-up area (*Figure 5*, *a* and *f*), certain disorders with the slope processes, such as landslides or soil erosions (*Figure 5*, *b* and *e*), which they were identified on agricultural land and which were defined as built-up areas.

Table 5. Accuracy assessment of metropolitan areas of this study – Supervised classification method

Metropolitan area	Overall	User's	Producer's
	accuracy, %		
Baia Mare	94	88	100.00
Brașov	82	64	100.00
Cluj-Napoca	86	74	97.37
Oradea	80	60	100.00
Satu Mare	87	76	97.44
Târgu Mureș	83	68	97.14

Regarding the assessment of accuracy at each category of land cover, the results provide various information about the identified elements. The agricultural land class offers percentages of accuracy between 70 and 80 per cent, because it occupies, in most cases, the largest area of land in metropolitan areas. In contrast, less extensive classes such as water, industrial areas or snow have values of over 84 per cent *(Table 6).* The areas covered with vegetation offer both efficient results, as in the case of Brașov or Oradea, but also less efficient as in Baia Mare or Cluj. The low percentages mentioned above are due to confusions with agricultural areas, observed especially in rural areas. The accuracy of the built-up areas is close to the overall accuracy, in some places even exceeding it, such as Oradea and Târgu Mureș. The values that exceed a slight 80 per cent belong to the metropolitan areas with a hilly relief (Cluj) or to the predominance of the areas with little very urbanised settlements (Satu Mare).

Also, a proximity analysis of the built-up areas was made at the level of every ATU. It took the form of cartograms in which again, buffers with a radius of 10 km, 20 km, and 30 km are illustrated *(Figure 6).*

This type of analysis highlights points related to the distribution of the built-up areas in the three deployed boundaries and the natural or spatial causes (the location of settlements within the metropolitan area) that led to these results. Thus, only the Brașov Metropolitan Area managed to exceed 20 per cent of the built-up area (23.7%) of the total area of land within a radius of 10 km. The other areas have a percentage between 10–19 per cent. Up to the 20 km limit, the percentage of built-up area does not exceed 8 per cent for the other areas except the Brașov Metropolitan Area.

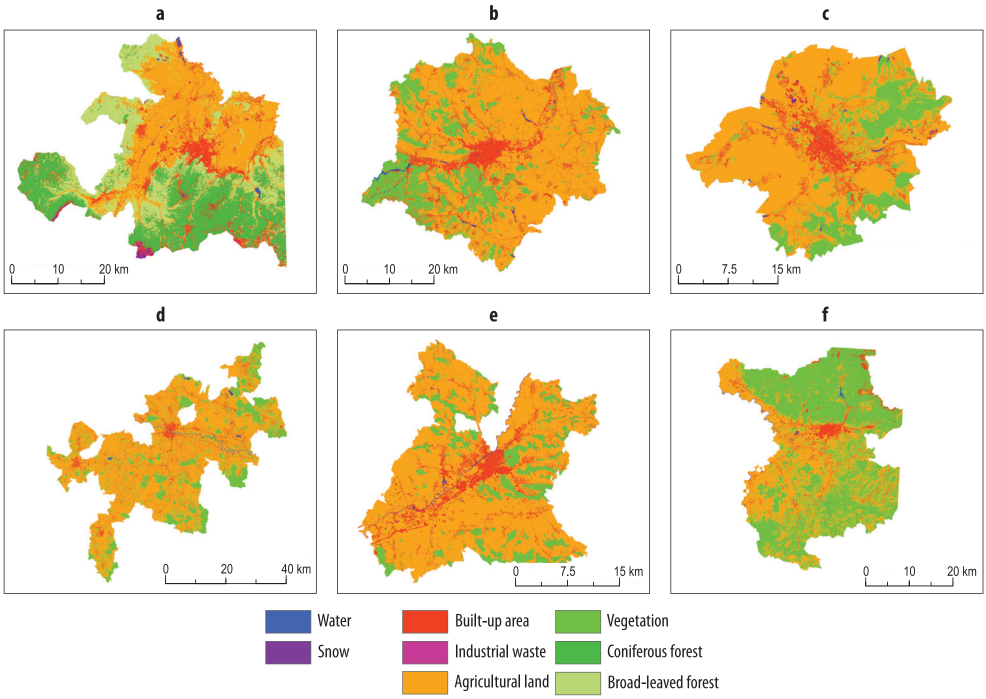


Fig. 5. Supervised classifications (Maximum Likelihood) of the six metropolitan areas (MA): a = Brașov MA; b = Cluj-Napoca MA; c = Oradea MA; d = Satu Mare MA; e = Târgu Mureș MA; f = Baia Mare MA

Table 6. Accuracy assessment of metropolitan areas on land cover classes

Metropolitan area	Overall	Built-up area	Agricultural land	Vegetation	Water	Snow	Industrial waste
	accuracy, %						
Baia Mare	86	82	78	87* 90**	98	86	84
Brașov	80	79	73	75	93	–	–
Cluj-Napoca	94	97	90	94	96	–	95
Oradea	83	81	74	82	96	–	–
Satu Mare	82	84	77	78	92	–	–
Târgu Mureș	87	92	75	86	95	–	–

*Broad leaved forest; **Coniferous forest.

The highest values belong to the central municipality of every area with the maximum values of over 40 km^2, in Cluj-Napoca and Brașov, which also have the highest average values. Most of the studied ATUs are in the average category of 3–6 km^2 due to weak economic development in member communes, where rural areas still predominate.

Regarding the SAR images, the representation of the built-up area had less conclusive results. This is also due to certain limitations of SAR data, more precisely, not identifying the horizontally built-up area (such as roads, car parks, squares, runways) due to plain textured SAR data and specular backscattering. In addition to this problem, some confusions with marshlands, high humidity areas are added or depending on the slope directions, exactly in the direction of the pass of satellite. These can cause lower values of accuracy, as in the

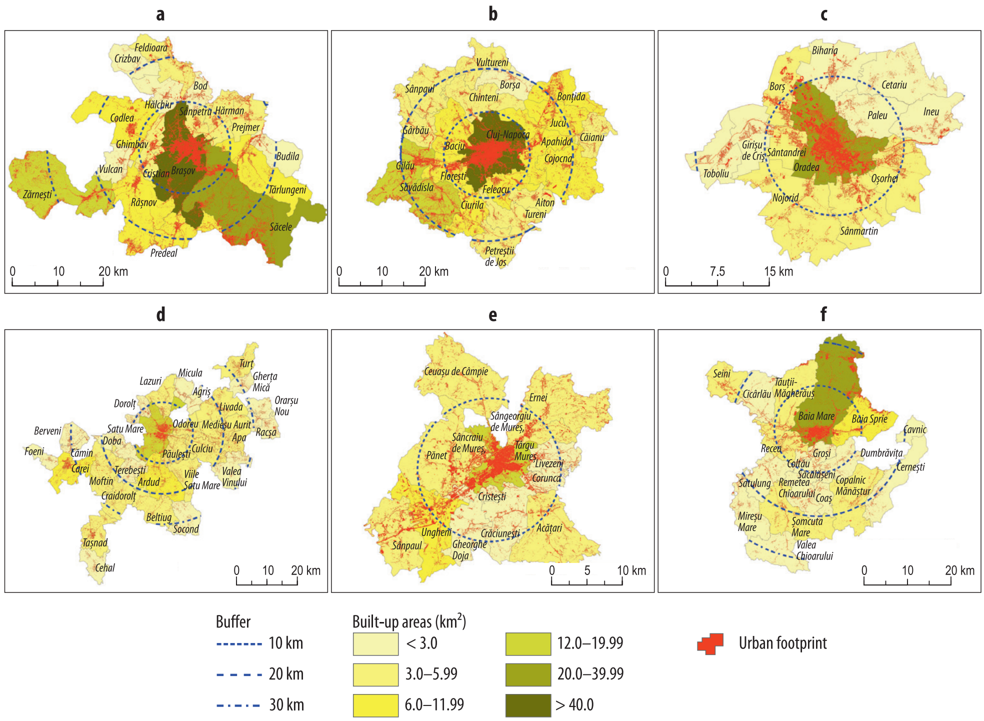


Fig. 6. Distribution of built-up areas at the level of administrative territorial units using Sentinel-2 data: a = Brașov MA; b = Cluj-Napoca MA; c = Oradea MA; d = Satu Mare MA; e = Târgu Mureș MA; f = Baia Mare MA

case with Oradea Metropolitan Area and Satu Mare Metropolitan Area. These two areas are located in the floodplains, which can produce confusions. For other areas, the situation is acceptable, so that the best values of accuracy were achieved for the areas offering distinct natural elements, such as the Baia Mare Metropolitan Area. Baia Mare city is located in a basin at the foot of the Igniş Mountains, which are covered with broad-leaved forests (*Figure 7*). The Brașov Metropolitan Area is another excellent example with an overall accuracy of 93 per cent and where the localities in the Brașov Basin are at a short distance from the high peaks of the mountains. The elevation difference is reaching 1,000 metres between the Brașov town and the Tâmpa Hill, which is in the immediate surrounding.

Referring to the proximity analysis, the built-up areas have lower values than the supervised classification method. For the first 10 km, Oradea Metropolitan Area has the highest percentage of built-up area (18.8%), followed by Baia Mare and Brașov. In the case of this method, there are also isolated values exceeding 10 per cent of the built-up area of the total surface, up to 20 km and even up to 30 km. This is because of confusion between the analysed category and numerous slope processes with landslides or surface erosions (*Figure 7*, *b* and *e*).

The previously mentioned information is derived from the presentation of data in the form of cartograms. The maximum values are lower than for the other used datasets, more exactly over 20 km^2 in the same territories of Cluj-Napoca and Brașov. The degree of confusion can be seen in the case of Cojocna ATU, located in the eastern of Cluj ATU. This fact is due to slope processes,

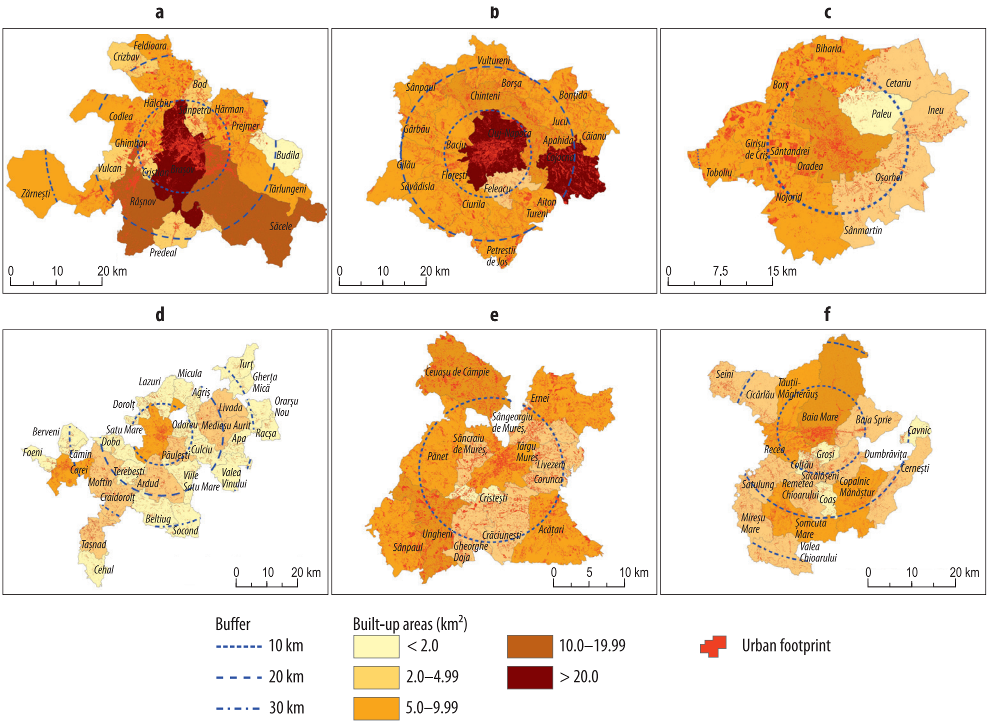


Fig. 7. Distribution of built-up areas at the level of administrative territorial units using Sentinel-1 data: a = Brașov MA; b = Cluj-Napoca MA; c = Oradea MA; d = Satu Mare MA; e = Târgu Mureș MA; f = Baia Mare MA

which cause placing it into the same category of over 20 km^2 of built-up area. The mean of the values decreases to 2–5 km^2, which is better observed in the Satu Mare Metropolitan Area, with a rare built-up area because of the dominance of agricultural land.

Discussions

In this paper, two methods of processing satellite imagery have been approached having direct applicability. As a result, both Sentinel-2A and Sentinel-2B multispectral images, as well as SAR spatial data acquired by Sentinel-1A, could provide specific information about the built-up areas. In this way, accurate information could be achieved monitoring the level of built-up area in the Transylvanian metropolitan areas in 2018.

Following the accuracy assessment of classification, multispectral images, which were processed by supervised classification have had more reliable results. They have succeeded in identifying certain objects with an impact on the environment – industrial waste, but also to present more precisely street networks and roads. Using specular backscattering and interferometric coherence, the study could get urban footprints with an acceptable degree of accuracy, but also, there are still opportunities for further enhancements. Limitations of SAR data are of a technical nature, mostly confusions with wetlands, slope processes, and the addition of unidentified horizontally built-up areas.

If there is a possibility to compare the results of this study with other studies from different regions but using similar methods, then there are many examples. For example, the values of the overall accuracy of supervised classifications can be analysed in comparison with several Landsat processing results of Brașov (Vorovencii, I. 2017): 88 per cent compared to the 86 per cent of this study. A more practical comparison can be achieved with a study that uses the MLC algorithm on Cluj-Napoca ATU (Holobâcă, I.H. *et al.* 2019). Thus, the study achieved an accuracy of 89 per cent over 80 per cent of this work. So, larger-scale analysis reduces the chances of a higher degree of accuracy, as reported in a study of Okara district, Pakistan (4,419 km^2) (Khalil, R.Z. and Haque, S.U. 2017). Thus, in the study mentioned above, although a similar methodology is used to exploit the interferometric coherence based on Sentinel-1 data, the degree of accuracy of the built-up area is only 68 per cent (user's accuracy) and 45 per cent (producer's accuracy). By applying a similar methodology, a much more convincing comparison can be resulted when analysing areas with approximately similar areas. In this regard, studies of the built-up class of two areas in Estonia (Koppel, Z. *et al.* 2015) manage to achieve values of accuracy between 84 and 88 per cent. In comparison, this study achieved varied and positive values of 78–93 per cent.

Conclusions

The proximity analysis proved to be broader and efficient to illustrate the current state of development of the Romanian metropolitan areas. Cartograms, buffers, and urban footprints have improved the quality and interpretation of information. Thus, two phenomena are observed. The first one is the concentration of the built-up areas in the proximity of the development poles, achieving an increase in the average built-up area for some regions and, thus, an approach of the member communes to the metropolitan character of the area (Braşov, Oradea, Cluj-Napoca). The other one is the scattering of the built-up space area by the overall average relatively low due to the slow progress of the other communes for the development of the metropolitan area, and because of the predominance of activities in the primary and secondary sectors: agriculture, forestry and industry for Satu Mare, Baia Mare, Târgu Mureş.

The results indicate moderate to high degrees of accuracy values, which are able to reach 94 per cent for multispectral datasets and 93 per cent for SAR data. The supervised classification and the interferometric coherence techniques were applied in an effective manner to studied areas, but the used methodology on multispectral data manage to achieve superior results due to more complete applicability on the characteristics of the data.

Therefore, Romanian metropolitan areas are a source of analysis, not only in terms of administrative, demographic or economic aspects but also from a scientific point of view, in order to highlight the information that contributes to development according to the functioning principles of the cities in the modern world.

REFERENCES

Abdikan, S., Sanli, F.B., Ustuner, M. and Calò, F. 2016. Land cover mapping using SENTINEL-1 SAR data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLI-B7. 757–761.

As-Syakur, A.R., Adnyana, I.W.S., Arthana, I.W. and Nuarsa, I.W. 2012. Enhanced Built-up and Bareness Index (EBBI) for mapping built-up and bare land in an urban area. *Remote Sensing* 4. 2957–2970.

Cîmpianu, C. and Corodescu, E. 2013. Landscape dynamics analysis in Iași Metropolitan Area (Romania) using remote sensing data. *Cinq Continents* 3. (7): 18–32.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37. (1): 35–46.

Congalton, R.G. and Green, K. 2009. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. Boca Raton, Lewis Publishers.

Copăcean, L., Popescu, C. and Cojocariu, L. 2015. Remote sensing methods for analysing vegetation and urban expansion. *Research Journal of Agricultural Science* 47. (4): 41–46.

Corbane, C., Faure, J.F., Baghdadi, N., Villeneuve, N. and Petit, M. 2008. Rapid urban mapping using SAR/Optical Imagery Synergy. *Sensors* 8. (11): 7125–7143.

Corbane, C., Pesaresi, M., Politis, P., Syrris, V., Florczyk, A.J., Soille, P., Maffenini, L., Burger, A., Vasilev, V., Rodriguez, D., Sabo, F., Dijkstra, L. and Kemper, T. 2017. Big earth data analytics on Sentinel-1 and Landsat imagery in support to global human settlements mapping. *Big Earth Data* 1. (1–2): 18–144.

Corodescu, E. and Cîmpianu, C. 2014. Assessing the spatial differences among some urban expansion driving forces in Constanța Metropolitan Area (Romania). *Scientific Annals of "Al. I. Cuza" University of Iaşi Geography Series* 60. (2): 77–95.

Deng, Y., Fan, F. and Chen, R. 2012. Extraction and analysis of impervious surfaces based on a spectral un-mixing method using Pearl River Delta of China Landsat TM/ETM+ Imagery from 1998 to 2008. *Sensors* 12. (2): 1846–1862.

Dewan, A.M. and Yamaguchi, Y. 2009. Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanisation. *Applied Geography* 29. 390–401.

EEA 2006. *The Changing Faces of Europe's Coastal Areas*. Copenhagen, Denmark, European Environment Agency. Report No 6/2006.

Esch, T., Marconcini, M., Felbier, A., Roth, A., Heldens, W., Huber, M., Schwinger, M., Taubenböck, H., Müller, A. and Dech, A. 2013. Urban footprint processor – fully automated processing chain generating settlement masks from global data of the TanDEM-X Mission. *IEEE Geoscience and Remote Sensing Letters* 10. (6): 1617–1621.

Ferretti, A., Monti-Guarnieri, A., Prati, C., Rocca, F. and Massonnet, D. 2008. *InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation*. ESA Publications.

Forkour, G., Dibobe, K., Serme, I. and Tondoh, J.E. 2018. Landsat-8 vs. Sentinel-2: examining the added value of sentinel-2's red-edge bands to land-use and land-cover mapping in Burkina Faso. *GIScience & Remote Sensing* 55. (3): 331–354.

FZMAUR 2013. *Federation of Metropolitan Areas and Urban Agglomerations in Romania*. Bucharest, Studiu POLICENTRIC.

Grigorescu, I., Mitrică, B., Mocanu, I. and Ticana, N. 2012. Urban sprawl and residential development in the Romanian metropolitan areas. *Romanian Journal of Geography* 56. (1): 43–59.

Grigorescu, I., Kucsicsa, G. and Mitrică, B. 2014. Assessing spatio-temporal dynamics of urban sprawl in the Bucharest metropolitan area over the last century. In *Land Use/Cover Changes in Selected Regions in the World.* Volume V. Eds.: Bičík, I., Himiyama, Y. and Feranec, J., Prague, Czech Republic, IGU-LUCC, 19–27.

Holobâcă, I.H., Ivan, K. and Alexe, M. 2019. Extracting built-up areas from Sentinel-1 imagery using land-cover classification and texture analysis. *International Journal of Remote Sensing* 40. (20): 8054–8069.

Huzui, A.E., Călin, I. and Stupariu, P.I. 2012. Spatial pattern analyses of landscape using multi temporal data sources. *Procedia Environmental Sciences* 14. 98–110.

INS, National Institute of Statistics Romania. 2019. *Permanent Resident Population.* Bucharest, Romania. Accessed July 2019. http://www.insse.ro.

Ivan, K. 2015. The spatio-temporal analysis of impervious surfaces in Cluj-Napoca, Romania. *Geographia Technica* 10 (2): 50–58.

Kaimaris, D. and Patias, P. 2016. Identification and area measurement of the built-up area with the Built-up Index (BUI). *International Journal of Advanced Remote Sensing and GIS* 5. (6): 1844–1858.

Khalil, R.Z. and Haque, S.U. 2017. InSAR coherence-based land cover classification of Okara, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science* 21. (1): 523–528.

Koppel, K., Zalite, K., Sisas, A., Voormansik, K., Praks, J. and Noorma, M. 2015. *Sentinel-1 for urban area monitoring – analysing local-area statistics and interferometric coherence methods for buildings' detection.* IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 26–31 July 2015. Milan, Italy. 1175–1178.

Kuemmerle, T., Muller, D., Griffiths, P. and Rusu, M. 2008. Land use change in Southern Romania after the collapse of socialism. *Regional Environmental Change* 9. (1): 1–12.

Li, H., Wang, C., Zhong, C., Su, A., Xiong, C., Wang, J. and Liu, J. 2017. Mapping urban bare land automatically from Landsat imagery with a simple index. *Remote Sensing* 9. (3): 249.

Lillesand, T.M. and Kiefer, R.W. 1994. *Remote Sensing and Image Interpretation.* 3rd Edition. Hoboken, N.Y., John Wiley and Sons, Inc.

Ma, Y. and Xu, R. 2010. Remote sensing monitoring and driving force analysis of urban expansion in Guangzhou City, China. *Habitat International* 34. (2): 228–235.

Mihai, B., Nistor, C. and Simion, G. 2015. Post-socialist urban growth of Bucharest, Romania – a change detection analysis on Landsat imagery (1984–2010). *Acta Geographica Slovenica* 55. (2): 223–234.

Mitrică, B. and Grigorescu, I. 2016. Dezvoltarea urbană şi ariile metropolitane (Urban development and metropolitan areas). In *Romania. Natura si Societate.* Eds.: Balteanu, D., Dumitrascu, M., Geacu, S., Mitrica, B. and Sima, M., Bucuresti, Editura Academiei Romane, 250–291.

Mucsi, L., Liska, C.M., Henits, L., Tobak, Z., Csendes, B. and Nagy, L. 2017. The evaluation and application of an urban land cover map with image data fusion and laboratory measurements. *Hungarian Geographical Bulletin* 66. (2): 145–15.

Padmanaban, R., Bhowmik, A.K., Cabral, P., Zamyatin, A., Almegdadi, O. and Wang, S. 2017.

Modelling urban sprawl using remotely sensed data: A case study of Chennai City, Tamilnadu. *Entropy* 19. (4): 163.

Pesaresi, M., Corbane, C., Julea, A., Florczyk, A.J., Syssis, V. and Soille, P. 2016. Assessment of the added-value of Sentinel-2 for detecting built-up areas. *Remote Sensing* 8. (4): 299.

Sandric, I., Mihai, B., Savulescu, I., Suditu, B. and Chitu, Z. 2007. Change detection analysis for urban development in Bucharest-Romania, using high resolution satellite imagery. *Urban Remote Sensing Joint Event* 2007. 1–8.

Sekertekin, A., Marangoz, A.M. and Akcin, H. 2017. Pixel-based classification analysis of land use land cover using SENTINEL-2 and LANDSAT-8 data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-4/W6. 91–93.

Vorovencii, I. 2017. Analysis of the changes in the metropolitan area of Brașov, Romania, using Landsat multi-temporal satellite image. *Environmental Engineering and Management Journal (EEMJ)* 16. (2): 303–316.

Xu, H. 2010. A new index for delineating built-up land features in satellite imagery. *International Journal of Remote Sensing* 29. (14): 4269–4276.

Yuan, F., Sawaya, K.E., Loeffelholz, B.C. and Bauer, M.E. 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multi-temporal Landsat remote sensing. *Remote Sensing of Environment* 98. (2): 317–328.

Zakeri, H., Yamazaki, F. and Liu, W. 2017. Texture analysis and land cover classification of Tehran using polarimetric Synthetic Aperture Radar imagery. *Applied Sciences* 7. 452.

Zha, Y., Gao, J. and Ni, S. 2003. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing* 24. (3): 583–594.

Zoran, M. and Weber, C. 2007. Use of multi-temporal and multispectral satellite data for urban change detection analysis. *Journal of Optoelectronics and Advanced Materials* 9. (6): 1926–1932.

DOI: 10.15201/hungeobull.70.1.2 Hungarian Geographical Bulletin **70** 2021 (1) 19–33.

Projections of the urban and intra-urban scale thermal effects of climate change in the 21st century for cities in the Carpathian Basin

Tamás GÁL, Nóra SKARBIT, Gergely MOLNÁR and János UNGER[1]

Abstract

This study evaluates the pattern of a night-time climate index, namely the tropical nights (T_{min} ≥ 20 °C) during the 21st century in several different sized cities in the Carpathian Basin. For the modelling, MUKLIMO_3 microclimatic model and the cuboid statistical method were applied. In order to ensure the proper representation of the thermal characteristics of an urban landscape, the Local Climate Zone (LCZ) system was used as land-use information. For this work, LCZ maps were produced using WUDAPT methodology. The climatic input of the model was the Carpatclim dataset for the reference period (1981–2010) and EURO-CORDEX regional model outputs for the future time periods (2021–2050, 2071–2100) and emission scenarios (RCP4.5, RCP8.5). As results show, there would be a remarkable increase in the number of tropical nights along the century, and there is a clearly recognizable increase owing to urban landform. In the near past, the number of the index was 6–10 nights higher in the city core than the rural area where the number of this index was negligible. In the near future this urban-rural trend is the same, however, there is a slight increase (2–5 nights) in the index in city cores. At the end of the century, the results of the two emission scenarios become distinct. In the case of RCP4.5 the urban values are about 15–25 nights, what is less stressful compared to the 30–50 nights according to RCP8.5. The results clearly highlight that the effect of urban climate and climate change would cause serious risk for urban dwellers, therefore it is crucial to perform climate mitigation and adaptation actions on both global and urban scales.

Keywords: climate change, urban climate, Local Climate Zones, urban climate modelling

Received November 2020; Accepted January 2021.

Introduction

In our days, the most important environmental phenomenon is climate change. At a global scale, the temperature change is already observable, and by the end of the 21st century it is projected to likely exceed 1.5 °C (Stocker, T.F. *et al.* 2013). The temperature increase has complex environmental effects in global, regional and local (urban) scales, too. The local consequences of these are at least as fundamental as those of a global scale, as the majority of the population is already concentrated in cities. The heat load in cities is supposed to get intensified as global temperature increase will be superimposed on urban temperature modification. Namely, owing to urban heat island (UHI) development the urban nocturnal temperature is usually higher than the rural one (Oke, T.R. *et al.* 2017). Overall, this can have far-reaching health effects (Baccini, M. *et al.* 2008; Bartholy, J. and Pongrácz, R. 2018). Therefore, the studies concerning the impact of global changes on local climate of cities are of a high significance for the urban inhabitants' health and well-being. Therefore, in order to plan and undertake the mitigation actions in particular cities, it is necessary to recognize the possible range of heat load increase there, in terms of both its magnitude and spatial extent.

[1] Department of Climatology and Landscape Ecology, University of Szeged. H-6722 Szeged, Egyetem u. 2. E-mails: tgal@geo.u-szeged.hu, skarbitn@geo.u-szeged.hu, molnarge@geo.u-szeged, unger@geo.u-szeged.hu

In the last few years, local authorities and urban planners in Hungary have begun to pay growing attention to the latest climate change projections. Their interest, of course, focuses on urban-scale features and phenomena, but there are few basic research results for urban areas. Based on these trends, new basic research results are needed to produce climate projections at the local level in order to provide basic information to urban planners on urban climate mitigation strategies or applied research in this field.

The effect of climate change on temperature is presented in IPCC reports (e.g. IPCC 2018). Recent climate model projections apply the Representative Concentration Pathways (Van Vuuren, D.P. *et al.* 2011), and the most commonly used scenarios are RCP4.5 and RCP8.5. These scenarios represent a global temperature increase of 2 °C and 4 °C by the end of the century, but at the regional level, the temperature change is highly variable.

Considering the Carpathian Basin, it is essential to evaluate climate projections for temperature and temperature-related climate indices, as no further climate change mitigation and adaptation plans can be implemented without this information. In case of temperature change there are numerous regional model results (e.g. Jacob, D. *et al.* 2014; Pieczka, I. *et al.* 2018). Based on these results, the temperature changes in this region are 1.5–2 °C (RCP4.5) and 3–4 °C (RCP8.5) by the end of this century.

In order to help the evaluation of the future climate trends it is very suitable to utilize a climate index projection, such as the number of tropical nights (TN, when the daily $T_{min} \geq 20$ °C). This particular index is a good indicator of the annual duration of adverse hot weather conditions, as a high minimum temperature also means a high daily temperature, taking into account the daily temperature cycle (Pieczka, I. *et al.* 2018). For TNs, the projected trends in the Carpathian Basin are as follows: In the period 2021–2040, their numbers are 10–15 (RCP4.5) and 10–20 (RCP8.5), and in the period 2081–2100 they are 20–30 (RCP4.5) and 40–60 (RCP8.5) (Pieczka, I. *et al.* 2018). It is important to highlight that these results are derived from regional climate models and the urban impact does not appear within these model outputs, so an evaluation of a detailed model experiment for urban areas in the Carpathian Basin would provide vital information for climate change related decisions.

It is essential to use an urban climate model to predict the climate in urban areas. Recently, these models have evolved rapidly (Kusaka, H. *et al.* 2001; Martilli, A. *et al.* 2002; Lemonsu, A. *et al.* 2012; Lee, S.-H. *et al.* 2016; Ryu, Y.H. *et al.* 2016). Most of these model development initiatives are related to the Weather Research and Forecasting Model (WRF), Molnár, G. *et al.* (2020) briefly discusses these models. There are only a few other smaller-scale modelling options, e.g. ENVI-met (Bruse, M. and Fleer, H. 1998), Town Energy Balance (Masson, V. 2000) and MUKLIMO_3 models (Sievers, U. 1995). MUKLIMO_3 offers a great possibility for climate projection for urban areas, since combined with the statistical cuboid-method it is capable for time effective simulation. The other advantage of this model is the representation of building arrays. In the urban parametrizations related to WRF the built-up is modelled with the urban canyon concept, however, in MUKLIMO_3 the built-up is regarded as a porous volume. This concept is more close to reality in open urban built-up zones, where urban canyons cannot be defined properly. The computational time efficiency and the replacement of urban canyon concept were the main reasons for using this model.

In the case of local-scale climate modelling, the selection of land cover data is crucial. There are a number of possible data sources for this, such as the CORINE land cover, the USGS land use dataset, and the Open Street Map. These databases have their advantages, however, none of them have been designed to represent urban thermal reactions. In the field of urban climatology, the Local Climate Zone (LCZ) classification (Stewart, I.D. and Oke, T.R. 2012) is widely accepted as a representation of urban land use (*Table 1*) and is used to characterize the environment of the measurement sites (e.g. Siu, L.W. and Hart, M.A. 2013; Stewart, I.D. *et al.* 2014; Lehnert, M. *et al.* 2015) or to map

*Table 1. Built and land cover LCZ classes**

Built types	Land cover types
LCZ 1 – Compact high-rise	LCZ A – Dense trees
LCZ 2 – Compact midrise	LCZ B – Scattered trees
LCZ 3 – Compact low-rise	LCZ C – Bush, scrub
LCZ 4 – Open high-rise	LCZ D – Low plants
LCZ 5 – Open midrise	LCZ E – Bare rock / paved
LCZ 6 – Open low-rise	LCZ F – Bare soil / sand
LCZ 7 – Lightweight low-rise	LCZ G – Water
LCZ 8 – Large low-rise	
LCZ 9 – Sparsely built	
LCZ 10 – Heavy industry	

*After Stewart, I.D. and Oke, T.R. 2012.

different urban neighbourhoods (e.g. Lelovics, E. *et al.* 2014; Zheng, Y. *et al.* 2018). Therefore, this scheme can also be used as surface input for numerical modelling (Žuvela-Aloise, M. 2017; Kwok, Y.T. *et al.* 2019). The application of this scheme is advantageous because it is based on the thermal characteristics of the urban areas, i.e. it can be linked to the UHI phenomenon, which is the most important climate modification in these areas. Appropriate application of LCZ in local-scale climate modelling provides a good basis for global comparisons or validation, and the trends obtained from the results can be generalized.

In this study the climate projection outputs of the EURO-CORDEX regional models, the MUKLIMO_3 microclimatic numerical model, and the cuboid method (Früh, B. *et al.* 2011) were used to explore the combined effects of regional climate change and urban climate. The modelling process is based on LCZs as appropriate urban parameterization. Our previous studies of the thermal indices draw attention to the importance of this topic: in case of Szeged there is a remarkable increase in different thermal indices by the end of the century, namely, a strong warming trend can be expected (Skarbit, N. and Gál, T. 2016; Bokwa, A. *et al.* 2018).

The purpose of this study is twofold:

(i) Analysis and comparison of the patterns of the annual values of tropical nights (TNs) quantifying the thermal load of the cities in the Carpathian Basin in the current (1981–2010) and future climate change periods based on two different future emission scenarios (RCP4.5 and RCP8.5).

(ii) Determining the overall additional thermal load in urban areas relative to their natural surroundings for each scenario during these periods.

Study areas

The investigation focuses on different sized cities with different geographical background in the Carpathian Basin, mainly on low-lying areas with moderate relief (*Figure 1*). The population of the selected 26 cities is between 20,000 and 1,675,000 (*Table 2*).

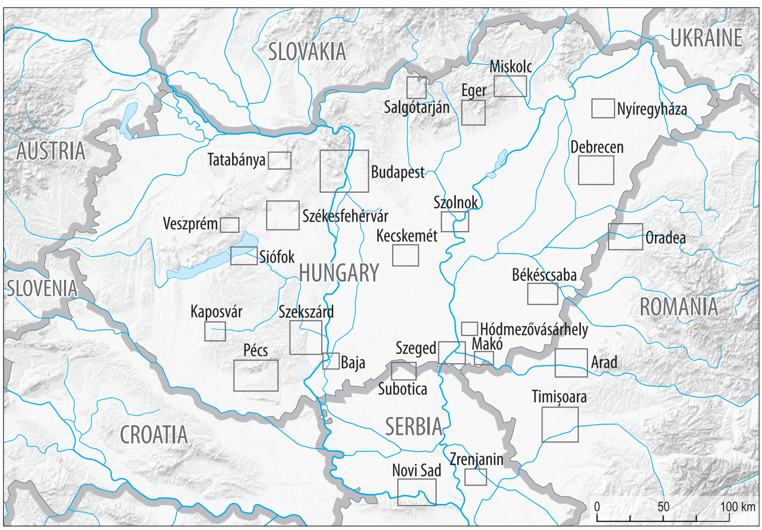


Fig. 1. Locations of the studied cities in the Carpathian Basin (modelling domains marked by black frames)

*Table 2. Population of the studied cities**

City size category by range of population in 1,000 inhabitants	City	Population, 1,000 inhabitants
1 (over 1,000)	*Budapest*	1,675
2 (between 200 and 400)	Timisoara (RO)	315
	Novi Sad (SRB)	215
	Oradea (RO)	207
	Debrecen	201
3 (between 100 and 199)	*Arad* (RO)	169
	Szeged	162
	Miskolc	158
	Pécs	147
	Nyíregyháza	120
	Kecskemét	110
	Subotica (SRB)	100
4 (between 50 and 99)	Székesfehérvár	96
	Zrenjanin (SRB)	80
	Szolnok	70
	Tatabánya	68
	Kaposvár	63
	Békéscsaba	59
	Veszprém	55
	Eger	52
5 (between 20 and 49)	*Hódmezővásárhely*	44
	Baja	36
	Salgótarján	35
	Szekszárd	32
	Siófok	25
	Makó	23

*Results of the cities written in italics are presented in details in this paper. *Source*: For Hungarian cities: https://nyilvantarto.hu, for other cities: https://worldpopulationreview.com/

An analysis of the current and future thermal situation of all 26 cities would go beyond the scope of this paper because of the length limitation. Therefore, we illustrate our results by selecting five city size categories, and we analyse the thermal situation of one city per category in detail (marked by italics in *Table 2*).

Methods

In order to get detailed information about the local scale future changes of thermal effects the MUKLIMO_3 model (Sievers, U. 1995) and cuboid method (Früh, B. *et al*. 2011) were applied to achieve high spatial resolution results inside the cities. The model is non-hydrostatic and calculates atmospheric temperature, relative humidity and wind field in a 3D grid by solving the Reynolds-averaged Navier-Stokes equations. Parametrizations are used for unresolved buildings, short-wave and long-wave radiation, balanced heat and moisture budgets in the soil (Sievers, U. and Zdunkowski, W. 1985). The initial meteorology conditions were ensured by a 1D profile from a reference station within the study area. To run the model, high-resolution orography and land use distribution data were needed. The horizontal resolution of 100 m was adjusted, while the vertical resolution changes in height and more accurate near to the surface, where the essential processes occur. The vertical resolution near to the surface is 10 m and increases by several steps to the top of the model domain where it is 100 m. For most cities 25 vertical layers were enough, however, in some cases, where the topography was more variable we applied more layers (in Budapest 35, Eger 36, Miskolc 38, Novi Sad 33, Pécs 36, Salgótarján 40, Tatabánya 35 and Veszprém 30 layers).

For our analysis, the orography data was provided by EU-DEM. The MUKLIMO_3 applies custom land use categories, thus, any land use classification system is usable if the necessary surface, vegetation and built-up parameters are provided. This property of the model allows applying any urban land use classification as an input for urban landforms. Using this advantage, we could apply the LCZ system to describe the land use.

We used Bechtel-method for LCZ mapping of the selected cities (see *Figure 1*), which applies free-access data and software (Bechtel, B. *et al.* 2015, 2019). This method is the basis of World Urban Database and Access Portal Tools (WUDAPT) which is a scientific initiative aiming to develop a global database for urban climate modelling. For this study, we used several Landsat images from different dates, in order to achieve more reliable LCZ classification. This approach ensures that the yearly changes of agricultural processes or vegetation cycle do not affect the final LCZ maps. The process was verified with field surveys in order to avoid misclassifications.

To represent the thermal effects of climate change several climate indices were calculated and to obtain these climate indices the so-called cuboid method was used, which is a statistical dynamical downscaling method (Früh, B. *et al*. 2011; Žuvela-Aloise, M. *et al*. 2014). This process is basically a tri-linear interpolation of air temperature, relative humidity and wind fields derived by MUKLIMO_3 simulations and produces 30 year mean of annual number of 6 different climate indices. The method assumes that heat load situations can occur in case of specified weather situations, which can be described by the mentioned variables. The necessary inputs for the calculation of these climate indices are a 30-year daily climate dataset from a reference station and 8 single-day MUKLIMO_3 simulations for two prevailing wind direction (16 simulations). In this study the model outputs related to the tropical nights (TNs) are presented.

The process of climate change was examined through two future periods, 2021–2050 and 2071–2100 as well as period 1981–2010 was considered as reference. To obtain input climate data for the cuboid method, the Carpatclim database (Szalai, S. *et al*. 2013) was applied for the reference period. It provides meteorological daily data for the Carpathian Region in spatial resolution of 0.1°. The database does not cover the entire area of Hungary, thus, cities in the western part of the country were excluded from the research.

For the 21st century, data of EURO-CORDEX model simulations with resolution 0.11° were used (Jacob, D. *et al*. 2014). The selection of the simulations was based on whether they include the necessary bias-corrected variables for the cuboid method e.g. air temperature, relative humidity wind speed and direction. Accordingly, 12 simulations were selected, which apply scenarios RCP4.5 and RCP8.5 also. The cuboid method was executed for all model simulations and the results were averaged by the scenarios.

Results and discussion

Examples of urban TN patterns by city categories

Due to its dense built-up and large spatial extent, the number of TNs is relatively high in Budapest in the period of 1981–2010, and the maximum value in the city centre exceeds 20 *(Figure 2*, b*)*. The number of TNs exceeds 10 in the remarkable part of the urban area and 15 in the interior. The pattern of higher values extends to the northeast due to the compact structure of this area (LCZ 3). Relatively high values also appear in the south-eastern part of the city, which may be caused by the prevailing wind direction. The high values of the southern city centre are the results of the LCZ 8, as this type of zone contains large impervious surfaces. This LCZ also appears scattered outside the urban area, with values above 5, especially in the south.

In both scenarios, there are clear changes in the period 2021–2050 compared to the reference period, but there is no considerable difference between them *(Figure 2*, c-d*)*. TN_{max} values are 31 and 35, respectively, according to RCP4.5 and RCP8.5. In most parts of the city, the value of TN in both cases exceeds 15. There are differences between the scenarios in the patterns of the values of 20 and 25, which are more extended into the North, South, and downtown areas for RCP8.5.

At the end of the century, there will be strong changes compared to the period 2021–2050, and the differences between the scenarios will become more remarkable *(Figure 2*, e-f*)*. According to RCP4.5 the number of TNs is over 20 in almost the whole city and the area of TNs over 25 is also expanded (TN_{max} is 42). At the centre, the typical value exceeds 30, but even values above 40 appear in a smaller area. For RCP8.5, TN_{max} is 71 and the number of TNs is over 40 almost throughout the city. The extension of values above 50 is also noteworthy, while in the city centre the number exceeds 60.

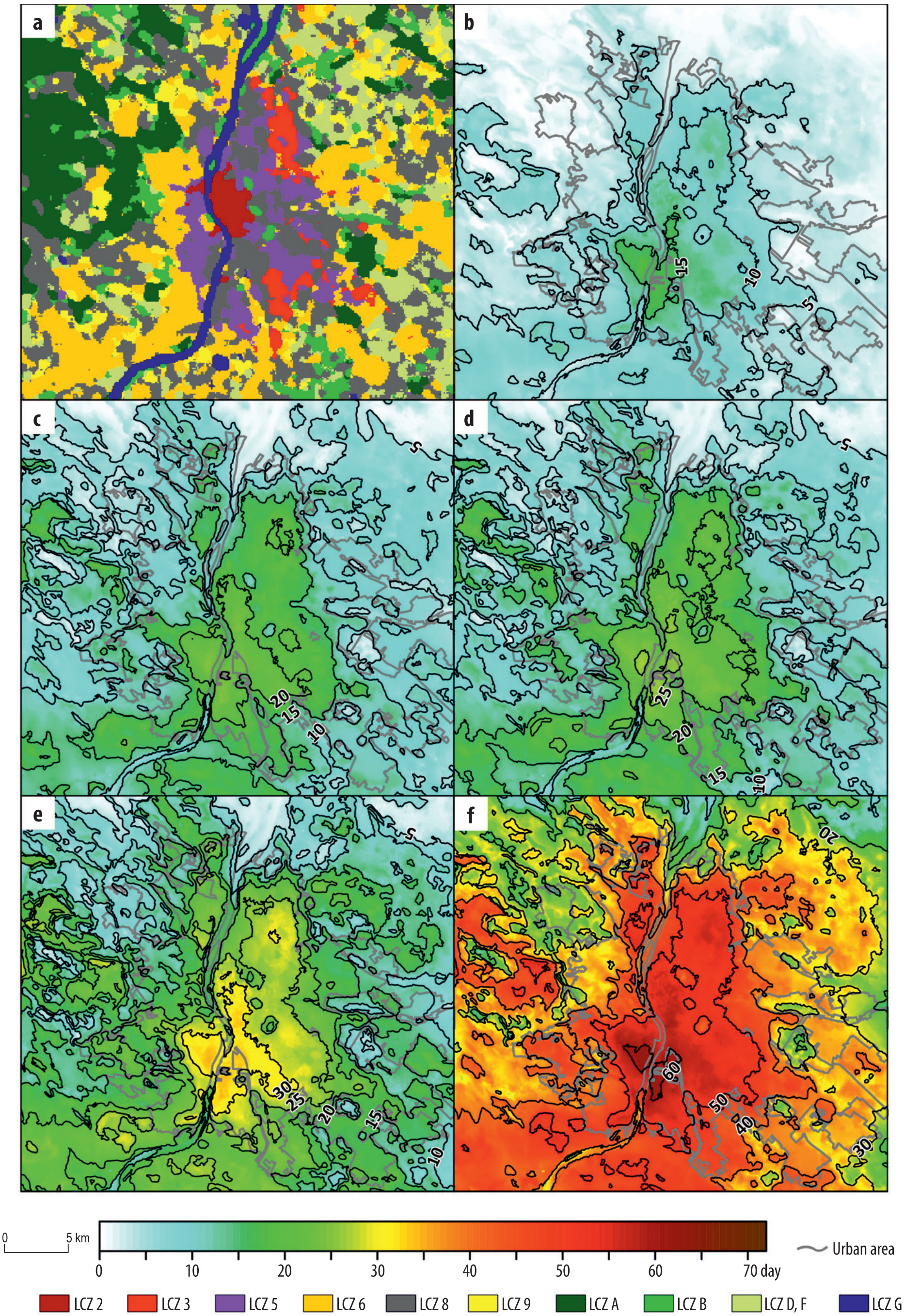


Fig. 2. LCZ map (a) and patterns of the tropical nights in Budapest (Hungary) in 1981–2010 (b), in 2021–2050 by RCP4.5 (c), in 2021–2050 by RCP8.5 (d), in 2071–2100 by RCP4.5 (e) and in 2071–2100 by RCP8.5 (f). The prevailing wind direction are NW and E.

In the case of Debrecen, the smaller population and areal extent compared to the capital is reflected in the number of TNs. Its value exceeds 5 in the more densely built-up western part of the city and in the LCZ 8 between 1981 and 2010 *(Figure 3*, b*)*. In the city centre, values above 10 occur mostly in the area of compact LCZs, but values above 15 can also be observed in a relatively small area (with a maximum of 16). The effect of the second dominant wind direction (north-east) also appears in the pattern.

There will be minimal changes in the period 2021–2050, the scenarios show similar results, and the change between them is negligible *(Figure 3*, c-d*)*. The only considerable change is the increased area of TNs over 10 and 15, which appear with slightly different magnitudes by scenarios. The maximum values are 17 and 19 according to the different RCPs.

Remarkable changes is observed in the period of 2071–2100 and the differences between the scenario values are relatively large *(Figure 3*, e-f*)*. According to RCP4.5, in most parts of the city the values are over 10 and the number of TNs in the interior exceeds 15, while in LCZ 2 it exceeds 20 (TN_{max} is 25). For RCP8.5, the values are more than twice as high: in most parts of the city, the number of TNs exceeds 30, while in the centre it is greater even 40 (TN_{max} is 51).

Considering Arad, which represents the next category of cities, the magnitude of TNs is similar, but slightly lower than in Debrecen. During the reference period, the number of TNs exceeds 5 in densely built-up areas and 10 in the small area of LCZ 8 (TN_{max} is 11) *(Figure 4*, b*)*. The effect of the prevailing wind directions is reflected in the north-west extent of the pattern.

In the case of this city, too, the near future will not bring major changes and the difference between the scenarios is minimal, the maximum values are 13 and 14 *(Figure 4*, c-d*)*. The change compared to the reference period is the increase in areas above 5 and 10. This increase occurs especially around the green area in the south-east and in the north-western parts of the city.

In 2071–2100, the changes according to RCP4.5 are noticeable, but not salient *(Figure 4*, e*)*. The pattern is similar to the previous period, but the values are higher of about 5 (TN_{max} is 21). The other change is the appearance of values above 5 in the western part of the study area, which may be the result of the prevailing wind directions and the dense tree zone (LCZ A). For RCP8.5, the changes are twice as high *(Figure 4*, f*)* in almost the entire city and in densely built-up areas the number of TNs exceeds 30 and 40, respectively (TN_{max} is 50).

Although the population of Zrenjanin is lower than that of the previous two cities, the number of TNs in the reference period is higher due to its location at a lower latitude *(Figure 5*, b). In almost the entire area of the city the value exceeds 5, except for the southern part. In the LCZ 8 and LCZ 5 it is over 10, while LCZ3 it has more than 15 (TN_{max} is 23).

In the period 2021–2050 the pattern values exceed 5 and 10, especially according to RCP8.5 *(Figure 5*, c-d*)*. In addition, values above 15 appear scattered across the western and southeastern areas. The TN_{max} is 21 and 24 for the different RCPs. The lack of increase of the maximum values in case of RCP4.5 is the result of the application of different climate input for the reference and future periods (Carpatclim and EURO-CORDEX).

Considering the results between 2071 and 2100, the changes are of a similar magnitude as in previous cities *(Figure 5*, e-f*)*. At RCP4.5, the number of TNs is over 15 throughout the city. Besides, values above 20 appear scattered throughout the pattern, especially in LCZ 8 and LCZ 5. In the core (dominated by LCZ 3), the values exceed 25 and even 30 in a small area (TN_{max} is 31). The outcomes of RCP8.5 during this period show far high values, which are slightly more than twice as high as those of RCP4.5: almost the entire area of the city has more than 40 TNs and values above 50 appear in the previously mentioned zones and are above 60 in the city core (TN_{max} is 62).

Hódmezővásárhely is the smallest among the example cities, however, this is not reflected in the number of TNs (*Figure 6*, b*)*.

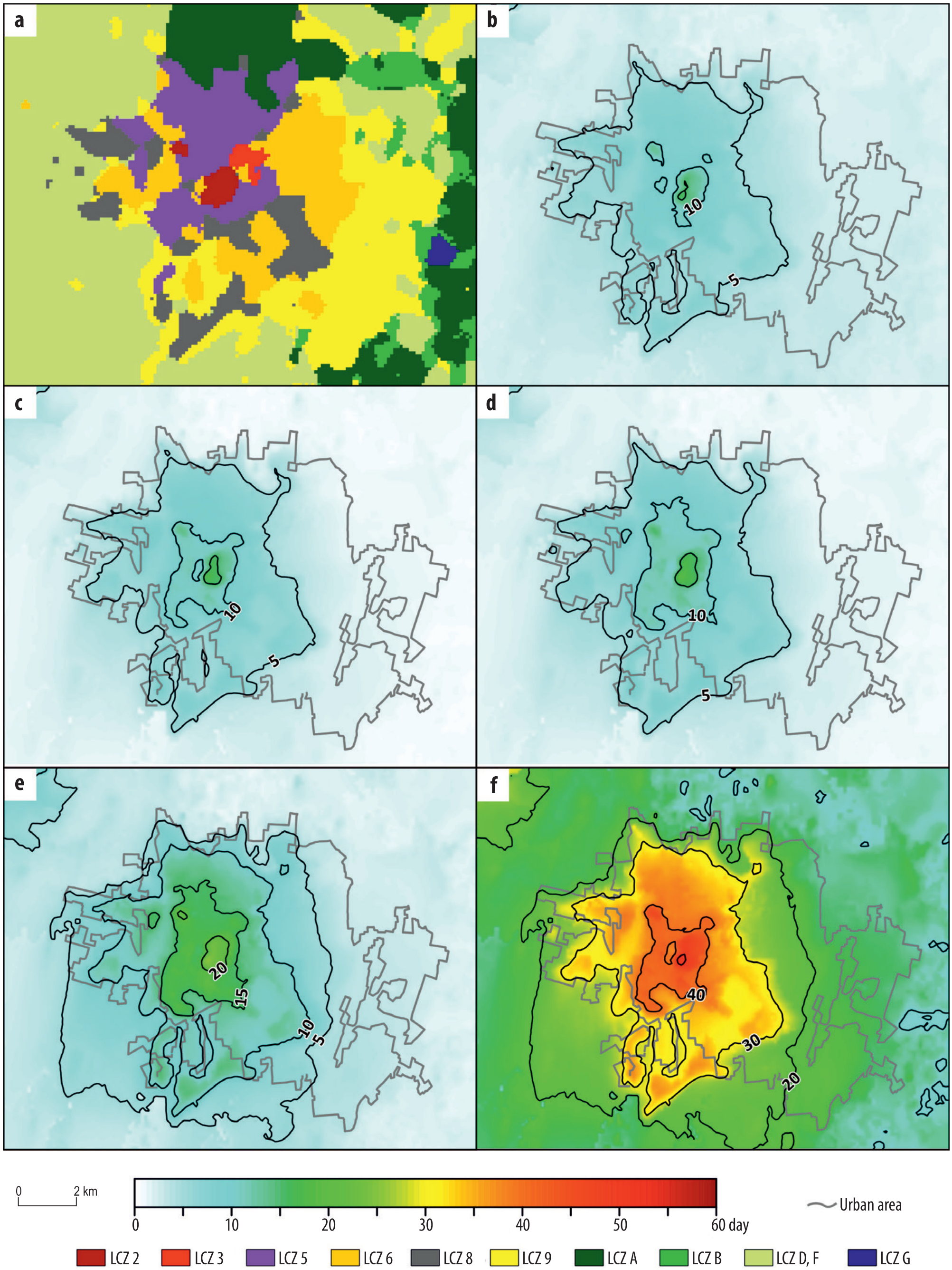


Fig. 3. LCZ map (a) and patterns of the tropical nights in Debrecen (Hungary) in 1981–2010 (b), in 2021–2050 by RCP4.5 (c), in 2021–2050 by RCP8.5 (d), in 2071–2100 by RCP4.5 (e) and in 2071–2100 by RCP8.5 (f). The prevailing wind directions are S and NE.

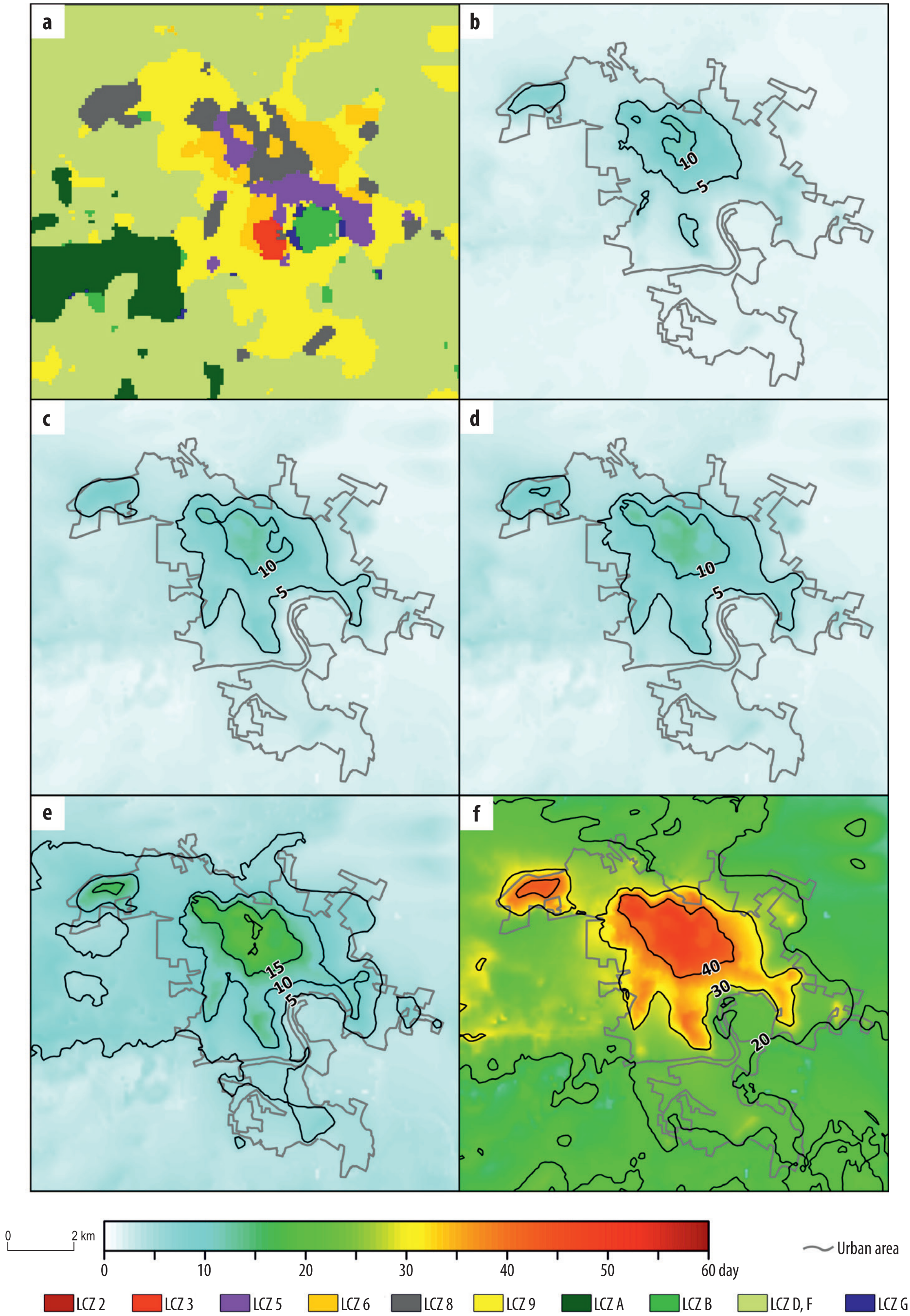


Fig. 4. LCZ map (a) and patterns of the tropical nights in Arad (Romania) in 1981–2010 (b), in 2021–2050 by RCP4.5 (c), in 2021–2050 by RCP8.5 (d), in 2071–2100 by RCP4.5 (e) and in 2071–2100 by RCP8.5 (f). The prevailing wind directions are S and SE.

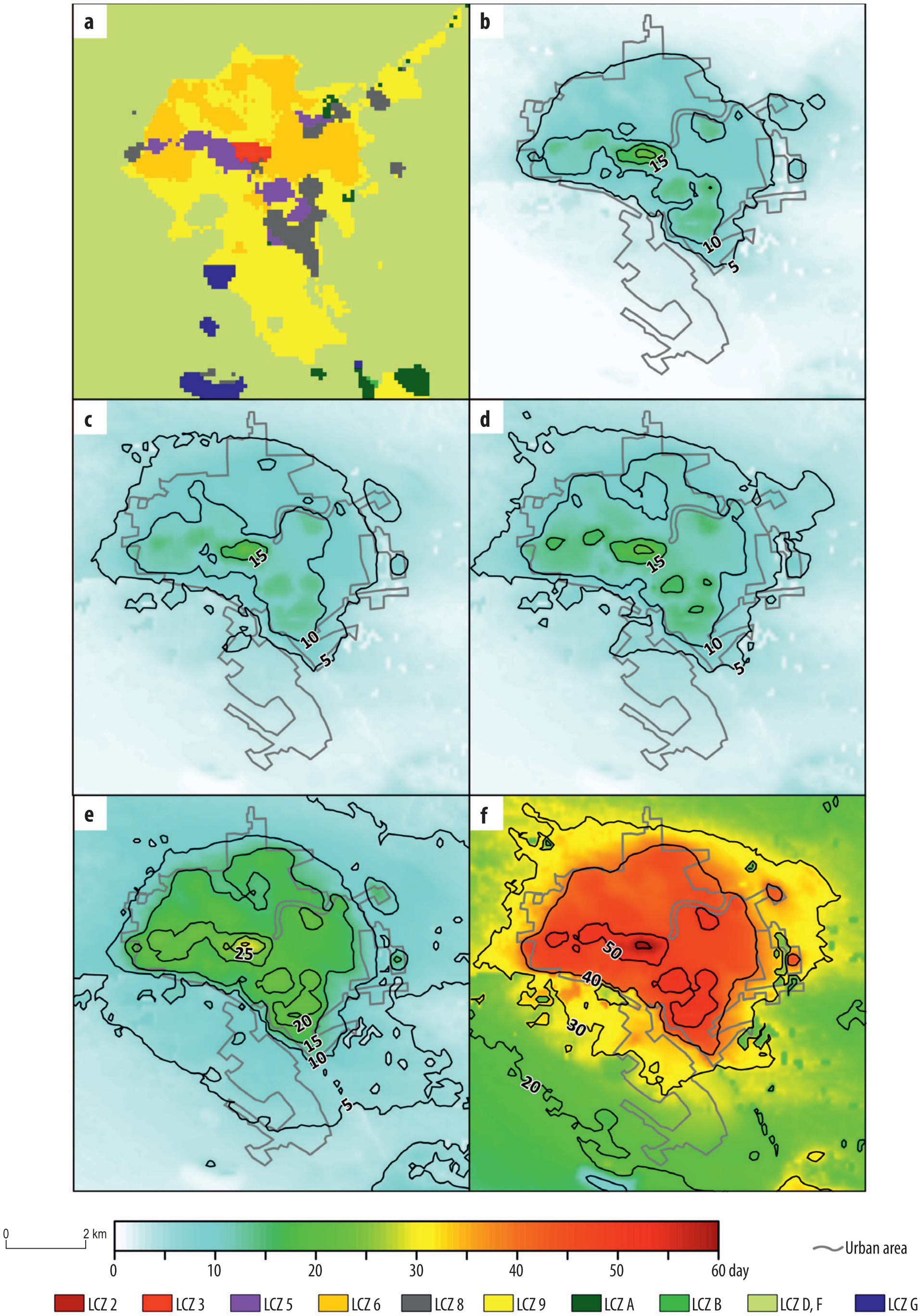


Fig. 5. LCZ map (a) and patterns of the tropical nights in Zrenjanin (Serbia) in 1981–2010 (b), in 2021–2050 by RCP4.5 (c), in 2021–2050 by RCP8.5 (d), in 2071–2100 by RCP4.5 (e) and in 2071–2100 by RCP8.5 (f). The prevailing wind directions are SE and NW.

In the reference period, the city boundary almost coincides with line 5, while in LCZ 8 the numbers exceed 10 (TN_{max} is 11).

In the near future, minor changes will take place, which is reflected in the expansion of value areas above 5 and 10 *(Figure 6,* c-d*)*. The main difference between the scenarios is the increased area of values above 10, which is even greater for RCP8.5: not only LCZ 5 and LCZ 8 are affected, but also the N-NE part of the city. The maximum values according to RCP4.5 and RCP8.5 are 12 and 13, respectively.

For 2071–2100, the change in RCP4.5 is not outstanding: the number of TNs exceeds 10 in the entire urban area and is greater than 15 in most of the city, which means the densely built-up south-west, the south-east LCZ 8 and the aforementioned north-northeast *(Figure 6,* e*)*. The TN_{max} does not exceed 20, which is exceptional among the presented cities. For RCP8.5, the values in the whole urban area exceed 30 and are higher than 40 in the previously mentioned areas, and exceed 45 in the south-west and south-east (TN_{max} is 48) *(Figure 6,* f*)*.

Urban-rural heat load differences

According to *Table 3*, the number of TNs in the reference period does not exceed 5 in the rural areas. In the urban areas the dispersion is high: the values are between 5 and 10 in most cities, while they exceed 10 in larger cities and 15 only in the southernmost ones (Novi Sad and Zrenjanin). In the period 2021–2050, there will be minimal changes compared to 1981–2010, and the difference between the scenarios is also minimal. For RCP4.5, rural values are still below 5 with the exception of 3 cities, while urban values are between 10 and 15. The deviation of the TNs of RCP8.5 from RCP4.5 during this period is only 1–2 nights. Remarkable changes appear in 2071–2100 especially in case of RCP8.5 and the difference between the scenarios is enormous. While the rural TNs of RCP4.5 are below 5 in most cases and do not exceed 15, RCP8.5 values are basically between 15 and 25 (except extreme cases). The urban TNs of RCP4.5 are usually between 15 and 25, however, for RCP8.5 there are very few cities where this number does not exceed 30. Typical TN values are between 40 and 50, but in four cases the number exceeds even 50 (e.g. Budapest).

The differences among the cities are mostly determined by the location, size, topography and built-up (LCZ) types. The highest values appear for larger and/or southern cities such as Budapest, Novi Sad and Zrenjanin. For smaller cities and/or cities with higher altitudes and latitudes (e.g. Salgótarján), the TN values are generally lower.

The results – particularly the rural values in *Table 3* – can be compared to Pieczka, I. *et al.* (2018), which is the only example of tropical night extrapolation in the Carpathian Basin. According to Pieczka, I. *et al.* (2018), in case of period 2021–2040 and 2081–2100 the values are 10 and 15–30 days higher, respectively. There are some possible explanations of these differences. Firstly, the time periods are different, and in case of 2081–2100 it could cause major differences since in theory the first 10 years should be less warm than the last 20 within the period of 2071–2100. Secondly, in our study the outputs of 12 different regional models were applied meanwhile and Pieczka, I. *et al.* (2018) presented the results only of a single model. As the temperature extrapolation of the models are also different, it could also explain partly of the above mentioned differences. Finally, the values presented in *Table 3* are the spatial mean of LCZ D areas within the domains, therefore several local and micro-scale climate effects (nearby water surfaces or forest areas, small scale terrain forms) occur, which are not implemented in regional scale models. Consequently, the comparison of these values is not entirely correct.

The built-up environment causes remarkable differences in the number of TNs between the rural and urban area. *Table 3* clearly shows that the maximum difference in each city depends on the size and location of the city and the time period and scenario. These results clearly support the motivation for local-scale climate modelling, as regional-scale

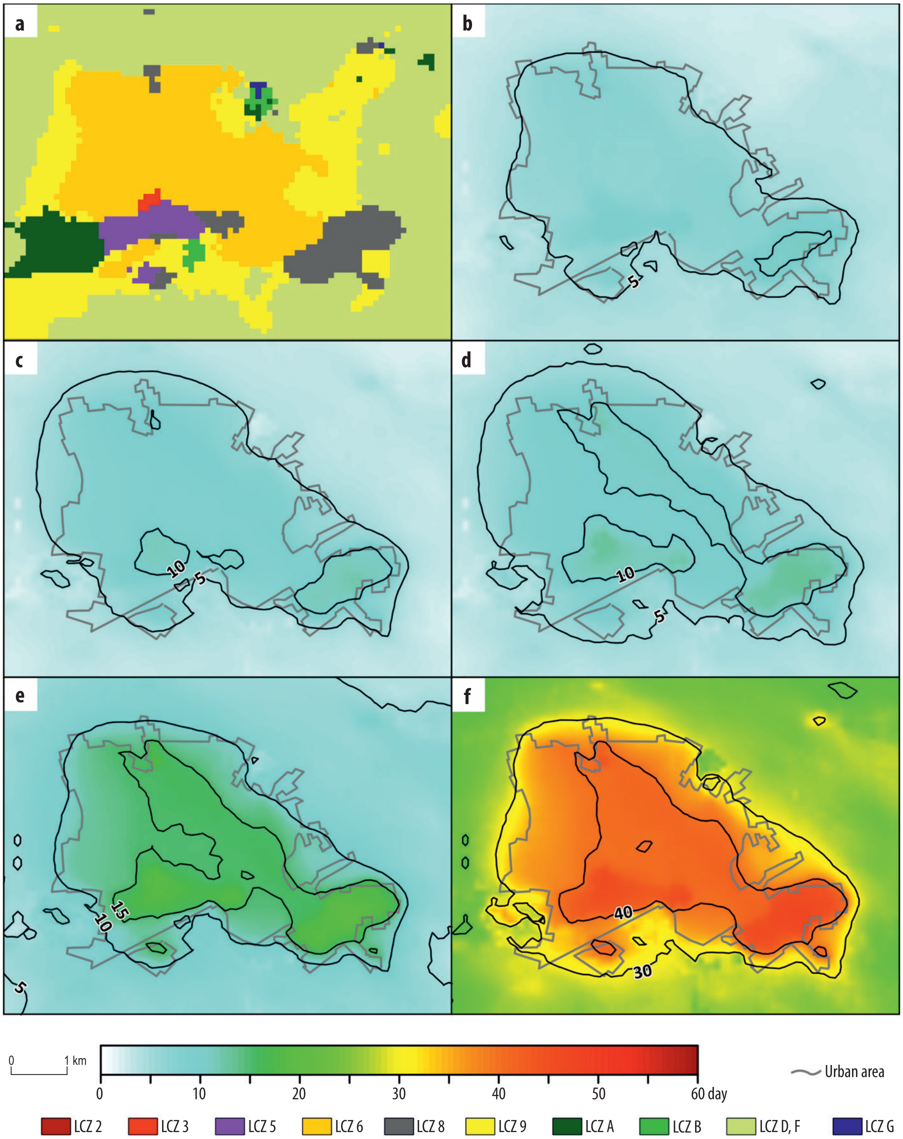


Fig. 6. LCZ map (a) and patterns of the tropical nights in Hódmezővásárhely (Hungary) in 1981–2010 (b), in 2021–2050 by RCP4.5 (c), in 2021–2050 by RCP8.5 (d), in 2071–2100 by RCP4.5 (e) and in 2071–2100 by RCP8.5 (f). The prevailing wind directions are S and NW.

modelling can only determine rural conditions, whereas at the local scale, urban and intra-urban conditions can also be explored. The knowledge gained in this way is very valuable, as this type of projection of the increasing heat load in cities varying from district to district during the century, allows the authorities and partly the individuals to take appropriate preventive measures to mitigate the expected negative effects.

*Table 3. General information on the urban-rural difference in the mean number of tropical nights during the 21st century by cities**

City category	Period	1981–2010		2021–2050				2071–2100			
	Scenario			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		R	U	R	U	R	U	R	U	R	U
1	*Budapest*	3	13	8	20	8	22	12	29	31	54
2	Timisoara (RO)	3	13	2	12	2	13	4	20	20	50
	Novi Sad (SRB)	5	18	6	17	7	19	11	26	32	53
	Oradea (RO)	2	6	2	6	2	7	4	11	18	34
	Debrecen	2	12	1	13	2	15	3	21	15	46
3	*Arad* (RO)	1	5	2	6	2	7	3	11	18	35
	Szeged	1	11	2	15	2	16	3	22	15	47
	Miskolc	1	3	1	6	1	7	3	14	14	35
	Pécs	2	6	5	13	5	14	9	21	28	48
	Nyíregyháza	1	9	1	10	1	12	2	17	11	40
	Kecskemét	1	10	1	14	2	15	3	22	16	47
	Subotica (SRB)	1	10	1	10	1	11	2	16	12	38
4	Székesfehérvár	2	7	3	10	4	11	6	17	24	41
	Zrenjanin (SRB)	1	17	2	16	3	18	5	26	23	56
	Szolnok	2	9	2	14	2	15	3	21	17	46
	Tatabánya	0	0	2	3	2	4	4	7	17	24
	Kaposvár	1	2	2	4	2	5	4	8	19	29
	Békéscsaba	2	10	1	11	1	12	2	18	13	43
	Veszprém	0	1	2	4	2	5	4	8	17	28
	Eger	0	0	1	3	1	3	2	5	10	19
5	*Hódmezővásárhely*	3	8	3	11	3	12	5	18	22	44
	Baja	2	6	3	11	3	12	5	18	24	46
	Salgótarján	0	0	1	2	1	3	2	4	11	17
	Szekszárd	2	6	3	10	3	10	6	16	20	36
	Siófok	3	9	6	13	6	14	11	22	36	54
	Makó	2	5	2	7	2	8	4	13	19	37

*Values are spatial means of different LCZs: R = LCZ D, U = the warmest LCZ in the given city. City categories and cities written in italics are explained in *Table 2.*

Conclusions

In this study the future changes in the number of TNs were examined through three time periods in several cities in the Carpathian Basin. The results reveal that both the size and latitude of cities affect the values that are higher in southern and larger cities. Inside the cities the built-up types, the location and prevailing wind directions are determinative factors. In general, the change in the number of TNs and the difference between the scenarios are not remarkable in 2021–2050, the substantial change will occur in 2071–2100, especially for RCP8.5.

Our results show the extent to which different built-up types modify (actually amplify) differently the effects of climate change. In this way, they provide detailed information on future processes not only for the regions (rural areas), but also for the cities, which are already, but will continue to be, the primary sites of human activity. Therefore, these results can serve as a guide for urban planners and local authorities to create neighbourhoods that are more liveable and better adapted to future changes.

Acknowledgements: This research was supported by the National Research, Development and Innovation Office, Hungary (NKFI K-120346) and Ministry of Human Capacities, Hungary grant 20391-3/2018/FEKUSTRAT and TUDFO/47138-1/2019-ITM. We acknowledge the CORDEX project for producing and making available their model output and the Deutscher Wetterdienst (DWD) for making available the MUKLIMO_3 model.'

REFERENCES

Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H.R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C. and Michelozzi, P. 2008. Heat effects on mortality in 15 European cities. *Epidemiology* 19. 711–719. Doi: 10.1097/EDE.0b013e318176bfcd

Bartholy, J. and Pongrácz, R. 2018. A brief review of health-related issues occurring in urban areas related to global warming of 1.5 °C. *Current Opinion in Environmental Sustainability* 30. 123–132.

Bechtel, B., Alexander, P.J., Böhner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L. and Stewart, I. 2015. Mapping local climate zones for a worldwide database of the form and function of cities. *ISPRS International Journal of Geo-Information* 4. 199–219.

Bechtel, B., Alexander, P.J., Beck, C., Böhner, J., Broussed, O., Ching, J., Demuzere, M., Fonteg, C., Gál, T., Hidalgo, J., Hoffmann, P., Middel, A., Mills, G., Ren, C., See, L., Sismanidis, P., See, L. Verdonck, M-L., Xu, G. and Xu, Y. 2019. Generating WUDAPT Level 0 data – Current status of production and evaluation. *Urban Climate* 27. 24–45. Doi: 10.1016/j.uclim.2018.10.001

Bokwa, A., Dobrovolný, P., Gál, T., Geletič, J., Gulyás, Á., Hajto, M.J., Holec, J., Hollósi, B., Kielar, R., Lehnert, M., Skarbit, N., Šťastný, P., Švec, M., Unger, J., Walawender, J.P. and Žuvela-Aloise, M. 2018. Urban climate in Central European cities and global climate change. *Acta Climatologica* 51–52. 7–35. Doi: 10.14232/acta.clim.2018.52.1

Bruse, M. and Fleer, H. 1998. Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling & Software* 13. 373–384. Doi: 10.1016/S1364-8152(98)00042-5

Früh, B., Becker, P., Deutschländer, T., Hessel, J.D., Kossmann, M., Mieskes, I., Namyslo, J., Roos, M., Sievers, U., Steigerwald, T., Turau, H. and Wienert, U. 2011. Estimation of climate-change impacts on the urban heat load using an urban climate model and regional climate projections. *Journal of Applied Meteorology and Climatology* 50. 167–184. Doi: 10.1175/2010JAMC2377.1

IPCC 2018. *Global Warming of 1.5 °C.* An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Eds.: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. Available at https://www.ipcc.ch/sr15/

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B. and Yiou, P. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. *Regional Environmental Change* 14. 563–578. Doi: 10.1007/s10113-013-0499-2

Kusaka, H., Kondo, H., Kikegawa, Y. and Kimura, F. 2001. A simple single-layer urban canopy model for atmospheric models: comparison with multi-layer and slab models. *Boundary-Layer Meteorology* 101. 329–358. Doi: 10.1023/A:1019207923078

Kwok, Y.T., Schoetter, R., Lau, K.K-L., Hidalgo, J., Ren, C., Pigeon, G. and Masson, V. 2019. How well does the local climate zone scheme discern the thermal environment of Toulouse (France)? An analysis using numerical simulation data. *International Journal of Climatology* 39. 5292–5315. Doi: 10.1002/joc.6140

Lee, S.-H., Lee, H., Park, S.B., Woo, J.W., Lee, D.I. and Baik, J.J. 2016. Impacts of in-canyon vegetation and canyon aspect ratio on the thermal environment of street canyons: numerical investigation using a coupled WRF-VUCM model. *Quarterly Journal of the Royal Meteorological Society* 142. 2562–2578. Doi: 10.1002/qj.2847

Lehnert, M., Geletič, J., Husák, J. and Vysoudil, M. 2015. Urban field classification by "local climate zones" in a medium-sized Central European city: the case of Olomouc (Czech Republic). *Theoretical and Applied Climatology* 122. 531–541. Doi: 10.1007/s00704-014-1309-6

Lelovics, E., Unger, J., Gál, T. and Gál, C.V. 2014. Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. *Climate Research* 61. 51–62. Doi: 10.3354/cr01220

Lemonsu, A., Masson, V., Shashua-Bar, L., Erell, E. and Pearlmutter, D. 2012. Inclusion of vegetation in the Town Energy Balance model for modelling urban green areas. *Geoscientific Model Development* 5. 1377–1393. Doi: 10.5194/gmd-5-1377-2012

Martilli, A., Clappier, A. and Rotach, M.W. 2002. An urban surface exchange parameterisation for mesoscale models. *Boundary-Layer Meteorology* 104. 261–304. Doi: 10.1023/A:1016099921195

Masson, V. 2000. A physically-based scheme for the urban energy budget in atmospheric models. *Boundary-Layer Meteorology* 94. 357–397.

Ministry of the Interior of Hungary. Available at https://nyilvantarto.hu (last accessed: 16.11.2020)

Molnár, G., Kovács, A. and Gál, T. 2020. How does anthropogenic heating affect the thermal environment in a medium-sized Central European city? A case study in Szeged, Hungary. *Urban Climate* 34.100673. Doi: 10.1016/j.uclim.2020.100673

Oke, T.R., Mills, G., Christen, A. and Voogt, J.A. 2017. *Urban Climates*. Cambridge, Cambridge University Press.

Pieczka, I., Pongrácz, R. and Bartholy, J. 2018. Future temperature projections for Hungary based on RegCM4.3 simulations using new Representative Concentration Pathways scenarios. *International Journal of Global Warming* 15. 277–292.

Ryu, Y.H., Bou-Zeid, E., Wang, Z.-H. and Smith, J.A. 2016. Realistic representation of urban trees in an urban canopy model. *Boundary-Layer Meteorology* 159. 193–220. Doi: 10.1007/s10546-015-0120-y

Sievers, U. and Zdunkowski, W. 1985. A numerical simulation scheme for the albedo of city street canyons. *Boundary-Layer Meteorology* 33. 245–257.

Sievers, U. 1995. Verallgemeinerung der Stromfunktionsmethode auf drei Dimensionen. *Meteorologische Zeitschrift* 4. 3–15.

Siu, L.W. and Hart, M.A. 2013. Quantifying urban heat island intensity in Hong Kong SAR, China. *Environmental Monitoring and Assessment* 185. 4383–4398. Doi: 10.1007/s10661-012-2876-6

Skarbit, N. and Gál, T. 2016. Projection of intra-urban modification of nighttime climate indices during the 21st century. *Hungarian Geographical Bulletin* 65. (2): 181–193. Doi: 10.15201/hungeobull.65.2.8

Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate. Cambridge and New York, Cambridge University Press.

Stewart, I.D. and Oke, T.R. 2012. Local Climate Zones for urban temperature studies. *Bulletin of American Meteorological Society* 93. 1879–1900. Doi: 10.1175/BAMS-D-11-00019.1

Stewart, I.D., Oke, T.R. and Krayenhoff, E.S. 2014. Evaluation of the 'local climate zone' scheme using temperature observations and model simulations. *International Journal of Climatology* 34. 1062–1080. Doi: 10.1002/joc.3746

Szalai, S., Auer, I., Hiebl, J., Milkovich, J., Radim, T., Stepanek, P., Zahradnicek, P., Bihari, Z., Lakatos, M., Szentimrey, T., Limanowka, D., Kilar, P., Cheval, S., Deak, Gy., Mihic, D., Antolovic, I., Mihajlovic, V., Nejedlik, P., Stastny, P., Mikulova, K., Nabyvanets, I., Skyryk, O., Krakovskaya, S., Vogt, J., Antofie, T. and Spinoni, J. 2013. *Climate of the Greater Carpathian Region*. Final Technical Report. Available at www.carpatclim-eu.org/pages/download/

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J. and Rose, S.K. 2011. The representative concentration pathways: an overview. *Climatic Change* 109. 5–31. Doi: 10.1007/s10584-011-0148-z

World Population Review. Available at https://worldpopulationreview.com/ (last accessed: 06.11.2020)

Zheng, Y., Ren, C., Xu, Y., Wang, R., Ho, J., Lau, K. and Ng, E. 2018. GIS-based mapping of Local Climate Zone in the high-density city of Hong Kong. *Urban Climate* 24. 419–448. Doi: 10.1007/s10661-020-08608-4

Žuvela-Aloise, M., Koch, R., Neureiter, A., Böhm, R. and Buchholz, S. 2014. Reconstructing urban climate of Vienna based on historical maps dating to the early instrumental period. *Urban Climate* 10. 490–508. Doi: 10.1016/j.uclim.2014.04.002

Žuvela-Aloise, M. 2017. Enhancement of urban heat load through social inequalities on an example of a fictional city King's Landing. *International Journal of Biometeorology* 61. 527–539. Doi: 10.1007/s00484-016-1230-z

Precipitation interpolation using digital terrain model and multivariate regression in hilly and low mountainous areas of Hungary

Tamás SCHNECK[1,2], Tamás TELBISZ[1] and István ZSUFFA[2,3]

Abstract

The relationship between precipitation and elevation is a well-known topic in the field of geography and meteorology. Radar-based precipitation data are often used in hydrologic models, however, they have several inaccuracies, and elevation can be one of the additional parameters that may help to improve them. Thus, our aim in this article is to find a quantitative relationship between precipitation and elevation in order to correct precipitation data input into hydrologic models. It is generally accepted that precipitation increases with elevation, however, the real situation is much more complicated, and besides elevation, the precipitation is dependent on several other topographic factors (e.g., slope, aspect) and many other climatic parameters, and it is not easy to establish statistically reliable correlations between precipitation and elevation. In this paper, we examine precipitation-elevation correlations by using multiple regression analysis based on monthly climatic data. Further on, we present a method, in which these regression equations are combined with kriging or inverse distance weighting (IDW) interpolation to calculate precipitation fields, which take into account topographic elevations based on digital terrain models. Thereafter, the results of the different interpolation methods are statistically compared. Our study areas are in the hilly or low mountainous regions of Hungary (Bakony, Mecsek, Börzsöny, Cserhát, Mátra and Bükk montains) with a total of 52 meteorological stations. Our analysis proved that there is a linear relationship between the monthly sum of precipitation and elevation. For the North Hungarian Mountains, the correlation coefficients were statistically significant for the whole study period with values between 0.3 and 0.5. Multivariate regression analysis pointed out that there are remarkable differences among seasons and even months. The best correlation coefficients are typical of late spring-early summer and October, while the weakest linear relationships are valid for the winter period and August. The vertical gradient of precipitation is between one and four millimetres per 100 metres for each month. The statistical comparison of the precipitation interpolation had the following results: for most months, co-kriging was the best method, and the combined method using topography-derived regression parameters lead to only slightly better results than the standard kriging or IDW.

Keywords: precipitation, elevation, DTM, kriging, IDW, co-kriging, multivariate regression

Received March 2020, accepted February 2021.

Introduction

The relationship between precipitation and elevation is a well-known topic in the field of geography and meteorology (Henry, A.J. 1919; Duckstein, L. *et al.* 1973; Basist, A. *et al.* 1994; Weisse, A.K. and Bois, P. 2001; Sasaki, H. and Kurihara, K. 2008; Haiden, T. and Pistotnik, G. 2009). Climatological precipitation maps of diversified terrains can be prepared using the connections among measured precipitation data at hydrometeorological stations. Nowadays, precipitation data can be accessed in high spatial and tem-

[1] Department of Physical Geography, Eötvös Loránd University, H-1117 Budapest, Pázmány Péter sétány 1/c. Hungary. Corresponding author's e-mail: tomi.schneck@gmail.com
[2] VITUKI Hungary Ltd., H-1173 Budapest, Mendei u. 3. Hungary.
[3] Department of Water and Environmental Policy, National University of Public Service, H-6500 Baja, Bajcsy-Zsilinszky u. 12–14. Hungary.

poral resolution due to radar measurements. However, these radar-derived precipitation data require correction. The use of digital terrain data can be an essential step in this data correction process (Crochet, P. 2009). Precipitation is an important input data in hydrological models, thus, the main reason for studying the relationship between precipitation and topography is to make hydrological models more accurate.

We often simplify the relationship of precipitation and elevation by stating that the amount of precipitation increases with elevation. However, this relationship is an oversimplification, because elevation, rise, exposure and orientation are equally important in defining this relation (Spreen, W.C. 1947).

Already a century ago, Henry, A.J. (1919) presented a statistical analysis of several sites with high amount of precipitation (e.g., Hawaii, India, Indonesia), in which he concluded that the increase of precipitation correlates mostly with slope steepness. Spreen, W.C. (1947) correlated the mean annual precipitation with elevation and other parameters, and it turned out that elevation itself determines only 30 per cent of precipitation variance. However, when he used multivariate regression including aspect, terrain, and the line of drift of the mountains, it turned out that these parameters together determine 85 per cent of precipitation variance. According to Duckstein, L. *et al.* (1973), it is important to examine whether the increasing precipitation in mountainous areas comes from the growing number of rainfall events or from the increasing amount of precipitation in each rainfall event. According to their observations, the amount of precipitation moderately increases with elevation during each rainfall event, and the seasonal amount of precipitation also increases linearly with elevation.

Basist, A. *et al.* (1994) stated that the best determining factors are combined topographic factors, while elevation itself does not correlate well with precipitation according to their regression analysis. Because of the cooling of air temperature, the maximum humidity decreases with higher elevation, therefore there is a theoretical 'elevation of maximum precipitation' (Alpert, P. 1986), thus, precipitation can increase only up to this elevation. However, due to the rarity of upland stations, it is hard to determine this 'elevation of maximum precipitation', but in the region of Alps it is estimated to be at 3,500 m a.s.l. (Schwarb, M. 2000), therefore a linear correlation between precipitation and elevation can be used only below this elevation, while above this elevation, the precipitation-elevation relationship can be modelled only by higher order polynomials. Sasaki, H. and Kurihara, K. (2008) examined this relationship for the months of June and July in Central Japan. In this case, they used raster-based precipitation data instead of station data to find a connection with elevation. Their results demonstrated that there is a statistically significant relationship between precipitation and elevation, but the correlation is low (r = 0.3-0.4). According to Smith, C.D. (2008), there is a strong linear relationship between the monthly sum of precipitation and elevation in the cold periods of the year in the Canadian Rocky Mountains, but in summer, this relation is much weaker. Cambi, C. *et al.* (2010) examined the central part of the Apennines in Italy from a hydrogeological perspective, but they also used station data of precipitation and temperature. Their research came to a conclusion that there are relationships between elevation and precipitation, and also between elevation and temperature, but the correlation is weaker (R^2 = 0.88) in the case of precipitation than in the case of temperature (R^2 = 0.93).

Several authors studied the horizontal trends in the spatial distribution of precipitation, which are often reflected in ecosystems as well. Ha, K.J. *et al.* (2007) investigated directional features of rainfall distribution over the Korean Peninsula, and they found that apparent band-type rainfall tends to be dominant with a SW–NE tilted pattern in July and August. Millett, B. *et al.* (2009) pointed out that the Prairie Pothole region has a strong NE–SW precipitation trend. Lauenroth, W.K. *et al.* (1999) emphasized that W–E gradient in precipitation and the N–S gradient in temperature result in corresponding gradients in plant community types of the Prairie. Ruiz Sinoga, J.D. *et al.* (2011) mentioned that precipitation is very irregular but generally decreases in a W–E gradient in southern Spain. Cortesi, N. *et al.* (2012) described that the annual precipitation concentration index shows a NW to SE gradient for Europe. Goodwell, A.E. (2020) presented the dominant directions of precipitation influence in the USA using longterm precipitation data and information theory. Although directional trends are often incorporated into interpolation methods, they can also be more directly examined by regression analysis.

The correction of precipitation data via digital elevation models is also a well-known field of research. Daly, C. *et al.* (1997) developed the method of PRISM where the precipitation field was corrected by an effective height grid which was a smoothed large-scale representation of the topography of the USA. In this case, the 'effective height' was calculated for each pixel as the difference between the real and the smoothed terrain. This model used several parameters to estimate the amount of precipitation, for instance, slope exposure, wind speed and wind direction data. Goodale, C.L. *et al.* (1998) developed a method for Ireland, in which precipitation data were mapped and corrected using digital terrain models (DTMs), polynomial regression and quadratic trend surfaces. The application of the quadratic trend surfaces allowed them to estimate the change in precipitation and in temperature in a regional scale, while the actual elevation allowed them to estimate the difference between the elevation and the trend surface. Weisse, A.K. and Bois, P. (2001) developed the method named AURELHY, which concentrated on rainfall events. In this model, the precipitation variables are connected to local topography using 'kriging' regression residuals and multivariate linear regression.

Szentimrey, T. and Bihari, Z. (2007) worked out a compound interpolation method for the Hungarian climatological studies called MISH. This method uses multiplicative interpolation formula for the lognormally distributed precipitation along with homogenization (called MASH), local statistical parameters and other background information (e.g., satellite, radar and predicted data) for the interpolation. Haiden, T. and Pistotnik, G. (2009) used station pairs across the Alpine region with a horizontal distance of about 4 km and a vertical distance of 1 km with 12-h precipitation observation intervals alongside with correction factors like precipitation intensity, wind speed and wet-bulb temperature (i.e. the temperature read by a thermometer covered in water-soaked cloth). This method can be used for making high-resolution precipitation maps in a mountainous area with a temporal resolution of 1 day or lower. Mair, A. and Fares, A. (2010) compared interpolation methods for Hawaii using 3 years of data measured by 21 meteorological stations. They came to the conclusion that the method named 'ordinary kriging' was the best interpolator. Ly, S. *et al.* (2011) also compared geostatistical interpolation methods for Belgium. They tested the following methods: 'Thiessen polygons', 'inverse distance weighting' and various types of 'kriging'. Elevation was used as an additional factor during the interpolation, and they had the conclusion that the best methods were the 'inverse distance weighting' and two types of 'kriging'. Noori, M.J. *et al.* (2014) used precipitation data measured at 21 meteorological stations in Duhok, North Iran for comparing the 'inverse distance weighting' method with its improved versions. They found that 'inverse distance weighting' can be used for interpolating precipitation data – with certain settings – because the correlation coefficient between the measured and predicted precipitation exceeded the value of 0.74 in most cases.

In Hungary, it is stated that the yearly sum of precipitation increases with 35 millimetres every 100 metres of elevation, but this gradient shows a decrease from southwest to northeast (Bartholy, J. and Pongrácz, R. 2013, OMSZ). In the case of Mátra Mountains Roncz, B. (1982) examined the precipitation-elevation relationship, and he used precipitation data from 64 stations. The research led to a conclusion that the relationship between elevation and precipitation can be described as a stochastic linear connection with a higher value of correlation coefficient in the period of spring and October, and a lower value in the period of winter and August.

The aim of our research is to study the relationship between precipitation and elevation in Hungary, thus, we examine areas where the topographic differences are relatively high (in a Hungarian context), namely Bakony, Mecsek, Börzsöny, Cserhát, Mátra and Bükk mountains. We use monthly sums of station-measured precipitation data because according to our hypothesis, there are significant differences in correlation among months. As for daily and rainfall event data, they have a higher random component, thus, statistical relationships are less recognizable. We apply simple and multivariate regression analysis to examine the relationship between precipitation and elevation and location coordinates. In the following, we also present how the results of the regression analysis and the DTM can be used in a combined interpolation process to derive topographically corrected precipitation rasters. Finally, we compare these methods to other interpolation methods, such as kriging, inverse distance weighting (IDW) and co-kriging. While kriging and IDW do not use explicit topographic information, in co-kriging, the DTM is added as a secondary variable. The results of these interpolations are compared using independent station data.

Data and study area

The data used for our work is provided by the Hungarian Meteorological Service (Országos Meteorológiai Szolgálat, OMSZ), the Hungarian General Directorate of Water Management (Országos Vízügyi Főigazgatóság, OVF) the Central Danubian Valley Water Management Directorate (Közép-Duna-völgyi Vízügyi Igazgatóság, KDVVIZIG) and the North Hungarian Water Management Directorate (Észak-magyarországi Vízügyi Igazgatóság, ÉMVIZIG). We used data from 52 stations found at six hilly and low mountainous study areas, of which 10 were located in Bakony, 8 in Mecsek, 8 in Börzsöny, 3 in Cserhát, 12 in Mátra and 10 in Bükk mountains *(Figure 1).* The combined North Hungarian Mountains study area extent is

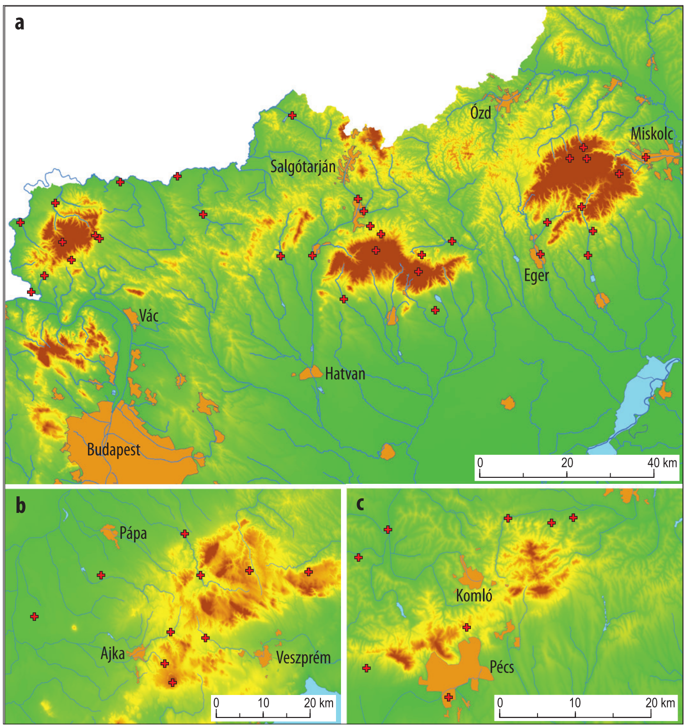


Fig. 1. Location of the applied meteorological stations (red crosses) in the North Hungarian Mountains (a), in the Bakony Mountains (b), and in the Mecsek Mountains (c)

marked with a red boundary in *Figure 1* (a), whereas the other study areas are shown in *Figure 1* (b) and (c). Precipitation data were available in monthly, daily and hourly time steps between 2011 and 2015. However, due to the high randomness of daily (and even more hourly) data, we used monthly sums of precipitation for each station in the present analysis. The mean station density of the study area is 1.5 station/100 km^2.

Methodology

Simple and multivariate regression analysis

The first step of our research was to perform a simple regression analysis on the monthly sums of precipitation. We investigated the relationship of precipitation and elevation for each month and each area. As we mentioned in the Introduction, several authors pointed out that there may be a directional trend in precipitation like the decrease of precipitation in a continental scale from the oceans to the inner parts of continents. Thus, we were also curious to know if directional changes can be recognized in precipitation patterns or not on the scale of Hungarian mountains. For this reason, easting and northing were also added as further independent parameters, therefore multivariate regression models were used.

In the case of simple regression, the relationship between precipitation and elevation is characterized by the following equation:

$$P = a_1 z + a_0 ,$$

where P is the amount of precipitation measured at the station, z is the elevation above sea level, while a_1 and a_0 are the coefficients of the regression equation.

Thereafter, we added northing and/or easting coordinates alongside elevation to see if North–South, East–West or other directional trend exists in precipitation. According to the Hungarian National Grid system (HD72 / EOV), x denotes northing and y denotes easting. However, as in most GIS systems, x is easting and y is northing, we used this latter notation. We tried several combinations. The combination of northing and elevation, the combination of easting and elevation and finally, the use of all three parameters. In these cases, the equations can be written as below:

$$P = a_2 z + a_1 x + a_0 , \tag{2}$$

$$P = a_2 z + a_1 y + a_0 , \tag{3}$$

$$P = a_3 z + a_2 y + a_1 x + a_0 , \tag{4}$$

where a_3, a_2, a_1 and a_0 are the coefficients of the equations.

Combination of deterministic and stochastic methods in the interpolation of precipitation

The steps following the regression analysis are illustrated in *Figure 2*. In the first step, the predicted precipitation is calculated for each meteorological station based on the coordinates of the station and the regression equations mentioned above. Thereafter, either kriging or IDW interpolation is used for the

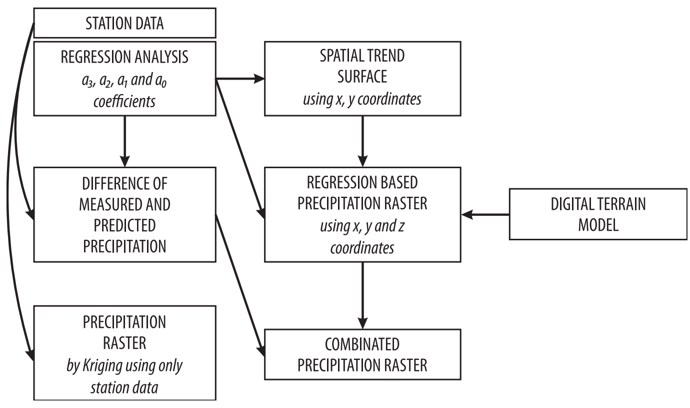


Fig. 2. Flow chart demonstrating the steps of the combined method

difference of the observed and predicted data. This is the stochastic element of the method.

In the next step, we calculate a linear trend surface by using regression equation (4) and the coefficients a_2, a_1 and a_0. Thereafter, with the inclusion of coefficient a_3, we create a precipitation field taking into account elevation based on a digital terrain model, SRTM (van Zyl, J.J. 2001; Rabus, B. *et al.* 2003) in our case. The error of SRTM elevation data is generally below 10 m, though random outliers may occur (Rodriguez, E. *et al.* 2006), thus, it causes little error with respect to several 100 metres of elevation differences within the study area. Its usability for Hungary in geomorphological studies was also thoroughly tested by Józsa, E. and Fábián, Sz.Á. (2016). The SRTM is the deterministic element of the method. Finally, the combined precipitation raster is calculated by adding the interpolated difference map to the regression-based precipitation raster.

The final map can be compared to the rasters created by kriging or IDW, which do not take elevation directly into account. Naturally, station precipitation data inherently include the effect of elevation. In the present study, we applied kriging using a linear variogram model and no anisotropy. The IDW was used with a power of 2 and without smoothing. All rasters had 1 km resolution.

The combined method is basically similar to the methods 'kriging with radar-based error correction' in Goudenhoofdt, E. and Delobbe, L. (2009) and 'conditional merging' in Sinclair, S. and Pegram, G. (2005). However, in the present case, the objective was not to elaborate a radar-based precipitation correction method but to perform a combined interpolation for meteorological station data taking elevation into account.

In addition, for comparison purpose, co-kriging method was also used alongside with kriging and IDW. During the co-kriging process, the measured precipitation values were used as a primary dataset, while the SRTM DTM as a secondary dataset. This interpolation method was also used among others by Azimi-Zonooz, A. *et al.* (1989) and Velasco-Forero, C.A. *et al.* (2009).

Results

Results of the simple and the multivariate regression analysis

All forms of regression equations mentioned in the methodology were studied for each study areas. The test demonstrated that if we use more variables in the model, then the value of the correlation coefficient (also the value of R^2) increases *(Figure 3).* It is also found that the relationship has monthly variations, therefore we suggest the use of monthly coefficients in the elevation-based correction of precipitation data, although even the coefficients for the same month in different years are varied to some extent.

The correlations based on the data of Mecsek and Bakony mountains are only significant if all variables are used, and even in these cases only few months are characterized by statistically significant correlations. In case of the merged North Hungarian Mountains, the use of only z as an independent variable can result significant correlation during the spring period, while using more variables results significant correlations for each month. The correlations were the strongest in the period of late spring-early summer and October, while the weakest correlations can be observed for August (see *Figure 3*). Thereafter, we calculated the precipitation values for the North Hungarian Mountains using the best-fit multiple regression model for each month. We compared the observed and calculated values in *Figure 4.* The point scatters are in agreement with the fact that determination coefficients are relatively low but significant.

The coefficient of elevation in the regression equation can be interpreted as the vertical precipitation gradient. Thus, based on the regression results, we got that the vertical precipitation gradients are between 0.010 and 0.035 both in simple and multivariate regressions with a peak in spring. This implies that in the North Hungarian Mountains monthly precipitation increases by 1.0–3.5 mm as elevation gets 100 m higher. However, the elevation coefficients of Mecsek and Bakony

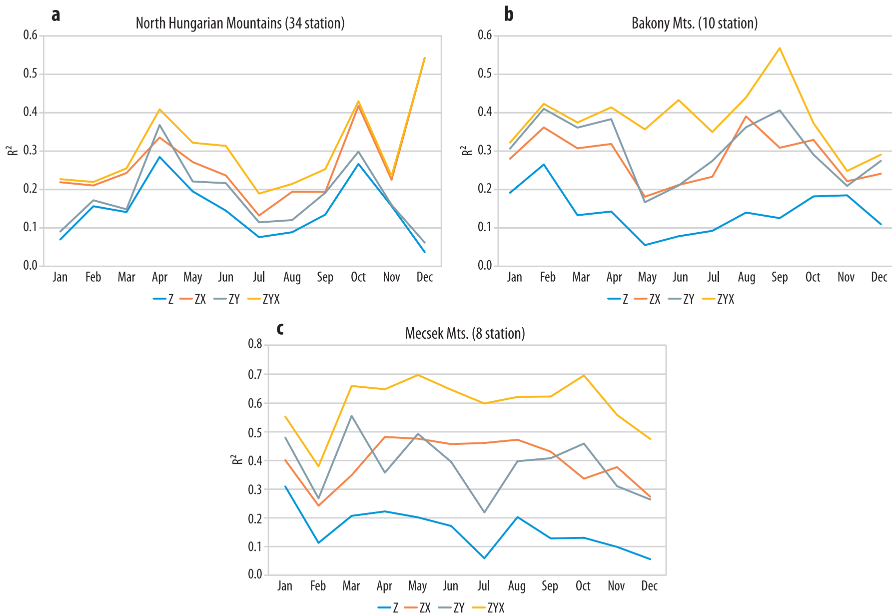


Fig. 3. Values of R^2 for each month according to each variable-combination in the regression equations. Variable-combinations: Z = elevation; ZX= elevation and easting; ZY = elevation and northing; ZYX = elevation, easting and northing. The values of R^2 are shown numerically where they are significant (at a = 0.05).

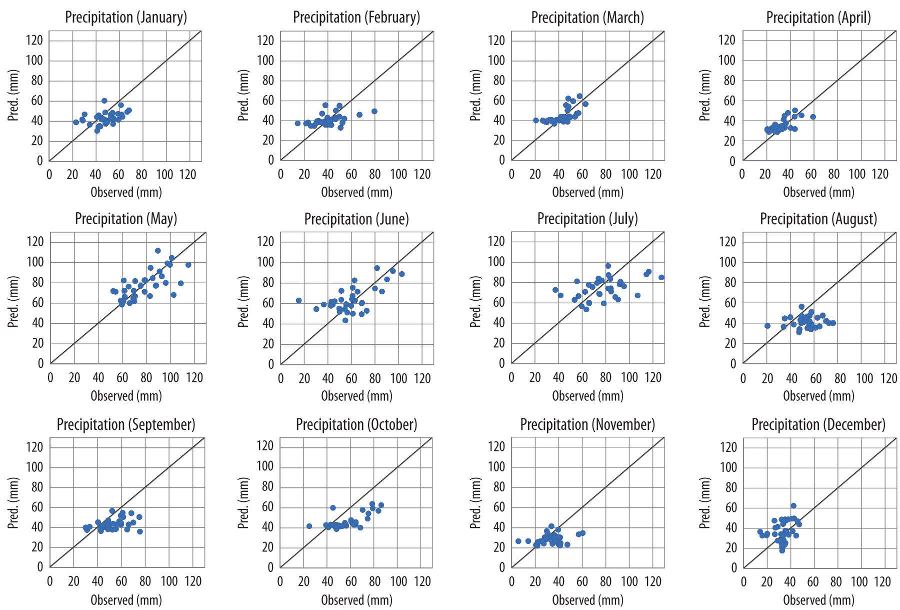


Fig. 4. Observed vs predicted (Pred) precipitation for each month using all independent variables for the North Hungarian Mountains (34 stations)

mountains are between -0.06 and +0.04 that indicates the lack of a clear relationship between precipitation and elevation. This might be due to the low topographical emergence of these mountains or the low density of station precipitation data.

As it can be seen in *Figure 5*, not only the strength but also the gradient of the precipitation-elevation relationship varies by month. In order to demonstrate the precipitation gradient by elevation, we hypothesized two fictional stations at the geometric centre of the study area, one at the lowest and one at the highest elevation of the given area. This way, the *x* and *y* coordinates do not influence the calculated precipitation values. The less steep the orange line in the diagrams of *Figure 5*, the higher the precipitation gradient by elevation is. Based on these diagrams, it is stated that the elevation influences precipitation more intensely in May, June, March and October, while the precipitation gradient is much smaller in the August, November, September and winter months.

Results of the combined interpolation method

The process is presented based on the example of the North Hungarian Mountains for the month of October *(Figure 6).* The process was run using 34 stations. October was chosen because this is one of the months with the highest correlation coefficients.

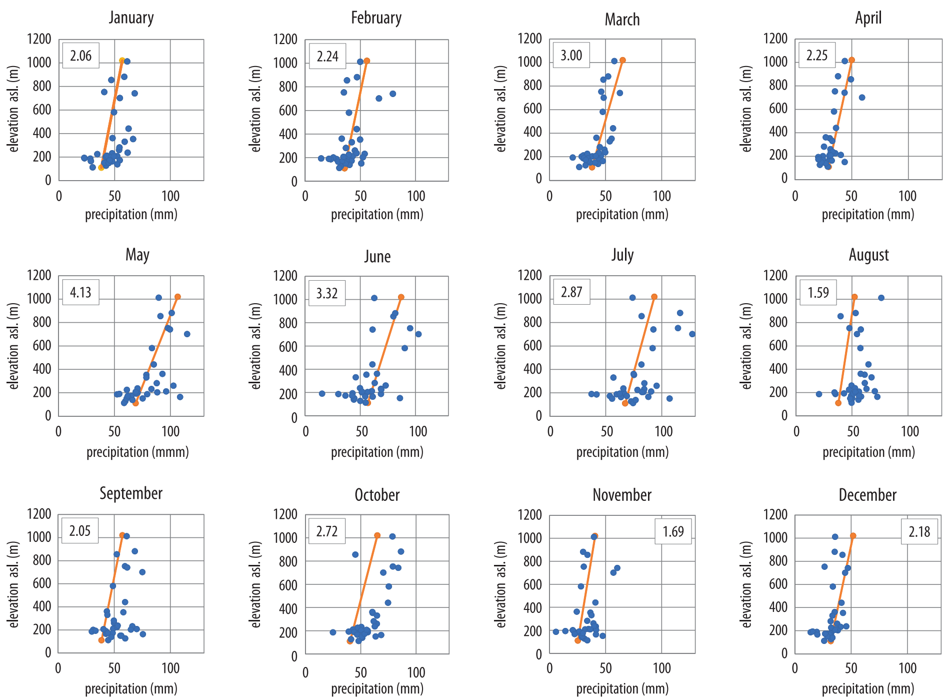


Fig. 5. Relationship between precipitation and elevation by month, in the North Hungarian Mountains study area. Measured precipitation values are marked with blue dots. Orange lines connect the values calculated for the highest and lowest elevation in the centre of the study area. The steepness of the line demonstrates how much the elevation influences the amount of precipitation. The more horizontal the line, the more influential the elevation is. The numbers in the boxes show the precipitation increment in mm by 100 metres of elevation difference. Although elevation is the independent variable, it is plotted on the Y- axis because it is vertical.

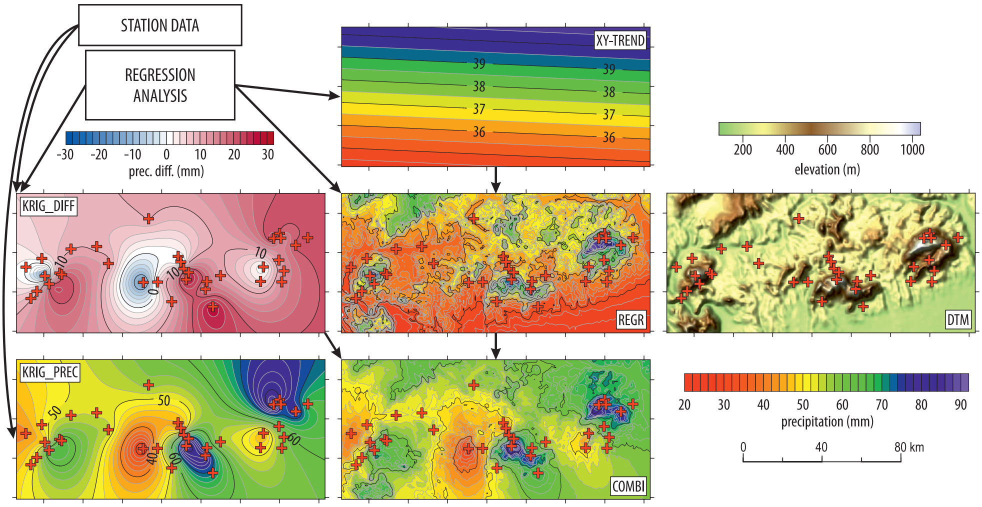


Fig. 6. Synthesized results of the combined method using data from October using kriging interpolation and applying the SRTM DTM of the North Hungarian Mountains. For further explanation see the text and *Figure 2*.

After performing the regression analysis, we calculated the difference map from the differences of the observed and predicted station data by using kriging interpolation (linear model, no anisotropy) first, and IDW (power 2, no smoothing) in the second turn (raster names are KRIG_DIFF, IDW_DIFF). Then a trend map (XY-TREND) was created using the regression coefficients of easting and northing. The trend surface shows us that the average precipitation increases in the direction of north-northeast. Thereafter, a regression-based map (REGR) was calculated using the SRTM digital elevation model (DTM) and the coefficient of *z*. At last, we added the difference map (KRIG_DIFF, IDW_DIFF) to the REGR map that resulted the combined map (CKRI, CIDW).

Comparison of the interpolation results

The comparison of the combined maps (CKRI, CIDW) and the maps resulted by kriging and IDW interpolations using the observed station data (KRIG_PREC, IDW_PREC) demonstrates that the combined process leads to rasters, which follow more closely the small topographic differences (see *Figure 6* bottom-left and bottom-centre image). Nevertheless, besides visual comparison, we carried out a statistical comparison of the results.

Precipitation data from 10 stations provided by the ÉMVIZIG were used for validation *(Figure 7)*. These measurements are independent of the previous datasets. Most of these stations are found in different settlements than the original stations, while some of them are in the same settlement, but at another location. The validation time interval was the same as the original, i.e. the period of 2011–2015. As *Figure 8* presents, the measured and predicted precipitation values strongly correlate for the combined kriging (CKRI) method, because the values of R^2 are above 0.9 for each month.

Thereafter, we used five different statistical parameters to compare the interpolation results *(Table 1)*. All parameters were calculated using the differences between the interpolation results and the observed values at the validation stations. The average shows if there is a systematic distortion between the

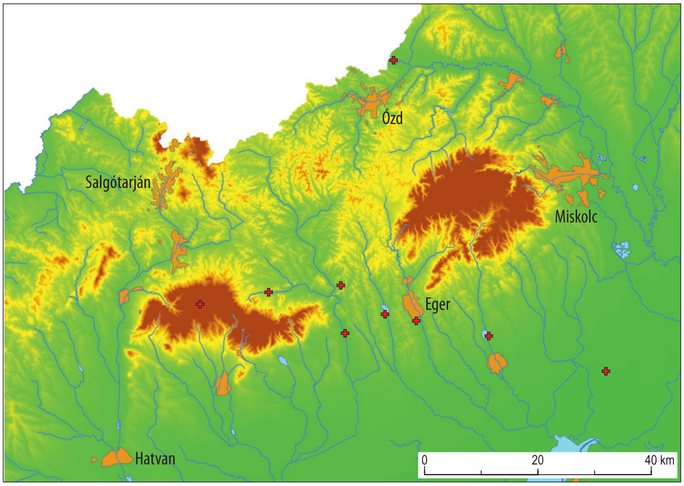


Fig. 7. Location of the meteorological stations (red crosses) used for comparison in the North Hungarian Mountains

observed and interpolated values. The minimum and maximum values present the largest negative or positive errors, finally, the standard deviation and the mean absolute error provide a general measure of how much the interpolated and observed values deviate from each other. For better visual comparison, the mean absolute error statistics are also shown in the diagram of *Figure 9*.

As we can see in *Table 1* and *Figure 9*, where the five interpolation methods are compared, the precipitation

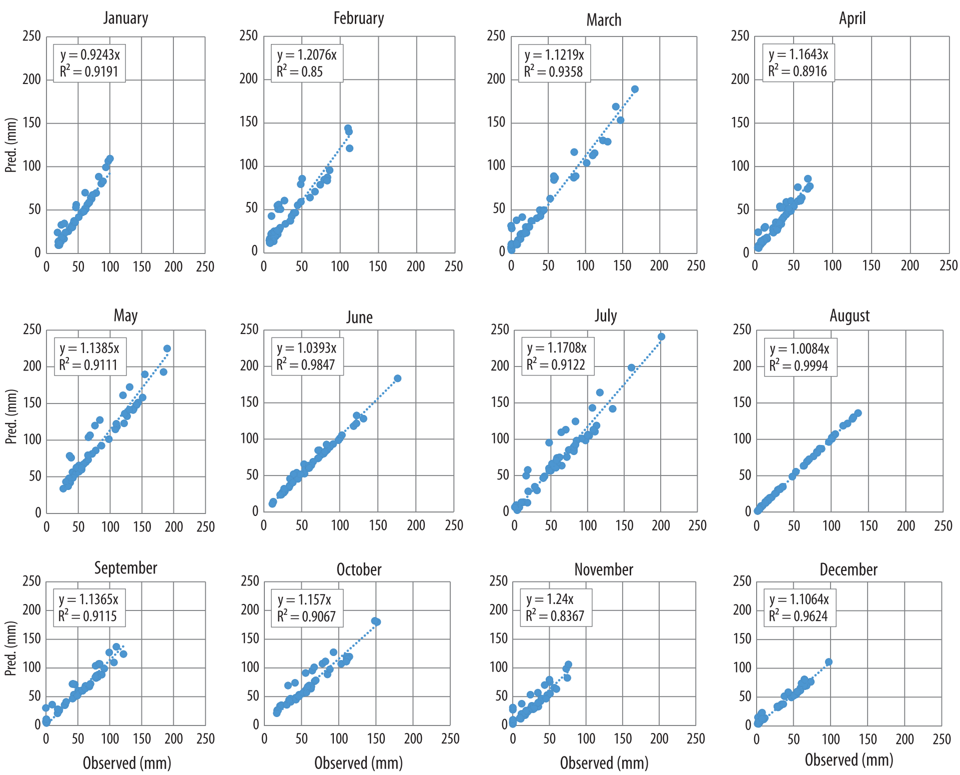


Fig. 8. Results of the validation using the combined kriging (CKRI) method. The observed data are from ÉMVIZIG, while the predicted value (Pred) is the result of our model.

Table 1. Statistics of the differences between the interpolated and observed monthly precipitation, mm*

Month	Average					Standard Deviation				
	CKRI	KRI	IDW	CIDW	COKR	CKRI	KRI	IDW	CIDW	COKR
January	12.06	12.82	14.91	12.17	-3.38	25.56	25.47	26.17	26.21	5.64
February	1.46	2.21	3.63	0.91	-1.95	7.94	8.08	6.76	7.00	5.64
March	0.64	1.27	3.46	0.78	-2.88	9.89	10.63	9.79	9.41	4.97
April	-0.76	-0.15	0.23	-2.04	-3.76	9.38	9.89	8.42	8.48	5.51
May	-4.31	-3.61	-0.73	-3.64	-5.77	20.30	19.75	16.31	17.19	10.62
June	-2.0	-1.51	-0.95	-5.16	-10.59	17.87	18.01	15.98	17.22	15.04
July	1.58	4.54	7.95	0.94	-6.68	19.83	20.73	19.54	17.30	19.43
August	-0.31	0.34	3.72	1.38	-0.62	12.60	12.74	13.52	13.46	9.46
September	1.53	2.29	2.34	-0.21	-3.17	10.54	10.58	7.27	7.83	6.08
October	0.33	1.15	2.74	-0.35	-6.72	9.91	11.20	9.61	9.24	8.64
November	2.97	3.49	4.04	2.06	-0.93	5.30	5.65	5.41	5.07	6.30
December	-5.17	-2.98	-1.75	-7.44	-6.42	12.59	9.81	9.43	12.72	22.80

*CKRI = combined kriging, KRI = kriging, IDW = inverse distance weighting, CIDW = combined IDW, COKR = co-kriging.

Table 1. Continued

Month	Minimum					Maximum					Mean Absolute Error				
	CKRI	KRI	IDW	CIDW	COKR	CKRI	KRI	IDW	CIDW	COKR	CKRI	KRI	IDW	CIDW	COKR
January	-54.14	-54.22	-55.97	-55.47	-18.64	74.49	73.87	72.78	75.83	15.13	19.74	20.09	21.06	19.67	5.10
February	-19.89	-19.77	-9.17	-11.72	-23.74	28.50	37.69	33.03	25.48	10.72	5.54	5.32	5.31	5.22	3.77
March	-36.72	-37.07	-26.48	-25.69	-16.60	33.63	30.78	36.24	34.70	9.28	5.82	6.17	6.66	5.87	3.81
April	-42.62	-42.27	-40.67	-43.14	-20.01	20.41	28.86	26.16	18.95	9.24	5.99	6.22	4.99	5.49	4.67
May	-69.89	-72.32	-66.96	-68.04	-33.61	31.90	35.09	33.89	34.19	26.51	14.80	13.49	11.44	12.44	8.91
June	-50.19	-52.26	-41.99	-46.05	-72.52	35.40	39.70	44.40	27.91	13.74	13.61	13.27	11.55	13.90	11.89
July	-35.28	-34.45	-27.14	-38.48	-77.79	64.76	70.70	62.14	33.98	65.59	15.44	16.01	15.94	14.21	12.89
August	-29.89	-29.41	-22.81	-29.89	-21.30	34.24	33.27	41.19	39.92	44.77	9.34	9.57	9.82	9.49	5.93
September	-26.57	-24.37	-14.77	-19.21	-23.77	33.70	34.17	19.24	16.42	18.91	6.98	7.18	5.82	6.08	4.78
October	-18.57	-20.23	-21.17	-20.41	-35.46	28.74	38.34	37.05	31.88	14.35	7.37	7.97	6.54	6.23	8.25
November	-9.95	-7.70	-6.47	-16.01	-27.18	16.28	18.83	17.03	14.93	15.40	4.47	4.67	5.08	3.89	4.11
December	-49.85	-33.30	-31.43	-46.25	-60.16	30.08	28.70	31.29	28.90	59.12	9.71	7.32	6.37	10.99	14.82

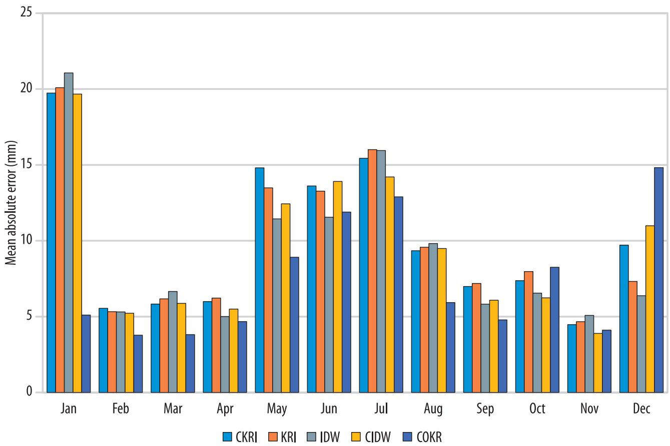


Fig. 9. Comparison of mean absolute error values for each month. CKRI = combined kriging; KRI = kriging; IDW = inverse distance weighting; CIDW = combined IDW; COKR = co-kriging

values of the combined interpolation methods perform slightly better than their original counterparts, but not for all months, and the differences are small. In addition, in slightly more cases, CIDW has less mean absolute error than CKRI. However, we experience that co-kriging provides the best estimates in most cases. Nonetheless, there are certain cases, when co-kriging results worse precipitation predictions than the other methods, namely in the months October, November (partly) and December. Further on, we found that all interpolators worked with relatively little error for February, March, April as well as for September, October and November.

Discussion and conclusions

Based on the above results, it can be stated that there is a linear relationship between the monthly sum of precipitation and elevation. The correlation coefficient of this relationship increases, if more observing meteorological stations and more spatial variables are taken into consideration. The values of the correlation coefficients were statistically significant for the whole study period only in case of the North Hungarian Mountains, where the correlation coefficient values varied from 0.3 to 0.5 for each month. These results are similar to the conclusions presented in the study of Sasaki, H. and Kurihara, K. (2008).

According to the results of our multivariate regression analysis, there are remarkable differences among seasons and also among months. The best correlation coefficients were observed in the period of late spring-early summer and October, while the weakest linear relationships were typical for the winter period and August. Roncz, B. (1982) also came to a similar conclusion that the values of correlation coefficients are higher in the period of spring and October. The orographic effect on precipitation is also stronger in these months in the North Hungarian Mountains. Our results demonstrate that one to four millimetres of precipitation increase can be noticed by every 100 metres of elevation increase for each month. This is again similar to the values of Roncz, B. (1982) referring to the Mátra Mountains. If the annual average of precipitation gradient by elevation is the question, then we get ca. 30-35 mm/100 metres of elevation change that is in agreement with the results of (Bartholy, J. and Pongrácz, R. (2013) and OMSZ (35 mm/100 m).

As *Figure 6* suggests, the advantage of the combined method over the simple interpolation of station data is the precipitation map, which follows more finely the topographic relief. However, differently to Goodale, C.L. *et al.* (1998) we came to the conclusion that in a regional scale the combined use of DTM and polynomial regression has only a neglectable advantage over the simple interpolations like kriging or IDW. On the other hand, co-kriging resulted significantly more precise precipitation predictions for most months, but not for all cases.

The reasons why there are only minor differences between the combined with topography and the standard interpolation methods are unclear at this stage. A more sophisticated distribution of base stations versus validation stations may help to answer this question in future research. Moreover, larger datasets may also contribute to improve interpolation methods and determine vertical gradients with higher precision. Anyway, if vertical precipitation coefficients are determined for a given region, then the combined with topography methods (and co-kriging as well) can help to calculate reliable precipitation rasters even if mountain station data is not available.

Acknowledgements**:** The research was funded by the National Research, Development and Innovation Office of Hungary (NKFIH) K124497 project. The authors thank G. Varga for his help in data acquisition.

REFERENCES

Alpert, P. 1986. Mesoscale indexing of the distribution of orographic precipitation over high mountains. *Journal of Climate and Applied Meteorology* 25. (4): 532–545.

Azimi-Zonooz, A., Krajewski, W.F., Bowles, D.S. and Seo, D.J. 1989. Spatial rainfall estimation by linear and non-linear co-kriging of radar-rainfall and raingage data. *Stochastic Hydrology and Hydraulics* 3. (1): 51–67.

Bartholy, J. and Pongrácz, R. (ed.) 2013. *Alkalmazott és városklimatológia* (Applied and urban climatology). Budapest, ELTE.

Basist, A., Bell, G.D. and Meentemeyer, V. 1994. Statistical relationships between topography and precipitation patterns. *Journal of Climate* 7. (9): 1305–1315.

Cambi, C., Valigi, D. and Di Matteo, L. 2010. Hydrogeological study of data-scarce limestone massifs: the case of Gualdo Tadino and Monte Cucco structures (Central Apennines, Italy). *Bollettino di Geofisica Teorica ed Applicata* 51. (4): 345–360.

Cortesi, N., González-Hidalgo, J.C., Brunetti, M. and Martin-Vide, J. 2012. Daily precipitation concentration across Europe 1971–2010. *Natural Hazards and Earth System Sciences* 12. (9): 2799–2810.

Crochet, P. 2009. Enhancing radar estimates of precipitation over complex terrain using information derived from an orographic precipitation model. *Journal of Hydrology* 377. (3–4): 417–433.

Daly, C., Taylor, G.H. and Gibson, W.P. 1997. The PRISM approach to mapping precipitation and temperature. In *Proceedings 10th AMS Conference on Applied Climatology*. American Meteorological Society, 20–23 October 1979. Reno, Nevada. Available at https://prism.oregonstate.edu/documents/pubs/1997appclim_PRISMapproach_daly.pdf

Duckstein, L., Fogel, M.M. and Thames, J.L. 1973. Elevation effects on rainfall: A stochastic model. *Journal of Hydrology* 18. (1): 21–35.

Goodale, C.L., Aber, J.D. and Ollinger, S.V. 1998. Mapping monthly precipitation, temperature, and solar radiation for Ireland with polynomial regression and a digital elevation model. *Climate Research* 10. (1): 35–49.

Goodwell, A.E. 2020. "It's raining bits": Patterns in directional precipitation persistence across the United States. *Journal of Hydrometeorology* 21. (12): 2907–2921.

Goudenhoofdt, E. and Delobbe, L. 2009. Evaluation of radar-gauge merging methods for quantitative precipitation estimates. *Hydrology and Earth System Sciences* 13. (2): 195–203.

Ha, K.J., Jeon, E.H. and Oh, H.M. 2007. Spatial and temporal characteristics of precipitation using an extensive network of ground gauge in the Korean Peninsula. *Atmospheric Research* 86. (3–4): 330–339.

Haiden, T. and Pistotnik, G. 2009. Intensity-dependent parameterization of elevation effects in precipitation analysis. *Advances in Geosciences* 20. 33–38.

Henry, A.J. 1919. Increase of Precipitation with Altitude. *Monthly Weather Review* 47. 33–41.

Józsa, E. and Fábián, Sz.Á. 2016. *Az SRTM-1 felszínmodell korrigálása Magyarországra* (Correction of terrain model SRTM-1 for Hungary). Természetföldrajzi Közlemények a Pécsi Tudományegyetem Földrajzi Intézetéből, Pécs, University of Pécs, 1–22. Doi 10.17799/2016.1.13.

Lauenroth, W.K., Burke, I.C. and Gutmann, M.P. 1999. The structure and function of ecosystems in the central North American grassland region. *Great Plains Research* 9. 223–259.

Ly, S., Charles, C. and Degre, A. 2011. Geostatistical interpolation of daily rainfall at catchment scale: the use of several variogram models in the Ourthe and Ambleve catchments, Belgium. *Hydrology and Earth System Sciences* 15. (7): 2259–2274.

Mair, A. and Fares, A. 2010. Comparison of rainfall interpolation methods in a mountainous region of a tropical island. *Journal of Hydrologic Engineering* 16. (4): 371–383.

Millett, B., Johnson, W.C. and Guntenspergen, G. 2009. Climate trends of the North American prairie pothole region 1906–2000. *Climatic Change* 93. (1): 243–267.

Noori, M.J., Hassan, H.H. and Mustafa, Y.T. 2014. Spatial estimation of rainfall distribution and its classification in Duhok governorate using GIS. *Journal of Water Resource and Protection* 6. (2): 75–75.

Rabus, B., Eineder, M., Roth, A. and Bamler, R. 2003. The shuttle radar topography mission – A new class of digital elevation models acquired by spaceborne radar. *ISPRS Journal of Photogrammetry and Remote Sensing* 57. (4): 241–262.

Rodriguez, E., Morris, C.S. and Belz, J.E. 2006. A global assessment of the SRTM performance. *Photogrammetric Engineering & Remote Sensing* 72. (3): 249–260.

Roncz, B. 1982. A csapadék magassági rendszere a Mátra hegységben (The altitude system of rainfall in the Mátra mountain range). *Acta Academiae Paedagogicae Agriensis.* Nova series, Tom. 16. 455–466.

Ruiz Sinoga, J.D., Garcia Marin, R., Martinez Murillo, J.F. and Gabarron Galeote, M.A. 2011. Precipitation dynamics in southern Spain: trends and cycles. *International Journal of Climatology* 31. (15): 2281–2289.

Sasaki, H. and Kurihara, K. 2008. Relationship between precipitation and elevation in the present climate reproduced by the non-hydrostatic regional climate model. *Scientific Online Letters on the Atmosphere* 4. 109–112.

Schwarb, M. 2000. *The Alpine precipitation climate: Evaluation of a high-resolution analysis scheme using comprehensive rain-gauge data*. Doctoral dissertation, Zurich, ETH.

Sinclair, S. and Pegram, G. 2005. Combining radar and rain gauge rainfall estimates using conditional merging. *Atmospheric Science Letters* 6. (1): 19–22.

Smith, C.D. 2008. The relationship between monthly precipitation and elevation in the Alberta foothills during the foothills orographic precipitation experiment. In *Cold Region Atmospheric and Hydrologic Studies. The Mackenzie GEWEX Experience.* Ed.: Woo, M., Berlin–Heidelberg, Springer, 167–185.

Spreen, W.C. 1947. A determination of the effect of topography upon precipitation. *Eos, Transactions American Geophysical Union* 28. (2): 285–290.

Szentimrey, T. and Bihari, Z. 2007. *Mathematical background of spatial interpolation, meteorological interpolation based on surface homogenized data bases (MISH).* COST Action 719. Budapest, COST Office, 17–27.

van Zyl, J.J. 2001. The shuttle radar topography mission (SRTM): A breakthrough in remote sensing of topography. *Acta Astronautica* 48. 559–565.

Velasco-Forero, C.A., Sempere-Torres, D., Cassiraga, E.F. and Gómez-Hernández, J.J. 2009. A non-parametric automatic blending methodology to estimate rainfall fields from rain gauge and radar data. *Advances in Water Resources* 32. (7): 986–1002.

Weisse, A.K. and Bois, P. 2001. Topographic effects on statistical characteristics of heavy rainfall and mapping in the French Alps. *Journal of Applied Meteorology* 40. (4): 720–740.

Mapping soil organic carbon under erosion processes using remote sensing

Azamat SULEYMANOV[1], Ilyusya GABBASOVA[1], Ruslan SULEYMANOV[1,2], Evgeny ABAKUMOV[3,4], Vyacheslav POLYAKOV[3] and Peter LIEBELT[5]

Abstract

This study aimed to map soil organic carbon under erosion processes on an arable field in the Republic of Bashkortostan (Russia). To estimate the spatial distribution of organic carbon in the Haplic Chernozem topsoil, we applied Sentinel-2A satellite data and the linear regression method. We used 13 satellite bands and 15 calculated spectral indices for regression modelling. A regression model with an average prediction level has been created (R^2 = 0.58, RMSE = 0.56, RPD = 1.61). Based on the regression model, cartographic materials for organic carbon content have been created. Water flows and erosion processes were determined using the calculated Flow Accumulation model. The relationship between organic carbon, biological activity, and erosion conditions is shown. The ^{13}C-NMR spectroscopy method was used to estimate the content and nature of humic substances of different soil samples. Based on the ^{13}C-NMR analysis, a correlation was established with the spectral reflectivity of eroded and non-eroded soils. It was revealed that the effect of soil organic carbon on spectral reflectivity depends not only on the quantity but also on the quality of humic substances and soil formation conditions.

Keywords: Soil organic carbon, remote sensing, sentinel, erosion, humic acids,13C-NMR

Received August 2020; Accepted February 2021

Introduction

Water erosion is one of the most dangerous processes due to the transformation of climatic conditions and anthropogenic impacts. Erosion of agricultural lands and subsequent fertility decline is one of the reasons for the abandonment of lands (Baude, M. *et al.* 2019; Suleymanov R. *et al.* 2020a). This is especially true for the southern regions of Russia, where degradation processes proceed at an accelerated pace (Kattsov, V.M. 2017). The Republic of Bashkortostan is located in the southern part of the Ural Mountains and characterized by actively occurring processes of water and wind erosion (Sobol, N.V. *et al.* 2015; Gabbasova, I.M. *et al.* 2016; Suleymanov, R. *et al.* 2019). The size of erosion rates can be judged by the following data: the land fund of the republic is 142,970 km^2, agricultural land occupies 73,430 km^2 (51.37%), 36,000 km^2 are erosion-hazardous (25.18%), 33,000 km^2 are exposed to water erosion (23.08%), wind erosion – 10,500 km^2 (7.35%), the joint action of water and wind erosion – 120 km^2 (0.08%) (Gabbasova, I.M. *et al.* 2016; Suleymanov, R. *et al.* 2020b).

[1] Laboratory of soil science, Ufa Institute of Biology, Ufa Federal Research Centre, Russian Academy of Sciences, 450054, pr. Oktyabrya 69, Ufa, Russia. Correspondent author's e-mail: filpip@yandex.ru

[2] Department of Geodesy, Cartography and Geographic Information Systems,, Bashkir State University, 450076, Zaki Validi 32, Ufa, Russia. E-mail: soils@mail.ru

[3] Faculty of Biology, Department of Applied Ecology, Saint Petersburg State University, 199034, 16th line of Vasilyevsky Island 29, Saint Petersburg, Russia. E-mail: e_abakumov@mail.ru

[4] Laboratory of Microbiological Monitoring and Bioremediation of Soils, All-Russia Insitute for Agricultural Microbiology, 196608, sh. Podbelsky 3, St. Petersburg, Russia

[5] Martin Luther University Halle-Wittenberg, 06120, Von-Seckendorff-Platz 4, Halle, Germany. E-mail: peter.liebelt@geo.uni-halle.de

Remote sensing (RS) is a useful tool in soil researches (Mulder, V.L. *et al.* 2011; Savin, I.Yu. *et al.* 2019). Multi- and hyperspectral images from unmanned aerial vehicles, aircraft, and space satellites are used for different scientific tasks. The active use of satellite data in last years is facilitated by improved spatial resolution, a large data set (multi-year image archives), a short interval, free access to satellite images (Sentinel, Landsat, and others) (Prudnikova, E.Yu. and Savin, I.Yu. 2015; Angelopoulou, T. *et al.* 2019). RS methods are more cost-effective and allow to cover large areas.

The integration of RS and GIS is a valuable tool for research, digital mapping, and modelling of erosion processes (Leh, M. *et al.* 2013; Guo, B. *et al.* 2018; Nampak, H. *et al.* 2018; Suleymanov, A.R. 2019; Yang, X. *et al.* 2020). Study soil erosion based on RS and GIS methods are currently being actively studied throughout the world (Desprats, J.F. *et al.* 2013; Wang, L. *et al.* 2013; Panagos, P. *et al.* 2015; Yermolaev, O.P. 2017; Golosov, V. *et al.* 2018; Frankl, A. *et al.* 2018; Sepuru, T.K. and Dube, T. 2018; Phinzi, K. and Ngetar, N.S. 2019; Magliulo, P. *et al.* 2020). Erosion processes are directly related to soil organic carbon (SOC) content. In a review article by Angelopoulou, T. *et al.* (2019), about evaluating SOC based on RS data, the authors conclude that recent advances in machine learning can help improve the overall accuracy and reliability of models. Thus, many studies confirm the successful use of satellite data in the study of transformation processes and automated mapping of SOC content (Mouazen, A.M. *et al.* 2007; Bartholomeus, H. *et al.* 2008; Dube, T. *et al.* 2018; Gholizadeh, A. *et al.* 2018; Bhunia, G.S. *et al.* 2019; Castaldi, F. *et al.* 2019; Chen, D. *et al.* 2019; Dou, X. *et al.* 2019; Vaudour, E. *et al.* 2019).

According to some studies (Ben-Dor, E. *et al.* 1997; Viscarra Rossel, R.A. *et al.* 2006b; Nocita, M. *et al.* 2015; Castaldi, F. *et al.* 2018, 2019), in order to model and predict the SOC content, recommended to use spectral characteristics located in the visible range at 450, 590, 664 nm, as well as the characteristics of the invisible range in the short-wave infrared SWIR range – between 1,600 and 1,900 nm and about 2,100 and 2,300 nm. At satellite Sentinel-2A, the bands of the visible spectrum B2, B3, B4 (490, 560, and 665 nm, respectively) and the invisible range in the SWIR region are B11 and B12 (1,610 and 2,190 nm, respectively). Thus, as Sentinel-2A has a close correspondence of the spectral characteristics, it allows the use of data for the estimation and modelling of SOC content in topsoil.

Soil colour is one of the key indicators for digital SOC mapping using RS (Mulder, V.L. *et al.* 2011). The qualitative and quantitative composition of humic acids in turn, affects the colour of the soil (Viscarra Rossel, R.A. *et al.* 2006a). Thus, humic substances are an indicator of the spectral reflectivity of the soil, with which a remote evaluation is possible. At the same time, soil organic matter (SOM) plays an important role in maintaining a good soil structure and directly affects the nature of erosion processes. SOM is responsible for the content of organic substances, nutrients, the activity of microorganisms, moisture retention.

Nuclear Magnetic Resonance (NMR) spectroscopy is a highly accurate physical and chemical tool for determining the composition and structure of soil organic matter (Quideau, S.A. *et al.* 2000; Chukov, S.N. *et al.* 2017, 2018; Polyakov, V. and Abakumov, E.V. 2020). The ^{13}C-NMR spectroscopy method allows to study the structural and compositional features of humic acid preparations of eroded soils, which will help to understand the ongoing processes of humification, degradation, and SOC transfer on eroded lands (Simpson, M.J. *et al.* 2008; Abakumov, E.V. *et al.* 2013; Rumpel, C. *et al.* 2014; Conte, P. *et al.* 2017).

Currently, in conditions of active anthropogenic impact, it is necessary to conduct local studies to understand the processes of transformation and degradation of SOC. Thus, our work aims to map SOC content, estimate and study transport processes on an eroded agricultural field, using Sentinel-2A satellite data, ^{13}C-NMR spectroscopy, and geomorphological methods. The developed methodology will allow us to simulate and evaluate the SOC content in the topsoil of agricultural land for monitoring and mapping.

Materials and methods

Site description

The study area is cropland (1,400 hectares) in long-term agricultural use located in the south of Russia, in the Zilair region of the Republic of Bashkortostan *(Figure 1).* The site is characterized by ploughing with a turnover of the soil layer at a depth of 10–15 cm. Wheat (*Triticum aestivum*) is predominantly growing on the plot. The cropland is located on gentle slopes of various exposures. According to geomorphometric analysis based on digital elevation model (DEM), the height of the study area varies from 460 m in the north-western part of the site to 377 m above sea level in the south-eastern part. The area mainly consists of slopes of up to 4°. The steepest sites are located in the southern, south-western, and northern parts of the site. The water erosion processes take place in the southern and northern parts of the territory. Wind erosion processes are also observed at the site.

The climate of the region is arid or slightly arid. The average annual air temperature is 1.4 °C, the average annual rainfall is 379 mm. According to the World Reference Base (WRB) for soil resources (IUSS Working Group WRB, 2014), the soil of the study site is characterized as Haplic Chernozems. The parent rocks are the eluvial-deluvial carbonate clays and heavy loams, as well as the eluvium of sandy schists.

Soil samples

The soil sampling work was carried out in October 2018 (49 full-profile sections and 5 pits). The soil samples were identified by satellite images to choose areas with different spectral reflectivity and erosion conditions. The exact coordinates of each soil point were identified using a global positioning system (GPS) with an accuracy of ±3 m. The crop has already been harvested at this time. Samples for the analysis SOC content were taken from

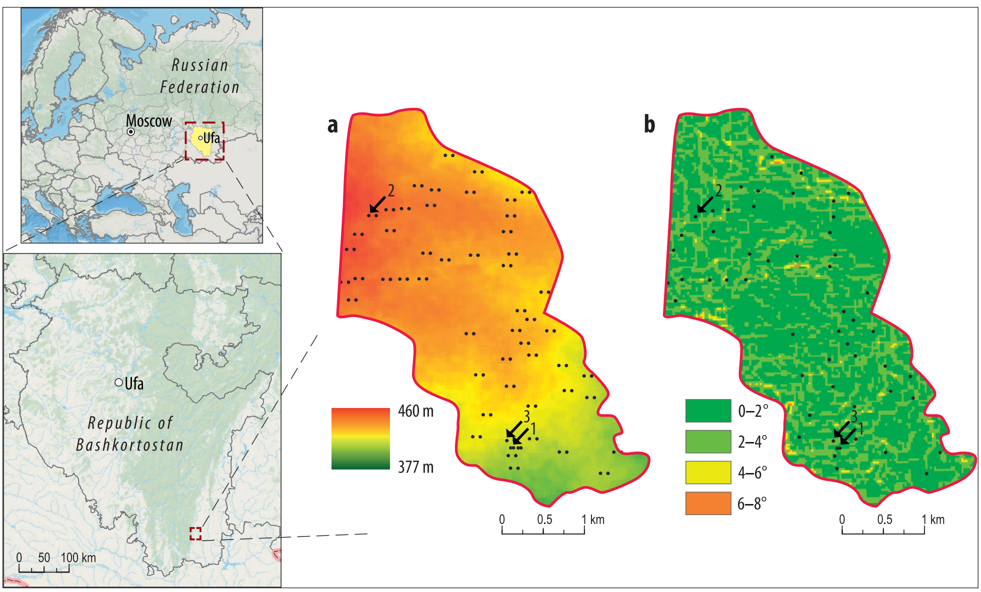


Fig. 1. Map of the study area (left) and spatial distribution of soil samples (n = 54). – a = elevation map in metres a.s.l.; b = slope map in degrees. Arrows and numbers (1–3) indicate samples for ^{13}C-NMR spectroscopy analysis.

the topsoil (0–10 cm). The carbon content was determined using the Tyurin method with colourimetric termination, according to Orlov and Grindel (Arinushkina, E.V. 1970; Sokolov, A.V. 1975). The microbiological activity of soils, the basal respiration, using incubation chambers was determined by standard protocol (Lal, R. *et al*. 2001). Soil basal respiration is defined as the steady rate of respiration in soil, which originates from the mineralization of organic matter.

Remote sensing data

The Sentinel-2 satellite free-access dataset (Level-2A processing) was used for the study. The satellite data contains 13 spectral bands with a spatial resolution of 10 to 60 m. *(Table 1).* The cloud-free scenes from 02.10.2018 were selected for the study. This scene time is selected for work with bare soil and reduce vegetation impact. Then images went through the stages of atmospheric and radiometric correction using the module "Semi-Automatic Classification Plugin" in QGIS 3.6.0.

For more complex analysis, the most popular spectral indices for predicting soil attributes have been selected. The following indices based on the combination of Sentinel-2A satellite bands were calculated: Normalized Difference Vegetation Index (NDVI), Transformed Vegetation Index (TVI), Enhanced Vegetation Index (EVI), Soil Adjusted Total Vegetation Index (SATVI), Soil-Adjusted Vegetation Index (SAVI), Moisture Stress Index (MSI), Green Normalized Difference Vegetation Index (GNDVI), Green-Red Vegetation Index (GRVI), Land Surface Water Index (LSWI), Modified Soil Adjusted Vegetation Index (MSAVI), the Second Modified Soil Adjusted Vegetation Index (MSAVI2), Brightness Index (BI), the Second Brightness Index (BI2), Redness Index (RI), Color Index (CI). The index formulae and descriptions are presented in *Table 2*.

Vegetation indices are important predictors and are actively used in the modelling and mapping of soil properties. For example, Bhunia, G.S. *et al.* (2019) successfully applied NDVI and BSI indices using a multivariate regression approach for SOC mapping. Gholizadeh, A. *et al.* (2018) showed that GNDVI and SATVI indices provided the strongest correlation with SOC on agricultural plots. Also, several studies conclude that vegetation indices are the most important variables in predicting soil properties (Gopp, N.V. *et al.* 2017; Chen, D. *et al.* 2019; Emadi, M. *et al.* 2020).

^{13}C-NMR spectroscopy

Soil samples for spectroscopy were selected according to the following parameters: a sample from a site of study area without water

Table 1. Sentinel-2A bands specifications

Band	Spectral range, nm	Spatial resolution, m	Spectral position, nm	Bandwidth, nm
B1	433–453	60	443	20
B2	458–523	10	490	65
B3	543–578	10	560	35
B4	650–680	10	665	30
B5	698–713	20	705	15
B6	733–748	20	740	15
B7	773–793	20	783	20
B8	785–900	10	842	115
B8a	855–875	20	865	20
B9	935–955	60	945	20
B10	1,360–1,390	60	1,380	30
B11	1,565–1,655	20	1,610	90
B12	2,100–2,280	20	2,190	180

Table 2. The calculated spectral indices

No.	Spectral index	Formula	Formula for Sentinel-2A	Details	References
1	NDVI	$\frac{NIR - R}{NIR + R}$	$\frac{B8 - B4}{B8 + B4}$	–	Rouse, J.W. Jr. *et al.* (1973)
2	GNDVI	$\frac{NIR - G}{NIR + G}$	$\frac{B8 - B3}{B8 + B3}$	–	Gitelson, A.A. *et al.* (1996)
3	EVI	$A\left(\frac{NIR - R}{NIR + C1 \cdot R - C2 \cdot B + L}\right)$	$2.5\left(\frac{B8 - B4}{B8 + 6 \cdot B4 - 7.5 \cdot B2 + 1}\right)$	A = 2.5 C1 = 6.0 C2 = 7.5 L = 1.0	Huete, A. *et al.* (2002)
4	CI	$\frac{R - G}{R + G}$	$\frac{B4 - B3}{B4 + B3}$	–	Pouget, M. *et al.* (1990)
5	BI	$\frac{\sqrt{(R \cdot R) + (G \cdot G)}}{2}$	$\frac{\sqrt{(B4 \cdot B4) + (B3 \cdot B3)}}{2}$	–	Escadafal, R. (1989)
6	BI2	$\frac{\sqrt{(R \cdot R) + (G \cdot G) + (NIR \cdot NIR)}}{3}$	$\frac{\sqrt{(B4 \cdot B4) + (B3 \cdot B3) + (B8 \cdot B8)}}{3}$	–	Escadafal, R. (1989)
7	TVI	$(\frac{NIR - R}{NIR + R} + 0.5)1/2 \cdot 100$	$(\frac{B8 - B4}{B8 + B4} + 0.5)1/2 \cdot 100$	–	Nellis, M.D. and Briggs, J.M. (1992)
8	SAVI	$\frac{(NIR - R) \cdot (1 + L)}{NIR - R + L}$	$\frac{(B8 - B4) \cdot (1 + L)}{B8 - B4 + L}$	L = 0.5	Huete, A.R. (1988)
9	SATVI	$\frac{SWIR1 - R}{SWIR1 + R + L} \cdot (1 + L) - SWIR2/2$	$\frac{B11 - B4}{B11 + B4 + L} \cdot (1 + L) - B12/2$	L = 1.0	Marsett, R.C. *et al.* (2006)
10	RI	$\frac{R \cdot R}{G \cdot G \cdot G}$	$\frac{B4 \cdot B4}{B3 \cdot B3 \cdot B3}$	–	Pouget, M. *et al.* (1990)
11	MSI	$\frac{SWIR1}{NIR}$	$\frac{B11}{B8}$	–	Rock, B.N. *et al.* (1985)
12	LSWI	$\frac{NIR - SWIR1}{NIR + SWIR1}$	$\frac{B8 - B11}{B8 + B11}$	–	Xiao, X. *et al.* (2004)
13	GRVI	$\frac{G - R}{G + R}$	$\frac{B3 - B4}{B3 + B4}$	–	Tucker, C.J. (1979)

Note: B, G, R, NIR, SWIR – reflection in blue, green, red, near infrared, short-wave infrared band, respectively.

erosion processes, with erosion processes and erosion sediment. Samples from the site without water erosion were taken at the top in the northern part of the site. Samples from the plot of erosion processes and sediment were taken at the southern part of the field (see *Figure 1*).

Humic acids (HAs) were extracted according to a published IHSS protocol (Swift, R.S. 1996). Solid-state CP/MAS ^{13}C-NMR spectra of HAs were obtained by Bruker Avance 500 NMR spectrometer. The repetition delay was 3 seconds. The number of scans was 6,500–29,000. Contact time is 0.2 μs.

Various molecular fragments were identified by CP/MAS $_{13}$C-NMR spectroscopy *(Table 3)*: carboxyl (–COOR); carbonyl (–C=O); CH_3–, CH_2–, CH–aliphatic; –C–OR alcohols, esters, and carbohydrates; phenolic (Ar–OH); quinone (Ar=O); aromatic (Ar–), which indicates the great complexity of the structure of HAs and the poly-functional properties that cause their active participation in soil processes (Lodygin, E.D. *et al.* 2014).

To standardize the quantitative characteristics of humic acid macromolecules, the following parameters were used: carbon ratio of aromatic structures to aliphatic structures, the decomposition rate of organic matter (C-Alkyl/ O-Alkyl), and humic acid hydrophobicity integral index (AL h,r + AR h,r, %).

Geomorphometric analysis

The geomorphometric analysis of the territory was carried out using the QGIS and SAGA GIS based on a digital elevation model (DEM) with a resolution of 30 m – NASA's Shuttle Radar Topography Mission (SRTM) (https://www2.jpl.nasa.gov/srtm). Maps of heights, slopes, and flow accumulation models were created. The Flow accumulation model determines the natural water direction for every pixel in a DEM. Flow accumulation operation calculates the total number of pixels that will drain into certain areas (Jenson, S.K. and Domingue, J.O. 1988).

Statistical analysis

Linear Least Squares Regression analysis was used to establish relationships between the values of satellite data and SOC content. A model was built separately for each band and index. Due to the limited number of soil samples available, a leave-one-out cross-validation procedure was applied (Khan, J. *et al.* 2010; Vaudour, E. *et al.* 2019). The advantage of leave-one-out is that each sample participates exactly once in control from all 'n' samples within the dataset. This procedure was repeated for all n samples (Gomez, C. *et al.* 2012).

Prediction accuracy was evaluated by the RMSE and the R^2 values. The model with the lowest RMSE and highest R^2 values was considered as the most applicable or ideal model (Jaber, S.M. *et al.* 2011). The R^2 was determined by the following classification (Vaudour, E. *et al.* 2019): models with $R^2 < 0.4$ show a poor or very low level of predictive ability; values of $0.5 < R^2 < 0.7$ indicate models with an average level of forecasting; models with $R^2 > 0.7$ are highly predictive.

The accuracy of the model was also determined by the classification, where RPD (re-

Table 3. Chemical shifts of atoms of the 13C molecular fragments of humic acids

Chemical shift, ppm	The type of molecular fragments
0–46	C, H-substituted aliphatic fragments
46–60	Methoxy and O, N-substituted aliphatic fragments
60–110	Aliphatic fragments doubly substituted by heteroatoms (including carbohydrate) and methine carbon of ethers and esters
110–160	C, H-substituted aromatic fragments; O, N-substituted aromatic fragments
160–185	Carboxyl groups, esters, amides, and their derivatives
185–200	Quinone groups; Groups of aldehydes and ketones

sidual prediction deviation) was calculated. RPD values < 1.0 indicate a poor predictive model; 1.0 < RPD < 1.4 indicate a weak model; 1.4 < RPD < 1.8 indicate a good model that can be used for evaluation; 1.8 < RPD < 2.0 indicate a good model; 2.0 < RPD < 2.5 show a very good model and values RPD > 2.5 indicate the excellent quality of the predictive model (Chang, C.-W. *et al.* 2001; Viscarra-Rossel, R.A. *et al.* 2006b).

The statistical analysis was performed using the "caret" package in R 4.0.3 (R Development Core Team, 2015) and RStudio (version 1.3.1093) (RStudio, 2015). The IDW and ordinary kriging interpolation maps were created using standard tools in QGIS.

Results and discussion

General statistics of soil properties: mean, minimum, maximum, standard deviation (SD), coefficient of variation (CV) are shown in *Table 4*. The values of SOC changed in the range from 1.93 to 5.52 per cent. The depth of the humic horizon is 20 to 70 cm, mean value – 46.32 cm. Spearman's correlation (R) between SOC content in the 0–10 cm layer and the topsoil is 0.59.

The regression analysis *(Figure 2)* showed that the maximum values of correlation coefficients R = 0.78, R^2 = 0.61 were detected at the invisible range B12 band (SWIR, the spatial resolution of 20 m and a spectral range of 2,190 nm). The SWIR band of Sentinel-2A for SOC mapping shows good results in other croplands studies. Thus, in the Gholizadeh, A. *et al.* (2018) study in the Czech Republic, the authors obtained the highest correlation values (R) of B4, B5, B11, and B12 bands. The correlation of the B12 band ranged from 0.29 to 0.69, depending on the field.

Table 4. Statistics description of Corg in the 0–10 cm layer and the depth of the humic horizon

Parameter	Corg, %	Depth of humic horizon, cm
n = 54		
Mean	3.72	46.32
Min	1.93	20,00
Max	5.52	70,00
SD	0.88	9.49
CV, %	23.65	20.49

The calculated spectral indices (see *Table 2*) showed less reliable correlation results (see *Figure 2*). The highest correlations were obtained using NDVI (R = 0.68, R^2 = 0.46), TVI (R = 0.67, R^2 = 0.45), and EVI (R = 0.60, R^2 = 0.36), which use bands of visible red and near-infrared range in their equations.

Attempting to diagnose the spatial distribution of the topsoil using bands and indices did not lead to reliable results. Since there is a correlation between the SOC content and the topsoil depth, the highest values in regression analysis are also shown by the B12 band (R = 0.51, R^2 = 0.26).

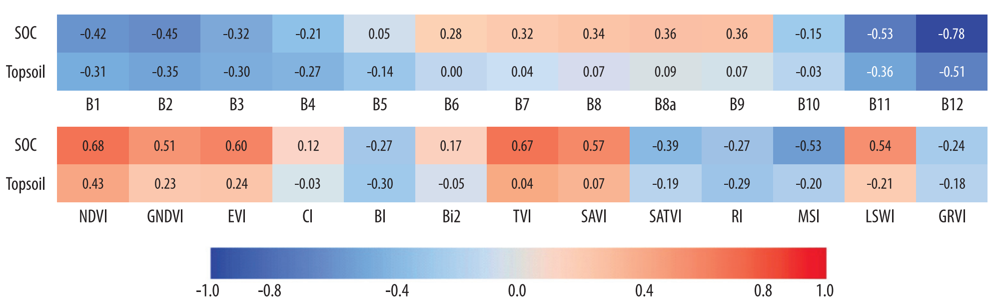


Fig. 2. The correlograms (Spearman correlation) of SOC and topsoil at bands of Sentinel-2A and calculated spectral indices. The correlation coefficients are significant at a level of 0.05.

The B12 band is the most appropriate variable for prediction SOC, according to RMSE and R^2 values *(Table 5)*. We obtained the model with RMSE = 0.56, RPD = 1.61, and R^2 = 0.58. According to the classification, this model characterizes as a good model with an average prediction level (Vaudour, E. *et al*. 2019). The RPD values in Gholizadeh, A. *et al.* (2018) were 1.60–1.92 depending on the territory; similar results using Sentinel-2 data were obtained by Vaudour, E. *et al.* (2019) on the study territory of France – 1.51. The RPD results of Castaldi, F. *et al.* (2019) were values 1.1–2.6 on the study areas in Germany, Belgium, and Luxembourg.

All other Sentinel bands and spectral indices are characterized by a very low level of predictive ability using a cross-validation procedure. However, the vegetation indices NDVI and TVI show values R^2 = 0.42. This approximation of the model to the average prediction level can be considered in future studies in similar areas and with a larger dataset.

The SOC content map based on the obtained regression equation was created using the B12 band of the satellite. Additionally, the SOC maps were created using the IDW and ordinary kriging methods to verify the spatial distribution based on the regression equation *(Figure 3).*

The comparative analysis of three models (regression analysis, IDW, ordinary kriging) showed that the largest areas with the highest SOC content (4.5–5.5%) are concentrated in the western, north-western, and northern parts of the investigated field. These areas are characterized by the highest elevation elements with slopes up to 4°. Based on regression analysis, we can also observe small areas with high SOC values in the north and central parts. The areas with the smallest SOC content are located in the south-east, north-east, and central parts of the cropland. These areas are mainly located at heights between ≈ 420 and 377 m. The areas of maximum topsoil values are located at the top of the plot in the western part and also small areas in the central part. Analysis of SOC and topsoil maps revealed a spatial correlation: areas with layer thicknesses of 50 to 70 cm are equivalent to areas of SOC content 3.5–5.5 per cent (see *Figure 3*).

The water flows have been identified using the Flow Accumulation model *(Figure 4).* The main powerful flows gather throughout the site, forming the main "arteries". The nature and direction of water flows are fully comparable with the nature of the territory relief: the main flows are concentrated in the centre of the site (direction from north-west to south-east), as well as in the northern and southern parts.

When verifying the Flow Accumulation model with field surveys, it was found that the strongest degradation processes occur in the southern part of the territory. This distribution is explained by the lowest part of the site and an increase in slope steepness (up to 6°). However, based on the analysis and maps obtained, the SOC content is not defined as homogeneous in the southern part of the area. The southern area is predominantly characterized by an average thickness surface horizon (up to 50 cm) and not high SOC content (1.5–3.5%). The study region (Trans-Ural steppe zone) is characterized by active wind erosion processes (Khaziev, F.Kh. 1995). Thus, we can observe small plots with high SOC content (3.5–5.5%) in areas closer to and along the road due to the accumulation of soil on the leeward side of these barriers (see *Figure 3*). Nevertheless, this distribution can also be

Table 5. Cross-validation performance statistics

Band	RMSE	R^2	Index	RMSE	R^2
B1	0.81	0.11	NDVI	0.66	0.42
B2	0.81	0.14	GNDVI	0.77	0.21
B3	0.86	0.04	EVI	0.72	0.31
B4	0.88	0.00	CI	0.89	0.04
B5	0.89	0.22	BI	0.87	0.02
B6	0.86	0.03	BI2	0.89	0.00
B7	0.85	0.05	TVI	0.66	0.42
B8	0.85	0.05	SAVI	0.74	0.26
B8a	0.84	0.07	SATVI	0.82	0.10
B9	0.85	0.06	RI	0.87	0.02
B10	0.89	0.02	MSI	0.76	0.23
B11	0.76	0.23	LSWI	0.76	0.24
B12	0.56	0.58	GRVI	0.87	0.00

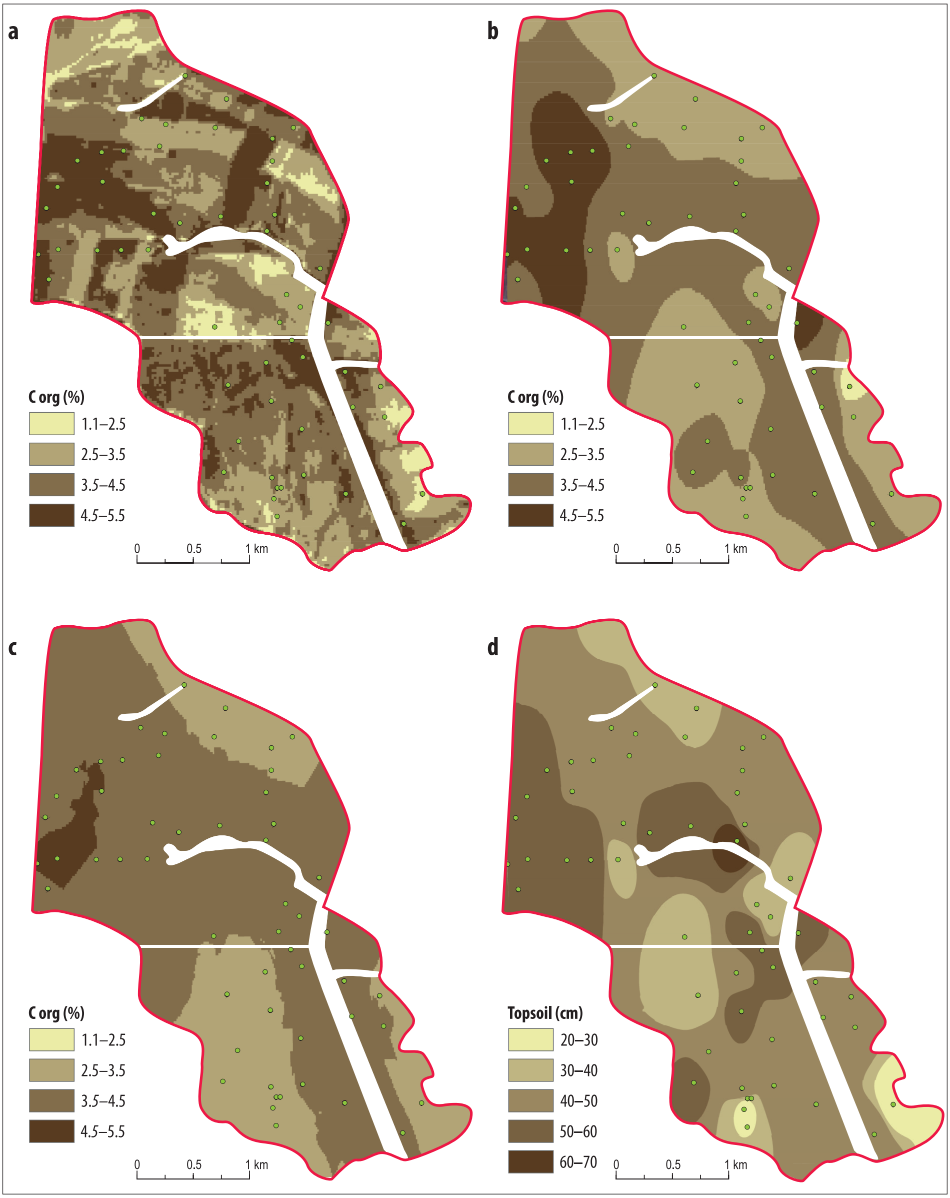


Fig. 3. The SOC content (0–10 cm) maps created using methods: a = Regression analysis based on satellite band B12; b = IDW; c = Ordinary kriging, and topsoil depth map using IDW method; d = Areas with vegetation and roads are masked by white colour.

caused by the influence of vegetation. We have masked areas with vegetation and roads, but the spatial resolution of the B12 band (20 m) can still account for this information.

The small areas of high SOC content (3.5% and more) are observed in the northern part, near the boundary of the field, which may well be consistent with the transfer of SOC

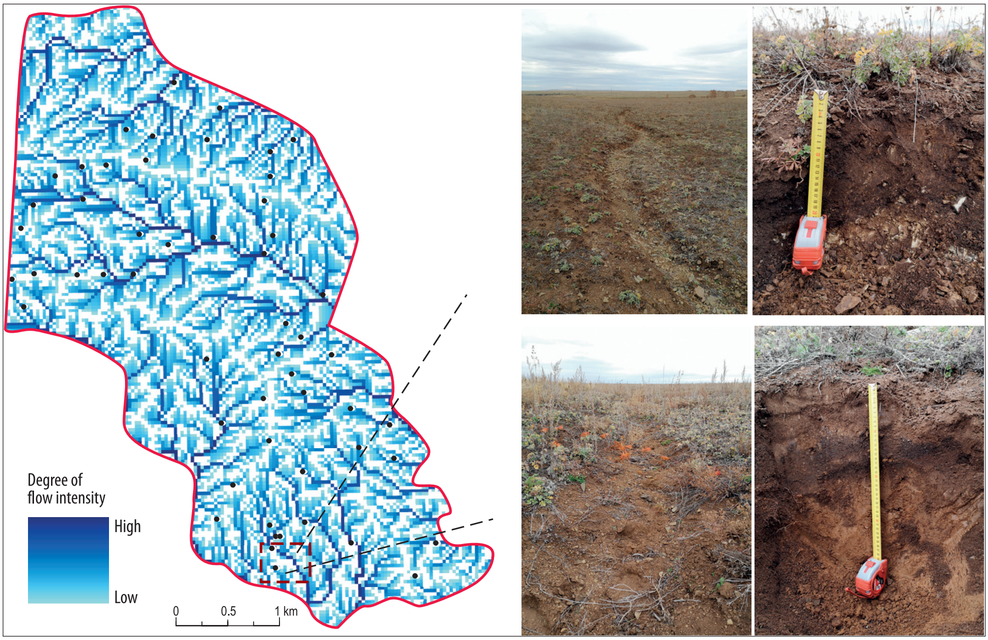


Fig. 4. Flow accumulation model map (left) and examples of rill erosion (right)

from the upper elements of the relief: this area is also characterized by lowering the relief and slopes up to 6–8°. Moreover, water erosion processes are actively occurring in this part of the field.

The lowest value of the microbiological activity of soils in the topsoil was detected in erosion sediment – 12.6 CO_2 g /100 g day^{-1}. Whereas in a non-erosive sample located a few meters from the erosion sediment, basal respiration is equal to 18.8 CO_2 g /100 g day^{-1}. The highest values are determined on the upper non-erosion elements of the terrain on average 25 CO_2 g /100 g day^{-1} (n = 7, SD = 5). Thus, the high microbiological activity is noted in not degradation process areas with the largest SOC content. The lower values of basal respiration are detected in an area vulnerable to erosion processes and the erosive sediment sample.

Verification of eroded and non-eroded soil samples of the south area of the field by ^{13}C-NMR spectroscopy revealed the following results *(Table 6)*. The sample No 1 (erosion sediment) is characterized by an increase in the aliphatic and oxygen-containing group compared to other samples; the ratio of AR/AL is 0.67. The erosion process led to a decrease in the aromaticity of HAs and the

*Table 6. Percentage of carbon in the main structural fragments of HAs from the studied surface soil horizons**

Sample	Chemical shifts, ppm						AR	AL	AR/AL	AL h,r + AR h,r, %	C,H – AL / O,N – AL
	0–46	46–60	60–110	110–160	160–185	185–200					
1	25	6	24	30	10	5	40	60	0.67	79	0.83
2	23	6	22	33	12	4	45	55	0.82	78	0.82
3	25	6	25	27	11	6	38	62	0.61	77	0.81

*According to 13C-NMR data. Note: AR = Aromatic fraction; AL = Aliphatic fraction; AL h,r + AR h,r = Hydrophobicity degree in per cent; C,H – AL/O, N – AL = The degree of decomposition of organic matter.

removal of stable soil carbon. The formation of aromatic components in the soil is a long-term thermodynamic process. We assume that under conditions of water erosion, the formation of long carbon chains (–C–C–) and oxygen-containing fragments (O–CH–) occurs. This distribution also occurs in waterlogging conditions (Lodygin, E.D. *et al.* 2001, 2014). Water flows prevent the processes of decomposition of plant residues in the soil due to erosion processes. It leads to the acceleration of the transformation processes.

The sample No 2, which is not affected by degradation processes, has more aromatic fragments in its composition than in the samples No 1 and 3. It is distinguished by the accumulation of aromatic and carboxylic fragments; the ratio of AR/AL is 0.82. The increase of these structures in the composition of HAs is associated with the transformation of humification precursors, especially lignin-containing plant residues. In the decomposition of plant residues, up to 30 per cent of lignin enters the soil, which during transformation is included in the composition of HAs in the form of aromatic structural units and carboxylic groups.

The eroded areas are characterized by a decrease in the aromaticity of SOC. There is the removal of dark-coloured materials of SOM and fine soil particles from such areas. They are characterized by less active processes of decomposition of plant residues and microbiological processes, and thus have lower HAs values and are visualized as lighter areas according to maps constructed by regression analysis and interpolation. Such areas of the field are also well identified according to the Flow Accumulation model, which determines the rate of water flow.

The sample No 3 is represented by a little clayey top of the area from which the sheet erosion started. According to NMR spectroscopy, more aliphatic fragments of HAs are formed here – AR/AL (0.61). Clay formations have a high heat capacity and moisture retention capacity (Abu-Hamdeh, N.H. 2003; Rozhkov, V.A. 2006). However, such formations are often quite dense aggregates in dry places. This soil structure affects the penetration and development of the root system, soil water and air movement, CO_2 emission, erosion, nutrient retention, and biological activity (Ciric, V. *et al.* 2012). Clayey particles capture nutrients from the environment well, but without sufficient moistening, they become inaccessible to the plants. We assume that moisture does not accumulate here, and there is no saturation of this area because of the location on top of the studied area. Thus, there is an oppression of the soil microbiota, which affects the lower degree of humification relative to the rest of the studied areas, which is confirmed in *Figure 5.*

From this diagram, we can observe the following distribution: sample No 1 (erosion sediment) has a higher degree of humification than sample No 2, which is not prone to erosion. Such a change of parameters is related to the dynamic re-deposition of small particles of soil. SOM binds well with the clay due to its large specific surface area of soil aggregates. Chemically bound organomineral compounds are removed from the soil profile under the influence of water erosion and accumulate in newly formed water flow areas. Prolonged hydration of such particles favourably affects the humification processes in soil and the formation of hydrophobic macromolecules. Thus, there is a thermodynamic selection of condensed HAs macromolecules and their stabilization.

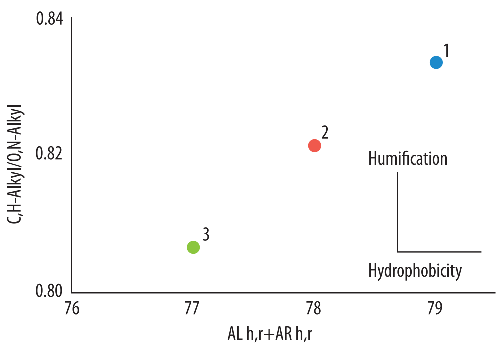


Fig. 5. The diagram of integrated indicators of the molecular composition of humic acids. AL h,r + AR h,r indicates the total number of un-oxidized carbon atoms.

Verifying the obtained results of NMR spectroscopy with remote sensing and geomorphometry data, it can be stated that non-eroded areas with high SOC content are characterized by darker colouration and intensive light absorption. This is due to the high decomposition of plant residues, microbiological activity, and a high degree of aromatic humic substances in our condition. Such areas are located on top of the site, as well as areas along roads, forest plantations, and in some low-lying areas of the terrain, where valuable soil structures are transferred through water and wind erosion.

The processes of rill water erosion are shown on space images mainly as darker and spots of SOC high values due to the re-deposition of the upper fertile fractions from the top relief elements. At the same time, the darker colouration of such areas is also affected by moistening, as such deep relief elements can retain wet soil for longer, which affects the spectral reflectivity of the soil. However, rill erosion zones do not always look like darker ones, as a movement of water flows, and repositioning of fractions is affected by micro-relief. Digital models with an ultra-high spatial resolution to identify micro-reliefs are needed.

Conclusions

To date, the method of application of RS and ^{13}C-NMR spectroscopy in the investigations and digital mapping of SOC is insufficiently studied. Based on the comprehensive study of the field in long-term agricultural use with ongoing erosion processes and slopes of up to 8 degrees, it can be concluded that:

1. Sentinel-2A data can be successfully used for mapping SOC content and their uncertainty in topsoil. In our study, the highest correlation values were shown by the SWIR B12 band with a spatial resolution of 20 m and a spectral range of 2,190 nm. The developed linear regression model has an average level of prediction. The maps created allowed us to estimate the spatial distribution of SOC content on the study plot.

2. Geomorphometric analysis of the territory allowed to define more precisely the relief character and directions of water flows that determine the development of erosion processes. We can conclude that in the erosion areas, due to the active movement of soil sediments by water flows, the territory is not homogeneous in SOC content. There is an active transfer of soil fractions, which forms areas of washing away and accumulation of soil sediments. In most cases, areas along forest plantations, roads, and low elevation elements are characterized by the accumulation of SOC transported by water and wind streams from the upper parts of the relief.

3. ^{13}C-NMR analysis has shown that the non-eroded areas have a developed humic acid structure due to the complete process of decomposition of vegetation and microbial activity. Together, this has a direct impact on soil colouration and thus determines the nature of the spectral reflectance of soils. Areas vulnerable to sheet erosion are characterized by reduced aromaticity of SOC. These areas define such areas as less dark on space images. Despite less developed processes of SOC formation in areas of rill erosion, these areas are characterized by a darker colour of soils due to the re-deposition of fertile fractions and moisture accumulation.

***Acknowledgements*:** The reported study was funded by RFBR according to the research project No 19-34-50082. The ^{13}C-NMR spectroscopy was performed in the Scientific Park of the St. Petersburg State University. Magnetic-resonance methods of investigations and elemental analyses were determined in Chemical Analysis and Materials Research Centre.

REFERENCES

Abakumov, E.V., Cajthaml, T., Brus, J. and Frouz, J. 2013. Humus accumulation, humification, and humic acid composition in soils of two post-mining chronosequences after coal mining. *Journal of Soils and Sediments* 13. (3): 491–500. Available at https://doi.org/10.1007/s11368-012-0579-9

Abu-Hamdeh, N.H. 2003.Thermal properties of soils as affected by density and water content. *Biosystems Engineering* 86. 97–102. Available at https://doi.org/10.1016/S1537-5110(03)00112-0

Angelopoulou, T., Tziolas, N., Balafoutis, A., Zalidis, G. and Bochtis, D. 2019. Remote sensing techniques for soil organic carbon estimation: A review. *Remote Sensing* 11. (6):676. Available at https://doi.org/10.3390/rs11060676

Arinushkina, E.V. 1970. *Soil Chemical Analysis Guide*. Moscow, Moscow State University. (in Russian)

Bartholomeus, H., Schaepman, M.E., Kooistra, L., Stevens, A., Hoogmoed, W.B. and Spaargaren, O.C. 2008. Spectral reflectance based indices for soil organic carbon quantification. *Geoderma* 145. (1–2): 28–36. Available at https://doi.org/10.1016/j.geoderma.2008.01.010

Baude, M., Meyer, B.C. and Schindewolf, M. 2019. Land use change in an agricultural landscape causing degradation of soil based ecosystem services. *Science of the Total Environment* 659. 1526–1536. Available at https://doi.org/10.1016/j.scitotenv.2018.12.455

Ben-Dor, E., Inbar, Y. and Chen, Y. 1997. The reflectance spectra of organic matter in the visible near-infrared and short wave infrared region (400–2500 nm) during a controlled decomposition process. *Remote Sensing of Environment* 61. (1): 1–15. Available at https://doi.org/10.1016/S0034-4257(96)00120-4

Bhunia, G.S., Shit, P.K. and Pourghasemi, H.R. 2019. Soil organic carbon mapping using remote sensing techniques and multivariate regression model. *Geocarto International* 34. (2): 215–226. Available at https://doi.org/10.1080/10106049.2017.1381179

Castaldi, F., Chabrillat, S., Chartin, C., Genot, V., Jones, A.R. and van Wesemael, B. 2018. Estimation of soil organic carbon in arable soil in Belgium and Luxembourg with the LUCAS topsoil database. *European Journal of Soil Science* 69. (4): 592–603. Available at https://doi.org/10.1111/ejss.12553

Castaldi, F., Hueni, A., Chabrillat, S., Ward, K., Buttafuoco, G., Bomans, B., Vreys, K., Brell, M. and van Wesemael, B. 2019. Evaluating the capability of the Sentinel 2 data for soil organic carbon prediction in croplands. *ISPRS Journal of Photogrammetry and Remote Sensing* 147. 267–282. Available at https://doi.org/10.1016/j.isprsjprs.2018.11.026

Chang, C.-W., Laird, D., Mausbach, M. and Hurburgh, C. 2001. Near-infrared reflectance spectroscopy – principal components regression analyses of soil properties. *Soil Science Society of America Journal* 65. (2): 480–490. Available at https://doi.org/10.2136/sssaj2001.652480x

Chen, D., Chang, N., Xiao, J., Zhou, Q. and Wu, W. 2019. Mapping dynamics of soil organic matter in croplands with MODIS data and machine learning algorithms. *Science of the Total Environment* 669. 844–855. Available at https://doi.org/10.1016/j.scitotenv.2019.03.151

Chukov, S.N., Ejarque, E. and Abakumov, E.V. 2017. Characterization of humic acids from tundra soils of northern Western Siberia by electron paramagnetic resonance spectroscopy. *Eurasian Soil Science* 50. (1): 30–33. Available at https://doi.org/10.1134/S1064229317010057

Chukov, S.N., Lodygin, E.D. and Abakumov, E.V. 2018. Application of 13C NMR spectroscopy to the study of soil organic matter: A review of publications. *Eurasian Soil Science* 51. (8): 889–900. Available at https://doi.org/10.1134/S1064229318080021

Ciric, V., Manojlovic, M., Nesic, Lj. and Belic, M. 2012. Soil dry aggregate size distribution: effects of soil type and land use. *Journal of Soil Science and Plant Nutrition* 12. (4): 689–703. Available at http://dx.doi.org/10.4067/S0718-95162012005000025

Conte, P., Di Stefano, C., Ferro, V., Laudicina, V.A. and Palazzolo, E. 2017. Assessing hydrological connectivity inside a soil by fast-field-cycling nuclear magnetic resonance relaxometry and its link to sediment delivery processes. *Environmental Earth Sciences* 76. (15):526. Available at https://doi.org/10.1007/s12665-017-6861-9

Desprats, J.F., Raclot, D., Rousseau, M., Cerdan, O., Garcin, M., Bissonnais, Y.L., Slimane, A.B., Fouche, J. and Monfort-Climent, D. 2013. Mapping linear erosion features using high and very high resolution satellite imagery. *Land Degradation & Development* 24. (1): 22–32. Available at https://doi.org/10.1002/ldr.1094

Dou, X., Wang, X., Liu, H., Zhang, X., Meng, L., Pan, Y., Yu, Z. and Cui, Y. 2019. Prediction of soil organic matter using multi-temporal satellite images in the Songnen Plain, China. *Geoderma* 356. 113896. Available at https://doi.org/10.1016/j.geoderma.2019.113896

Dube, T., Muchena, R., Masocha, M. and Shoko, C. 2018. Estimating soil organic and aboveground woody carbon stock in a protected dry Miombo ecosystem, Zimbabwe: Landsat 8 OLI data applications. *Physics and Chemistry of the Earth, Parts A/B/C* 105. 154–160. Available at https://doi.org/10.1016/j.pce.2018.03.007

Escadafal, R. 1989. Remote sensing of arid soil surface color with Landsat thematic mapper. *Advances in Space Research* 9. (1): 159–163. Available at https://doi.org/10.1016/0273-1177(89)90481-X

Emadi, M., Taghizadeh-Mehrjardi, R., Cherati, A., Danesh, M., Mosavi, A. and Scholten, T. 2020. Predicting and Mapping of Soil Organic Carbon Using Machine Learning Algorithms in Northern Iran. *Remote Sensing* 12. (14):2234. Available at https://doi.org/10.3390/rs12142234

Frankl, A., Prêtre, V., Nyssen, J. and Salvador, P.-G. 2018. The success of recent land management efforts to reduce soil erosion in northern France. *Geomorphology* 303. 84–93. Available at https://doi.org/10.1016/j.geomorph.2017.11.018

Gabbasova, I.M., Suleimanov, R.R., Khabirov, I.K., Komissarov, M.A., Fruehauf, M., Liebelt, P., Garipov, T.T., Sidorova, L.V. and Khaziev, F.Kh. 2016. Temporal changes of eroded soils depending on their agricultural use in the southern Cis-Ural region. *Eurasian Soil Science* 49. (10): 1204–1210. Available at https://doi.org/10.1134/S1064229316100070

Gholizadeh, A., Žižala, D., Saberioon, M. and Borůvka, L. 2018. Soil organic carbon and texture retrieving and mapping using proximal, airborne and Sentinel-2 spectral imaging. *Remote Sensing of Environment* 218. 89–103. Available at https://doi.org/10.1016/j.rse.2018.09.015

Gitelson, A.A., Kaufman, Y.J. and Merzlyak, M.N. 1996. Use of a green channel in remote sensing of global vegetation from EOS-MODIS. *Remote Sensing of Environment* 58. (3): 289–298. Available at https://doi.org/10.1016/S0034-4257(96)00072-7

Golosov, V., Yermolaev, O., Rysin, I., Vanmaercke, M., Medvedeva, R. and Zaytseva, M. 2018. Mapping and spatial-temporal assessment of gully density in the Middle Volga region, Russia. *Earth Surface Processes and Landforms* 43. (13): 2818–2834. Available at https://doi.org/10.1002/esp.4435

Gomez, C., Coulouma, G. and Lagacherie, P. 2012. Regional predictions of eight commonsoil properties and their spatial structures from hyperspectral Vis–NIR data. *Geoderma* 189–190. 176–185. Available at https://doi.org/10.1016/j.geoderma.2012.05.023

Gopp, N.V., Nechaeva, T.V., Savenkov, O.A., Smirnova, N.V. and Smirnov, V.V. 2017. Indicative capacity of NDVI in predictive mapping of the properties of plow horizons of soils on slopes in the south of Western Siberia. *Eurasian Soil Science* 50. 1332–1343. Available at https://doi.org/10.1134/S1064229317110060

Guo, B., Yang, G., Zhang, F., Han, F. and Liu, C. 2018. Dynamic monitoring of soil erosion in the upper Minjiang catchment using an improved soil loss equation based on remote sensing and geographic information system. *Land Degradation & Development* 29. (3): 521–533. Available at https://doi.org/10.1002/ldr.2882

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X. and Ferreira, L.G. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 39. (1): 195–213. Available at https://doi.org/10.1016/S0034-4257(02)00096-2

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment* 25. (3): 295–309. Available at https://doi.org/10.1016/0034-4257(88)90106-X.

IUSS Working Group WRB, 2014. World reference base for soil resources. In: *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*. World Soil Resources Reports No. 106. Rome, FAO.

Jaber, S.M., Lant, C.L. and Al-Qinna, M.I. 2011. Estimating spatial variations in soil organic carbon using satellite hyperspectral data and map algebra. *International Journal of Remote Sensing* 32. (18): 5077–5103. Available at https://doi.org/10.1080/01431161.2010.494637

Jenson, S.K. and Domingue, J.O. 1988. Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing* 54. (11): 1593–1600.

Kattsov, V.M. (ed.) 2017. *Report on Climate Risks in the Russian Federation.* Saint Petersburg, Saint Petersburg State University. (in Russian)

Khan, J., Aelst, S.V., and Zamar, R. 2010. Fast robust estimation of prediction error based on resampling. *Computational Statistics & Data Analysis* 54. 3121–3130. Available at https://doi.org/10.1016/j.csda.2010.01.031

Khaziev, F.Kh. (ed.) 1995. *Soils of Bashkortostan. Vol. 1. Ecologic-Genetic and Agro-productive Characterization.* Ufa, Gilem. (in Russian).

Lal, R., Kimble, J.M., Follet, R.F. and Stewart, B.A. (eds.) 2001. *Assessment Methods for Soil Carbon.* Boca Raton, FL, USA, Lewis Publishers.

Leh, M., Bajwa, S. and Chaubey, I. 2013. Impact of land use change on erosion risk: An integrated remote sensing, geographic information system and modelling methodology. *Land Degradation & Development* 24. (5): 409–421. Available at https://doi.org/10.1002/ldr.1137

Lodygin, E.D., Beznosikov, V.A. and Vanchikova, E.V. 2001. Functional groups of fulvic acids from gleyic peaty-podzolic soil. *Eurasian Soil Science* 34. (4): 382–386.

Lodygin, E.D., Beznosikov, V.A. and Vasilevich, R.S. 2014. Molecular composition of humic substances in tundra soils (13C-NMR spectroscopic study). *Eurasian Soil Science* 47. 400–406. Doi: 10.1134/S1064229314010074

Magliulo, P., Russo, F. and Lo Curzio, S. 2020. Detection of permanently eroded land surfaces through multi-temporal analysis of Landsat data: A case study from an agricultural area in southern Italy. *Environmental Earth Sciences* 79. (3): 73. Available at https://doi.org/10.1007/s12665-020-8814-y

Marsett, R.C., Qi, J., Heilman, P., Biedenbender, S.H., Watson, M.C., Amer, S., Weltz, M., Goodrich, D. and Marsett, R. 2006. Remote sensing for grassland management in the arid Southwest. In *Rangeland Ecology and Management* 59. (5): 530–540. Available at https://doi.org/10.2111/05-201R.1

Mouazen, A.M., Maleki, M.R., de Baerdemaeker, J. and Ramon, H. 2007. On-line measurement of some selected soil properties using a VIS–NIR sensor. *Soil and Tillage Research* 93. (1): 13–27. Available at https://doi.org/10.1016/j.still.2006.03.009

Mulder, V.L., de Bruin, S., Schaepman, M.E. and Mayr, T.R. 2011. The use of remote sensing in soil and terrain mapping – A review. *Geoderma* 162. (1):

1–19. Available at https://doi.org/10.1016/j.geoderma.2010.12.018

Nampak, H., Pradhan, B., Rizeei, H.M. and Park, H.-J. 2018. Assessment of land cover and land use change impact on soil loss in a tropical catchment by using multi-temporal SPOT-5 satellite images and Revised Universal Soil Loss Equation model. *Land Degradation & Development* 29. (10): 3440–3455. Available at https://doi.org/10.1002/ldr.3112

Nellis, M.D. and Briggs, J.M. 1992. Transformed vegetation index for measuring spatial variation in drought impacted biomass on Konza Prairie, Kansas. *Transactions of the Kansas Academy of Science* 95. (1–2): 93–99. Available at https://doi.org/10.2307/3628024

Nocita, M., Stevens, A., van Wesemael, B., Aitkenhead, M., Bachmann, M., Barthès, B., Ben Dor, E., Brown, D.J., Clairotte, M., Csorba, A., Dardenne, P., Demattê, J.A. M., Genot, V., Guerrero, C., Knadel, M., Montanarella, L., Noon, C., Ramirez-Lopez, L., Robertson, J., Sakai, H., Soriano-Disla, J.M., Shepherd, K.D., Stenberg, B., Towett, E.K., Vargas, R. and Wetterlind, J. 2015. Soil spectroscopy: An alternative to wet chemistry for soil monitoring. *Advances in Agronomy* 132. 139–159. Available at https://doi.org/10.1016/bs.agron.2015.02.002

Panagos, P., Borrelli, P. and Meusburger, K. 2015. A new European slope length and steepness factor (LS-Factor) for modelling soil erosion by water. *Geosciences* 5. (2): 117–126. Available at https://doi.org/10.3390/geosciences5020117

Phinzi, K. and Ngetar, N.S. 2019. The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. *International Soil and Water Conservation Research* 7. (1): 27–46. Available at https://doi.org/10.1016/j.iswcr.2018.12.002

Polyakov, V. and Abakumov, E.V. 2020. Humic acids isolated from selected soils from the Russian Arctic and Antarctic: Characterization by two-dimensional 1H-13C HETCOR and 13C CP/Mas NMR spectroscopy. *Geosciences* 10. (1): 15. Available at https://doi.org/10.3390/geosciences10010015

Pouget, M., Madeira, J., Le Floch, E. and Kamal, S. 1990. *Caracteristiques spectrales des surfaces sableuses de la region cotiere Nord-Ouest de l'Egypte: Application aux donandes satellitaires SPOT.* 2eme JoumCes de Tanddetection: Caracterisation et suivi des milieux terrestres en regions arides et tropicales. 4–6/12/1990. Collection Colloques et Seminaires, Paris, ORSTOM.

Prudnikova, E.Yu. and Savin, I.Yu. 2015. Satellite assessment of dehumification of arable soils in Saratov region. *Eurasian Soil Science* 48. (5): 533–539. Available at https://doi.org/10.1134/S1064229315050075

Quideau, S.A., Anderson, M.A., Graham, R.C., Chadwick, O.A. and Trumbore, S.E. 2000. Soil organic matter processes: Characterization by 13C NMR and 14C measurements. *Forest Ecology and Management* 138. (1): 19–27. Available at https://doi.org/10.1016/S0378-1127(00)00409-6

R Development Core Team, 2015. *R: A Language and Environment for Statistical Computing*. Vienna, R Foundation for Statistical Computing. Available at http://www.Rproject.org/.

Rock, B.N., Williams, D.L., and Vogelmann, J.E. 1985. *Field and airborne spectral characterization of suspected damage in red spruce (picea rubens) from Vermont*. NASA Technical Reports, ID 19860052270. Greenbelt, MD, USA. NASA Goddard Space Flight Center. Available at https://ntrs.nasa.gov/search.jsp?R=19860052270

Rouse, J.W. Jr., Haas, R.H., Schell, J.A. and Deering, D.W. 1974. *Monitoring vegetation systems in the Great Plains with ERTS.* NASA Special Publication 351. 309. Greenbelt, MD, USA. NASA Goddard Space Flight Center

Rozhkov, V.A. (ed.) 2006. *Soil Science*. Moscow, Nauka. (in Russian)

RStudio, 2015. *RStudio: Integrated Development Environment for R*. Boston, MA. USA, Available at http://www.r-studio.com

Rumpel, C., Chaplot, V., Ciais, P., Chabbi, A., Bouahom, B. and Valentin, C. 2014. Composition changes of eroded carbon at different spatial scales in a tropical watershed suggest enrichment of degraded material during transport. *Biogeosciences* 11. (12): 3299–3305. Available at https://doi.org/10.5194/bg-11-3299-2014

Savin, I.Yu., Zhogolev, A.V. and Prudnikova, E.Yu. 2019. Modern trends and problems of soil mapping. *Eurasian Soil Science* 52. (5): 471–480. Available at https://doi.org/10.1134/S1064229319050107

Sepuru, T.K. and Dube, T. 2018. An appraisal on the progress of remote sensing applications in soil erosion mapping and monitoring. *Remote Sensing Applications: Society and Environment* 9. 1–9. Available at https://doi.org/10.1016/j.rsase.2017.10.005

Simpson, M.J., Otto, A. and Feng, X. 2008. Comparison of solid-state Carbon-13 nuclear magnetic resonance and organic matter biomarkers for assessing soil organic matter degradation. *Soil Science Society of America Journal* 72. (1): 268–276. Available at https://doi.org/10.2136/sssaj2007.0045

Sobol, N.V., Gabbasova, I.M. and Komissarov, M.A. 2015. Impact of climate changes on erosion processes in Republic of Bashkortostan. *Arid Ecosystems* 5. (4): 216–221. Available at https://doi.org/10.1134/S2079096115040137

Sokolov, A.V. 1975. *Agrochemical Methods of Soil Studies.* Moscow, Nauka. (in Russian)

Suleymanov, A.R. 2019. Geomorphometric and geoinformation approach to meliorative evaluation of the territory. In *Climate Change Impacts on Hydrological Processes and Sediment Dynamics: Measurement,* *Modelling and Management*. Eds.: Chalov, S., Golosov, V., Li, R. and Tsyplenkov, A. Cham, Springer International Publishing, 72–75. Available at https://doi.org/10.1007/978-3-030-03646-1_14

Suleymanov, R., Saifullin, I., Komissarov, M., Gabbasova, I., Suleymanov, A. and Garipov, T. 2019. Effect of phosphogypsum and turkey litter on the erodibility of agrochernozems of the southern Cis-Ural (Russia) under artificial heavy rainfall. *Soil & Environment* 38. (1): 81–89. Available at https://doi.org/10.25252/SE/19/71730

Suleymanov, R., Zaykin, S., Suleymanov, A., Abakumov, E. and Kostecki, J. 2020a. Changes in basic soil physical properties of agrochernozyems under no-till conditions. *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi* 30. 963–972. Available at https://doi.org/10.29133/yyutbd.754479

Suleymanov, R., Yaparov, I., Saifullin, I., Vildanov, I., Shirokikh, P., Suleymanov, A., Komissarov, M., Liebelt, P., Nigmatullin, A. and Khamidullin, R. 2020b. The current state of abandoned lands in the northern forest-steppe zone at the Republic of Bashkortostan (Southern Ural, Russia). *Spanish Journal of Soil Science* 10. (1): 29–44. Available at https://doi.org/10.3232/SJSS.2020.V10.N1.03

Swift, R.S. 1996. Organic matter characterization. In *Methods of Soil Analysis, Part 3. Chemical Methods.* Eds.: Sparks, D.L., Page, A.L., Helmke, P.A. and Loepert, R.H., SSSA Book Series No 5., Madison, WI, USA, SSSA–ASA, 1011–1069. Available at https://doi.org/10.2136/sssabookser5.3.c35

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* 8. (2): 127–150. Available at https://doi.org/10.1016/0034-4257(79)90013-0

Vaudour, E., Gomez, C., Fouad, Y. and Lagacherie, P. 2019. Sentinel-2 image capacities to predict common topsoil properties of temperate and Mediterranean agroecosystems. *Remote Sensing of Environment* 223. 21–33. Available at https://doi.org/10.1016/j.rse.2019.01.006

Viscarra Rossel, R.A., Minasny, B., Roudier, P. and McBratney, A.B. 2006a. Colour space models for soil science. *Geoderma* 133. (3–4): 320–337.

Viscarra Rossel, R.A., Walvoort, D.J.J., McBratney, A.B., Janik, L.J. and Skjemstad, J.O. 2006b. Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma* 131. (1): 59–75. Available at https://doi.org/10.1016/j.geoderma.2005.03.007

Wang, L., Huang, J., Du, Y., Hu, Y. and Han, P. 2013. Dynamic assessment of soil erosion risk using Landsat TM and HJ satellite data in Danjiangkou Reservoir Area, China. *Remote Sensing* 5. (8): 3826–3848. Available at https://doi.org/10.3390/rs5083826

Xiao, X., Zhang, Q., Braswell, B., Urbanski, S., Boles, S., Wofsy, S., Moore, B. and Ojima, D. 2004. Modeling gross primary production of temperate deciduous broadleaf forest using satellite images and climate data. *Remote Sensing of Environment* 91. (2): 256–270. Available at https://doi.org/10.1016/j.rse.2004.03.010

Yang, X., Zhang, X., Lv, D., Yin, S., Zhang, M., Zhu, Q., Yu, Q. and Liu, B. 2020. Remote sensing estimation of the soil erosion cover-management factor for China's Loess Plateau. *Land Degradation & Development* 31. (11): 1–14. Available at https://doi.org/10.1002/ldr.3577

Yermolaev, O.P. 2017. Geoinformation mapping of soil erosion in the Middle Volga region. *Eurasian Soil Science* 50. (1): 118–131. Available at https://doi.org/10.1134/S1064229317010070

Diversity and local business structure in European urban contexts

Szabolcs FABULA[1], Rikke SKOVGAARD NIELSEN[2], Eduardo BARBERIS[3], Lajos BOROS[1], Anne HEDEGAARD WINTHER[2] and Zoltán KOVÁCS[4]

Abstract

This article investigates the interconnectedness between neighbourhood diversity and local business structures. For this purpose, interviews with residents and entrepreneurs were conducted in three European cities: Budapest, Copenhagen, and Milan. The results show that diversity in the economic structure of urban neighbourhoods is equally important with regards to residents' quality of life, the image of the neighbourhood, and local social cohesion. Therefore, the main recommendation is that policy makers should act to preserve the diversity of local business structures, and that the concept of diversity itself should be understood in a broader sense, taking local peculiarities into account.

Keywords: urban diversity, local entrepreneurship, neighbourhood services, business ecosystem, comparative analysis

Received January 2021, accepted March 2021.

Introduction

Contemporary cities are getting more diversified with regards the ethnic, cultural, and socio-economic composition of their residents (Vertovec, S. 2007; Schiller, M. 2016). The diversification of population has a profound impact on local business structure and the variety of services, vice versa, the diversification of businesses not only satisfies residents' demand but also attracts people with different socio-economic background, and influences people's socio-spatial practices and thereby diversity in general (Nicholls, W. and Uitermark, J. 2016; Van Gent, W. and Musterd, S. 2016).

In this study, the concept of hyper-diversity (Tasan-Kok, T. *et al.* 2013) is applied in the study of the interrelationship between diversifying business structures and the attitude of local entrepreneurs and residents at the neighbourhood level. Increasingly thematised in public discourse, hyper-diversity is defined in this study as the diversification of the population not only in socio-economic and ethnic terms but also regarding lifestyle, attitudes and activities (Ibid). The concept of hyper-diversity offers new insights into a better understanding of the increasing complexities of urban societal and economic processes, and it also serves as the basis of new instruments for formulating policy recommendations for local stakeholders (Tasan-Kok, T. *et al.* 2017).

This paper links two major strands of diversity research that recently appeared in

[1] Department of Economic and Social Geography, University of Szeged, Egyetem u. 2., H-6720 Szeged, Hungary. E-mails: fabula.szabolcs@geo.u-szeged.hu (corresponding author), borosl@geo.u-szeged.hu

[2] Department of the Built Environment, Aalborg University, A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark. E-mails: risn@build.aau.dk, ahw@build.aau.dk

[3] Department of Economy, Society, Politics; University of Urbino Carlo Bo, Via A. Saffi 42, Urbino, Italy. E-mail: eduardo.barberis@uniurb.it

[4] Department of Economic and Social Geography, University of Szeged, Egyetem u. 2. H-6720 Szeged, Hungary; and Research Centre for Astronomy and Earth Sciences, Geographical Institute, Budaörsi út 45. Budapest, Hungary. E-mail: zkovacs@geo.u-szeged.hu

the literature. On the one hand, it builds on recent findings regarding the economic impacts of diversity, focusing on how the diversification of local businesses shapes urban space (e.g., Hatziprokopiou, P. *et al.* 2016). In this regard, there is a common assumption in the literature that local enterprises and services are strongly linked to residents' everyday practices, and they actively shape perceptions of urban economy and diversity (e.g., Syrett, S. and Spulveda, L. 2011). The concept of hyper-diversity is also aimed to shed light on new dimensions of interconnection between diversity and local firms, moving beyond viewing diversity merely in relation to migration and ethnic background (Tasan-Kok, T. *et al.* 2013).

The other strand of academic discourse relevant to this study is related to international comparative research on diversity. Recent studies in the field have emphasised the role of emerging new forms and conditions of diversity as well as their policy implications in various urban contexts (Meissner, F. and Vertovec, S. 2015; Rath, J. and Swagerman, A. 2015; Raco, M. 2018). Since urban diversity is a dynamic phenomenon, the social composition of neighbourhoods and the everyday practices of residents can change quickly even within a relatively short period of time. However, policies often lag behind 'real world changes', and appropriate responses are hindered by the increasing fluidity and complexity of societal relations (Vertovec, S. 2009). In this study the analytical triad framework of Vertovec, S. (2009) is combined with the hyper-diversity concept which allows for a broader understanding of diversity, not limited by the conventional approach of solely focusing on migration background.

The main aim of this paper is to analyse the interconnectedness of neighbourhood diversity and local business structure in different urban contexts. For the sake of analysis, field research, including interviews with residents and entrepreneurs, was carried out in rapidly changing and highly diverse neighbourhoods in three European cities: Budapest, Copenhagen, and Milan.

The remaining part of the paper is divided into four sections. First, a literature review is presented in order to lay out the theoretical framework for the research, leading to the formulation of the main research questions. The subsequent section describes the research methods and the case study areas. This is followed by the analysis of the empirical research data. In the final section main research findings are discussed and their most important policy implications are highlighted.

Neighbourhood diversity and business ecosystems

The growing diversity of contemporary urban societies is the outcome of increasing migration, growing ethnic and cultural intermixing (Faist, T. 2009; Vertovec, S. 2010); emerging new identities (Valentine, G. 2013); accelerating social mobility and an increase in the complexity of the human resource pool (Syrett, S. and Spulveda, L. 2011, 2012); and also social segmentation resulting from varying access to consumption goods and assets (Jayne, M. 2006). Due to their increased heterogeneity, Vertovec, S. (2007) labelled urban societies as super-diverse, which is an especially fitting term in North American and Western European cities impacted by intense immigration in recent decades. The term super-diversity also refers to the fact that immigrant communities show high levels of heterogeneity in terms of their socio-demographic composition, religious affiliation, social status, and political views. In this study, we intend to go one step further by using the concept of hyper-diversity, according to which cities are getting more diverse not only in socio-economic and ethnic terms but also regarding the lifestyles, attitudes, and daily activities of their residents (Tasan-Kok, T. *et al.* 2013). The concept of hyper-diversity assumes that personal identities and social affiliations are marked by increased diversity due to significant variety in structures, paths, and trajectories of belonging. The policy relevance of hyper-diversity lies in the fact that 'traditional' social categories, like race or nationality, hinder effective policy-making and action, therefore the context-dependent characteristics of different neighbourhoods as well as hyper-diverse societal and economic formations should be taken into account (Raco, M. and Tasan-Kok, T. 2019).

Recent studies suggest that diversity has a positive impact on urban economies. Diverse urban societies have several resources that are favourable in terms of starting a business. A tolerant, ethnically and culturally diverse urban milieu also attracts creative people, who may eventually launch businesses of their own (Florida, R. 2002). In addition, attractive urban environments, available amenities, and versatile social networks can all be crucial factors in attracting and binding entrepreneurs to a city or a neighbourhood (Van Kempen, R. 2006). Ethnic diversity and the presence of long-established immigrant communities may also lead to higher enterprise density. In addition, by tapping into ethnic market niches and making use of social capital, immigrants are more likely to set up a business venture in diverse neighbourhoods (Kloosterman, R. and Rath, J. 2001), as demonstrated by research carried out in Amsterdam and Rotterdam (Kloosterman, R. and van der Leun, J.P. 1999), and in Antwerp and Izmir (Tasan-Kok, T. and Vranken, J. 2008; Eraydin, A. *et al.* 2010). Cross-cultural encounters between ethnic and immigrant communities can also result in a more thriving local business sphere, as was shown in a case study conducted on Walworth Road in London (Hall, S.M. 2011). In general, a more diverse population produces and distributes a wider range of information and creates a market for a broader range of goods and services, thereby inspiring an increased number of people to contribute to meeting market demand by setting up businesses of their own (Saxenian, A.L. 1999; Rodríguez-Pose, A. and Storper, M. 2006; Nathan, M. 2011; Barberis, E. and Solano, G. 2018).

By affecting the development of local enterprises, diversity also influences the range of services available in a neighbourhood. Greater diversity in the population, for instance, may result in the creation of new services (Leadbeater, C. 2008) by means of connecting and fusing dissimilar or disconnected markets, products, suppliers, and consumers. Emerging new products and new skills, in turn, may positively influence productivity, as Bellini, E. *et al.* (2008) demonstrated in their study using data of NUTS3 regions in 12 European countries. However, other studies suggest a different relationship between diversity and local services. Using the Census Bureau's Zip Code Business Pattern data for New York, Meltzer, R. and Schuetz, J. (2012), for example, found that neighbourhoods with higher shares of less affluent and minority residents have lower numbers of retail facilities and less diversity in retail supply than wealthier and predominantly white neighbourhoods.

Although it is widely accepted in the literature that there is a positive relationship between urban diversity and the range of available amenities and services at neighbourhood level, it is also acknowledged that conflicts can emerge in connection with access to such amenities and services. For example, variegated needs may lead to tensions over the provision of public services (Borck, R. 2007; Syrett, S. and Sepulveda, L. 2011). This is also well-demonstrated in neighbourhoods affected by urban regeneration where the relocation of traditional small businesses and the marginalisation of their clientele (mainly long-term, less affluent residents) are often observed (Zukin, S. *et al.* 2009). The commercial transformation of a neighbourhood may facilitate the marginalisation of less affluent residents, resulting in their physical and symbolic exclusion from the production of urban space (Talen, E. 2010; Shaw, S.J. 2011). However, particular configurations of social relations can create urban milieus in which diversity becomes a saleable asset without harming local communities (Zukin, S. and Kosta, E. 2004; Chan, W.F. 2005). All of these findings indicate the relevance of analysing power relations that permeate representations of diversity, otherness, and boundaries between more and less accepted forms of social difference.

Previous research suggests that there is a link between neighbourhood businesses and representations of diversity. Urban commercial spaces are settings for complex and conflict-ridden negotiations of social difference and diversity (Everts, J. 2010; Pastore, F. and Ponzo, I. 2016). For example, according to Piekut, A. and Valentine, G. (2017), encounters in different spaces affect the acceptance of diversity in different ways. On the one hand, encounters in spaces of socialisation and consumption have a favourable impact on attitudes towards ethnic and religious minorities. On the other hand, Camina, M.M. and Wood, M.J. (2009) point out that while retail facilities serve as the setting for a considerable proportion of daily encounters, the features of these places do not necessarily allow for close contact. Citing Gilroy, P. (2004), Jones, H. *et al.* (2015) argue that although globalized consumption spaces (e.g., plazas, franchised cafés) often bring together a multicultural mix of consumers, encounters in these spaces can be better understood in terms of the notion of 'civil inattention', given that the people there rarely want to establish closer contact with people from other social groups. To sum up, power relations are clearly at play in commercial service provision and consumption, in that, dominant social groups can exert control over the aesthetic representations, public images, and social utilisation of space, thereby exercising a kind of symbolic ownership which leads to the exclusion of alternative forms of diversity.

The complexity of the interconnectedness between diversity and services available to inhabitants is aptly described by Hiebert, D. *et al.* (2014) in their study on urban markets. First of all, markets bring together people with very different backgrounds, structuring the encounters between them. Secondly, markets reflect diversity in terms of the commercial and consumption activities of minorities, and they may shape social perceptions and stereotypes with respect to the groups concerned. Furthermore, such mental constructs influence the way difference and diversity are perceived and accepted, as there is a close connection between consumption and the social construction of diversity due to the fact that diversity and economic activities affect each other. Hiebert, D. *et al*. (2014) refer to Vertovec's (2009) analytical framework for diversity research and suggest that the complexities of social differentiation can be better understood if diversity is investigated in terms of three analytical domains: configurations, representations, encounters.

The structural–discursive–interactional conceptual triad conceptualised by Vertovec, S. (2009, 2010) consists of the following three elements:

(1) 'Configurations' refer to measurable aspects of diversity (e.g., the distribution of the population by age, sex, origin, etc.) and its political, legal, and economic contexts.

(2) 'Representations' show how diversity is conceived of by different groups in a society, including both dominant representations (e.g., official categorisations, models, policies) and demotic representations (e.g., everyday ideas, social narratives, folk art).

(3) 'Encounters' cover experiences in connection with diversity in everyday life through interpersonal and inter-group relations.

These three domains are distinguished from each other only for "methodological abstraction and analytical interrelation" (Vertovec, S. 2015, p. 15); otherwise they mutually affect each other. Furthermore, the domains are in a constant state of change, but each of them changes at a different pace, which results in a domain lag (Vertovec, S. 2009). This means that policy-making cannot always follow the dynamism of social practices, emerging societal constructs, and hybrid identities. Based on the literature, research questions addressed in this paper are as follows:

(1) What is the interrelationship between diversity and local business structure in urban neighbourhoods?

(2) In what ways does diversity impact the quality and spectrum of consumer services in urban neighbourhoods?

(3) How urban policy can facilitate concerted actions regarding neighbourhood diversity in order to boost local economies?

Research methods and case study areas

This study is based primarily on qualitative research methods. Between September 2014 and March 2015, a total of 150 in-depth interviews (50 in each case study area) were conducted with inhabitants of three European neighbourhoods: Józsefváros (Budapest), Bispebjerg (Copenhagen), and the north-eastern area of Milan (covering the district of Niguarda and the district of via Padova). Interviewees were asked about their local experiences, everyday activities, social networks, and relations to the neighbourhood. In addition, 120 interviews were conducted with entrepreneurs (40 in each case study area) between September 2015 and January 2016. The entrepreneurs were asked about their motivations for launching a business, the evolution and the current performance of their business, long-term plans, customers and suppliers, relationships with other entrepreneurs, and the importance of location and social diversity. In addition, relevant national, city-wide, and neighbourhood diversity-related policy documents were analysed.

The socio-economic profile of residents in the case study areas is shown by *Table 1*. Józsefváros is the 8th district of Budapest with about 76,000 inhabitants and is one of the most diverse areas of the city regarding its population, building stock, public spaces, and service provision. Traditionally, it has always been a lower-class district within Budapest, but recent urban renewal programs have changed the urban landscape resulting in the influx of younger and better off strata (Berényi, E.B. and Szabó, B. 2009; Nzimande, N.P. and Fabula, Sz. 2020). The district is also a popular destination for in-migrants from other parts of the country and more recently from abroad. Consequently, the proportion of non-Hungarian ethnic groups is much higher in Józsefváros than the Budapest average (11.9% and 7.8%, respectively, in 2011).

Bispebjerg is located North of the centre of Copenhagen and has approximately 55,000 inhabitants. It is a highly diverse area in terms of income level, education and occupation, household structure, and ethnicity, and also with regard to the lifestyles and living conditions of residents. Similar to Józsefváros, it has traditionally been a lower-class area, but its social composition has been changing recently due to urban renewal programs. However, the neighbourhood is still relatively deprived in comparison to the rest of Copenhagen. Its different parts are also very diverse, not only in terms of social and ethnic composition, but also regarding the activities of residents, the quality of services, and the built environment. In 2013, residents of non-Danish origin accounted for approx. 30 per cent of the local population, compared to approx. 11 per cent for the whole of Denmark.

The case study area in Milan *(Niguarda* and *via Padova)* has 73,000 residents and is one of the most diversified areas in the city in terms of population and household composition (with approx. 25% foreigners), age and income. This area has also undergone signifi-

Table 1. Main socio-demographic indicators of the case study areas

Indicators	Józsefváros (Budapest)	Bispebjerg (Copenhagen)	Via Padova–Niguarda (Milan)
Area, km^2	6.85	6.83	6.31
Total population, persons	76,446 (2018)	55,239 (2018)	73,876 (2017)
Average age of local population, years	40.70 (2011)	35.40 (2018)	45.70 (2017)
Residents holding foreign/multiple citizenship, %	11.90 (2011)	15.00 (2019)	24.60 (2017)
Unemployment rate, %	1.33 (2019)	3.90 (2017)	8.20 (2011)
Rate of social housing, %	10.00 (2017)	32.00 (2019)	5.60 (2011)**
Residents holding a degree, %	27.04 (2011)	43.20 (2018)	17.30 (2011)***
Average annual per capita income, EUR	Approx. 7,500 (2016)	Approx. 24,000 (2016)*	Approx. 24,000 (2017)****

*The lowest in Copenhagen. **Share of residential buildings owned by public institutions. ***Estimated data. ****Estimate based on the average officially declared taxable income at municipal level (EUR 30,737).

cant changes in recent decades, with migrant flows coming first from the surrounding countryside and northern Italy, then from southern Italy (Foot, J. 1997), and, in recent years, from outside Europe. Coupled with social mobility processes, the mix of old and newly built housing stock has created plural segments in terms of social class, age, ethnicity, and identity (Arrigoni, P. 2010).

Because of their limited number, the three neighbourhoods merely illustrate our arguments rather than allowing for rigorous comparison. However, the selection procedure applied in the study is far from random, as the case study areas represent various types of cities in Europe (Scandinavian welfare-state, post-communist, and Southern European), each with quite different points of departure to become a hyper-diverse city.

Relationship between urban diversity and local businesses – evidence from Budapest, Copenhagen, and Milan

The analytical part of the paper is based on Vertovec's (2009) conceptual triad. Accordingly, the following sections discuss configurations, representations, and encounters with respect to diversity in the three case study areas, with a focus on the connection between the experiences of residents and changes in local business structures.

Configurations

The diversity of the investigated neighbourhoods shows distinct similarities. First, their built environment and population exhibit 'mosaicity', and, due to historical legacies (i.e., the fact that they are traditionally blue-collar neighbourhoods), the share of smaller and lower-quality dwellings and less affluent households is still relatively high. Second, recent renewal activities have resulted in upmarket housing and attracted better-off residents. Third, in all three neighbourhoods, the share of the non-native population in the total population is higher than the city average. In the case study areas in Copenhagen and Milan there are sizeable immigrant communities, whereas in Józsefváros (Budapest), the share of Roma ethnic group is sizeable. It is also important to note that even though the case study areas have recently become targets of urban regeneration, nevertheless, housing prices remained lower in these neighbourhoods in the last few years compared to other parts of the cities. As a result, all three areas can be considered as entry-points where immigrants can find a niche in the housing and labour markets of the investigated cities.

I lived here for 7–8 years. My home was at the end of this street. Over the years, I witnessed the dynamic improvement of this neighbourhood (Palotanegyed). I saw Krúdy Street become a very popular part of the city during the last couple of years. Also, local hotels have attracted many tourists, which has resulted in higher purchasing power in the area. The price of residential properties here just keeps rising, while the proportion of well-to-do people is increasing. (Female, 37 years old, ethnic Hungarian, owner of a vegan bistro and gift shop, Budapest.)

The level of socio-spatial segregation did not reach extreme levels in the studied neighbourhoods in the past, but rather a social-mix prevailed due to the diversified local housing stock (palaces of the bourgeoisie, high-rise tenements, and low-rise housing etc.). However, recent regeneration programmes and concomitant societal changes have induced new segregation processes that shrink the opportunities of social interactions. At the same time, these processes have also created new opportunities for intercultural encounters. The relevance of hyper-diversity is especially evident in cases when similarities in lifestyle bring together residents with very different demographic, socio-economic, and ethnic backgrounds.

There is a Danish woman, she is like 100 per cent Danish, but we used to be able to communicate really well nonetheless. Nowadays, we're both very busy so we don't meet that much, but we used to talk about personal problems and things like that, since she's a single mum, too. (Female, 24 years old, student and single mother, with Iraqi background, living in social housing, Copenhagen.)

Increasing neighbourhood diversity in the case study areas manifests itself in the diversification of lifestyles, consumption practices, and local businesses as well. As regards the structure of these local businesses, the business types identified in the three cities do show some variation, but there are certain types that are common to all of them. First, in all three cities, there are a number of traditional small enterprises (e.g., artisan shops) with low profit rates, mostly owned by native locals, many of whom mirror the old working-class character of the case study areas. Second, ethno-businesses are also common in all three areas. Established by immigrants, most of these businesses offer low-innovation services, such as catering, retailing in convenience stores, or specialist retailing (e.g., selling Iranian carpets). Third, global chain stores as well as creative firms and technology-intensive firms are also present in the three neighbourhoods, with the latter type mostly managed by younger entrepreneurs who belong to the native population. In conclusion, the composition of the local business environment in the case study areas demonstrates how the societal transformation and diversification of these neighbourhoods may re-configure economic activities and local services.

The relevance of the hyper-diversity concept is also indicated by the variation between subgroups of local entrepreneurs which may be distinguished from each other in terms of their motives for starting a business as well as their clientele. Some of the interviewees chose entrepreneurship to engage in economic activities in line with their lifestyle preferences. This is what was done, for example, by single parents who want increased independence and flexibility in running their own business. Others launched businesses in response to changes in social composition in the case study areas, trying to satisfy new forms of consumer demand (e.g., demand for a vegan food store or a paleo pastry shop). Other notable subgroups include hobby entrepreneurs who transformed their free-time activities into a business (e.g., artists, craftsmen), social entrepreneurs, and family enterprises. It must be noted, however, that individual members of each subgroup may have very different social backgrounds (for instance, the category of family businesses is made up of both immigrants and natives). It follows that local economic activities point to the disappearance of boundaries between rigid societal categories as well as the growing significance of lifestyle, range of interests, and activities.

Diversification affects not only the composition of the population and the businesses in the neighbourhoods but also local power relations. Although the share of worse-off households is still relatively high in the case study areas, urban regeneration projects have triggered gentrification. Such processes often involve the expansion of transnational companies and fashionable specialty shops (i.e., 'boutiquing') along with the residualisation of economically less powerful, long-established businesses (Zukin, S. *et al.* 2009). It is quite common that businesses characterised by higher knowledge intensity perform better (e.g., in terms of revenues), while traditional small businesses that mainly serve the daily needs of local residents face much worse prospects. In most cases, the ethno-businesses present in the case study areas also belong to the less successful segment of local businesses. It follows that, with market competition intensifying and the retail landscape changing, older long-term residents are faced with the decision between shopping at small traditional shops and switching to impersonal supermarkets. It is also the case that some old stores are unable to pay rising rents and, thus, 'disappear' when their lease ends.

> These large shopping malls and chain stores can do what I am not allowed to: they can sell flowers and food, too. And they can buy flowers much cheaper than me. That's a horrible thing! For instance, let's just take Lidl stores. They buy flowers from the Netherlands directly from wholesalers, while my flowers go through a chain of dealers. (Female, 63 years old, owner of a flower shop, ethnic Hungarian, Budapest.)

It appears that the current diversity of local populations and businesses is likely to be temporary, with gentrification further transforming the landscape of services, resulting in greater homogeneity, and, in particular, a trend toward upscale homogeneity.

Representations

According to Vertovec, S. (2009), diversity has both demotic and dominant representations. While the former reflects society's everyday ideas about diversity, the latter mirrors the views of political interest groups and policymakers. In this study, interviewees confirmed that their neighbourhoods have a negative but steadily improving external image, which is also indicated by increasing property prices and the influx of skilled and better-off residents (Czirfusz, M. *et al.* 2015; Verga, P.L. and Vitrano, C. 2016; Smith, M.K. *et al.* 2018; Skovgaard Nielsen, R. and Hadegaard Winther, A. 2019).

> What is happening at the moment is that it's really difficult to find a home out here. What I see at the estate agent's is that prices are incredibly high. This way, eventually it'll only be high-income people who can afford to live here, and I think that would be such a shame. (Female, 38 years old, higher-level education, ethnic Danish, lives in an owner-occupied terraced house with husband and children, Copenhagen.)

According to opinions expressed by residents, the wide range of locally accessible services and amenities is one of the greatest assets of the case study areas. There is a plethora of various shops, providing many kinds of goods and services for a very diverse consumer base. Furthermore, diversity contributes to a vibrant urban milieu, making the case study areas livelier and more liveable within the wider context of the cities that they belong to.

Most of the interviewed residents and entrepreneurs have a positive attitude towards neighbourhood diversity. However, some negative opinions are also voiced. For instance, in Copenhagen, certain customer groups are reluctant to visit particular areas of the city because of neighbourhood diversity. Similarly, in Budapest and Milan, some entrepreneurs with unsuccessful businesses see diversity as a problem, and they attribute their lack of success to ethnic diversity in their neighbourhood (in particular, the presence of specific minority entrepreneur groups, e.g. those who run 'cheap Chinese shops'). This is especially the case in market niches where competition is fierce, and it is also common during periods of economic recession (e.g., the 2008 crisis). However, a number of entrepreneurs, in fact, directly benefit from the diverse image of the case study areas. For example, in Copenhagen, interviewees confirmed that diversity attracts customers to the neighbourhood in search of certain products; while in Budapest and Milan, diversity is a pull factor for social enterprises targeting specific disadvantaged groups, and it also serves as a source of inspiration for creative businesses and for the tourism industry.

> The idea arose while I was having breakfast close to a Chinese restaurant. Via Padova is so promising, and very, very unusual. (…) It is a source of inspiration for me. Even prosaic things can be inspiring, like seeing an Indian guy in his colourful clothes. (…) So this is just the perfect area! (Male, 40 years old, ethnic Italian background, running an Art Gallery, Milan.)

Regarding dominant representations in the three cities, the analysis of local governmental policies showed that (1) diversity is generally seen as a positive phenomenon, but its negative aspects (e.g., deprivation, poverty) are also widely acknowledged in policy discourses; (2) at the metropolitan level, diversity is handled in a more tolerant and pragmatic way than at the national level (Raco, M. 2018). Local policies are, indeed, relevant in dealing with diversity in all three case study areas, but they mostly influence planning and regulation issues. However, in terms of advancing broader socio-economic goals, policies at the metropolitan level and the national level are of more significance.

Out of the three cities, only Copenhagen has an explicit diversity policy, while in Budapest and Milan, diversity-related policy goals are less frequently formulated. Copenhagen has, in fact, declared diversity as a goal, thus, its local policies aim to support diverse types of needs and lifestyles in the city. Diversity is celebrated, and, as a diverse city, Copenhagen is regarded as a socially rewarding and dynamic place to live. In the Municipality of Copenhagen, *"A diverse city life is an important part of a socially sustainable city"* (Municipality of Copenhagen 2009). In addition, the fostering of diversity serves specific policy goals, namely, economic competitiveness and social cohesion. In order to increase economic competitiveness, policies aim to attract skilled labour, investors, and tourists, thereby facilitating opportunities for diverse encounters in consumption. Social cohesion, on the other hand, is expected to be strengthened by promoting intercultural dialogue, providing access to public services, and preventing segregation. However, it is also the case that deprivation and other negative aspects of diversity are often downplayed in favour of positive ones. In sum, the social democratic welfare system in Denmark, which is rooted in a universalistic perspective, traditionally supports collective consumption, for example, in education and health care. In this context, policy interventions related to diversity can lead to increased diversification both in terms of consumption practices and encounters amongst various social groups (Skovgaard Nielsen, R. *et al.* 2015).

In contrast to Copenhagen, in Budapest, and especially in Milan, political attitude towards diversity is selective and shows two main characteristics. On the one hand, both in Budapest and Milan, explicit and systematic engagements with diversity are quite rare at the metropolitan level, while conceptualisations of diversity are primarily shaped by neoliberal urban policies, which focus on cultural consumption and the attraction of economically 'desirable' social groups (e.g., creative classes of people, tourists). On the other hand, diversity is mainly considered a challenge or problem rather than an asset or resource, especially within the context of dealing with immigration and ethnicity. Correspondingly, the focus is on the mitigation of the negative impacts of diversity as they affect social cohesion, and also on combating social inequalities in general. Consequently, the main policy priority is the redistribution of resources rather than the cultural recognition of minorities and the fostering of interactions (Barberis, E. *et al.* 2017).

To sum up, diversity policies in the three cities show utilitarian traits, with the advantages of diversity mostly being defined in terms of competitiveness and economic gains (e.g., with respect to attracting a creative labour force or tourists). However, the diversity of local businesses and the blurring of boundaries between entrepreneur types are rarely taken into account. All things considered, Copenhagen seems to be the most pro-diversity city. It is also important to note, however, that the effects of some policies – or the effects of the lack of policies – may be conflicting. For instance, neighbourhood regeneration leads to increasing diversity, but beyond a certain point, this process may result in the gentrification and homogenisation of the local population and businesses.

Encounters

Neighbourhood businesses create spaces that facilitate interactions within and across groups of entrepreneurs and groups of consumers. To investigate interactions among entrepreneurs, the supplier connections of the business persons interviewed as part of the study were scrutinised during the interviews. The analysis shows that, in general, intra-neighbourhood supplier connections are rare in the three case study areas; which indicates that the relevance of other factors outweighs the role of neighbourhood connectedness in this respect. First, businesses seem to require a higher degree of physical proximity (for instance, a location in the same building or shared outdoor facilities) in order to form networks. Second, similarity regarding the fields of business activities or the professional background of entrepreneurs appears to be a prerequisite to building comprehensive networks. For example, in Milan, ethnic caterers usually call attention to the fact that their suppliers and raw materials are Italian as a way of guaranteeing quality and to gain the trust of a diverse customer base.

> I don't use Chinese stuff, just Italian ones. All our products are from a professional Italian brand. (Male, 46 years old, Egyptian background, Barber's, Milan.)

As demonstrated, professional networks may cut across boundaries between neighbourhoods as well as between ethnic and other social groups, resulting in intercultural encounters and also in improved social capital for entrepreneurs to utilise.

However, interethnic cooperation can be hindered by perceived cultural distance and stereotypes. Derogatory classifications and stereotypes are (re-)produced among migrant groups, too, and they can produce segmentation in terms of the geographies of collaboration. Cultural and social distance among migrants, which is quite visible in group-making at local level (Pastore, F. and Ponzo, I. 2016), can trickle down and take new shapes in the business collaboration-competition processes.

> I don't like their manners so much. For example, Arabs are too unreserved, and they touch you with their hands. I don't like that. Also, they are easily offended, and they are aggressive. And the Chinese, well, they have a totally different mind-set. On the other hand, I have good relations with Indians. They supply me with spirits, and we also exchange favours. (Male, 23 years old, Ecuadorean, Latino restaurant, Milan.)

The above observations indicate that urban policies aiming to maximise benefits from diversity should promote cooperation between entrepreneurs from different backgrounds and also aim to create appropriate spaces for interaction between such business persons.

Interactions between entrepreneurs and customers depend on the activities and local embeddedness of the businesses. Large or highly specialised companies rarely rely on a clientele from the local area. In fact, the location of such businesses is virtually irrelevant to some of them because they primarily trade on the internet, work in wholesale, or cater to larger companies or public institutions located across the country or abroad (which is especially true for businesses engaged, for example, in the field of construction, property development, and environmental services). As for mainstream businesses, they usually have a very diverse range of clients (and not necessarily just intra-neighbourhood clients). This is also the case for several ethnic shops.

> I have a very mixed customer base, from Italians to South Americans, from Arabs to Syrians – I even have Filipino customers. I don't know of any ethnicity that's missing here, since I also get people from black Africa and – thanks to the Expo – also European groups, like Germans and Dutch people. (…) We are a multicultural business, we have different foods, and we are able to satisfy everyone's preferences. Romanians come because they always find something they like, and this is true for Africans and Italians, too, since we serve international cuisine. (Male, Italian, Egyptian origins, Kebab shop, Milan.)

In consumer–consumer interactions, it is important to note that locally-embedded businesses provide goods and services to a very diverse and mainly neighbourhood-based clientele, tailoring their supply to the lifestyles, tastes, and consumer power of their customers.

> Well, the regulars often buy themselves a beer and then get the newspaper from over there, and then they come back here to read it and drink their beer. And they're definitely locals. (…) You know, many of the locals in this area live alone. They have very small flats, and the others here at the pub are their friends in a way. They basically come down here to chat with them. You know, just being with other people is something they can't do at home. (Owner of traditional Danish-style pub run by her family for 40 years, Copenhagen.)

It should be noted, however, that neighbourhood revitalisation and the concomitant restructuring of the local business landscape also shape interactions between residents (see also e.g., Boros, L. *et al.* 2016). This process evokes ambivalent feelings: on the one hand, people are happy to get new products and services; on the other hand, long-established residents are concerned about the disappearance of 'traditional, good old places'. In this regard, narratives such as 'there is too much diversity in the neighbourhood' can be observed in the interviews, along with negative sentiments towards 'new, other' lifestyles.

> I think too many foreign shops have opened, and the others seem to be disappearing. I feel that the area is becoming too dominated by these foreign shops. I think a mix would have been better than dominance. (Female, 64 years old, on early retirement, ethnic Danish background, social housing, Copenhagen.)

Clearly, neighbourhood transformation and diversification is a conflict-ridden process. Although commercial spaces, such as retail facilities, do create encounters between residents and also across some social groups, they often entail the exclusion of others. Moreover, some residents are, in fact, repelled by certain places, and they have a negative opinion of diversity. Correspondingly, otherness and ethnic boundaries are often reconfigured in conflicts over 'out-of-place' businesses, sometimes even leading to the political mobilisation of residents.

> Well, small shops are closing down one after the other, and they are being replaced by these internet cafés. But one of those has already closed down, too, thanks God. It was here for quite a long time, actually, but in the end there was enough pressure from local residents to make it possible to shut down the place. (…) These internet cafés attract people who you don't want to see (in your neighbourhood). (Female, 66 years old, old-age pensioner, ethnic Hungarian, Budapest.)

Despite negative sentiments, public spaces, bars and restaurants, general stores, and local markets bring together people with similar lifestyles and consumption habits in everyday situations, creating space for interactions across societal boundaries and contributing to a better understanding of 'other' people (Curley, A.M. 2010). This can influence the perception of diversity positively, and it can also reduce prejudices (Blokland, T. and van Eijk, G. 2010; Peters, K. and De Haan, H. 2011). Several interviewees said that their neighbourhoods are like small villages in the texture of the city, where almost everybody knows everybody else. The daily activities of these people are partly framed by local shops and similar facilities, thus, such spaces can bolster community identity.

> This neighbourhood is attractive for a special reason. The lifestyle of local families and residents is similar to that of people living in villages. Most of the people here are in daily contact with each other. We often meet at the market as well as local shops. The renovation of Teleki Square was completed a few months ago, and now we have several new community places where people can meet and get together in their free time. (Female, 63 years old, old-age pensioner, Hungarian, Budapest.)

Interactions between residents may even evolve into long-term relationships, thereby strengthening neighbourhood social capital.

> I used to know a lot of people from the shop, and I would help everyone who asked me to. I helped with administration, legal things, and things like how to rent a place, or where to go to get things done. (…) There is this friend of mine from Egypt. He opened a restaurant. (…) The authorities wanted to fine him once. But I got him a lawyer, who helped. (Male, 65 years old, old-age pensioner, ethnic Hungarian, Budapest.)

In sum, the concept of hyper-diversity is applicable to interactions, too, as the interviews conducted demonstrate how seemingly homogeneous social groups show considerable inner heterogeneity with respect to lifestyles and consumption practices. In this context, meaningful interactions can contribute to eradicating certain stereotypes and prejudices, while also providing economic benefits by allowing entrepreneurs to cooperate with partners (e.g., suppliers) across ethnic and cultural boundaries. In addition, local businesses provide a framework for inter-group encounters in public spaces and spaces of consumption, thus, they have the potential to strengthen social cohesion.

Discussion and conclusions

The principal aim of this study was to reveal the interconnectedness between neighbourhood diversity and local business structure. For this purpose, findings from qualitative research conducted among residents and local entrepreneurs in three European cities have been presented.

Reflecting on the first research question, which concerns the interrelationship between diversity and local business structures in urban neighbourhoods, first, it can be concluded that social and cultural diversity was not the primary pull factor for the interviewed entrepreneurs when it came to deciding where to open businesses. Instead, it was the diversity of local property markets and the availability of affordable business locations which played a crucial role in their decisions to start businesses in the neighbourhoods, while the diversity of consumers became an influential factor in their business activities only after they moved to the areas in question.

Second, due to neighbourhood regeneration and gentrification, upgrading in retail and services can be observed in the case study areas. However, this process has also had negative impacts on local businesses, with the residualisation or displacement of many old, traditional shops; which is a phenomenon similar to experiences in other cities (e.g., Zukin, S. *et al.* 2009). Additionally, the relevance of the hyper-diversity concept is noticeable in this context. On the one hand, the clientele of the interviewed entrepreneurs is very heterogeneous, which indicates the significance of adapting business practices to diverse lifestyles and consumption practices. On the other hand, ethnic market niches are less common in the case study areas, especially in Budapest, which is a post-socialist Eastern European city without a considerable recent history of immigration (in comparison to Copenhagen or Milan).

Third, local businesses also have considerable impacts on the representations of diversity and of various social groups in the case study areas. Regarding *demotic* representations of diversity (Vertovec, S. 2009), it was a common view among the interviewees that the diversity in retail and services was one of the main advantages of the neighbourhoods in question. Furthermore, definitions of diversity developed by the interviewees often included elements such as the heterogeneity of local urban functions, services, and shops. Thus, our study corroborates previous findings about the significance of neighbourhood services in terms of shaping people's perceptions of an area and also with respect to their housing choices (Allen, N. 2015). As for *dominant* representations of diversity (Vertovec, S. 2009), in the three cities, such representations are mostly linked to competitiveness or social tensions. In economic development policy, these representations are aligned with internationally mainstream ideas about creative workforces and creative cities, in line with Florida's (2002) thesis. However, our interviews suggest that diversity should be viewed in a broader sense (an idea that will be discussed in more detail in answer to the third question below).

Regarding the *second research question*, which is related to the effects of neighbourhood diversity on consumer services available to residents, the interviews demonstrate that local services are crucial to residents' quality of life. With general neighbourhood upgrading in the case study areas, there is an ongoing diversification in the local business sector – a process which has positive as well as negative consequences for consumers. For example, diversification results in a greater retail supply but also residualisation as well as the displacement of traditional small shops. With regard to hyper-diversity, the relevance of lifestyle and consumer habits is indicated by the fact that growth in the number and quality of services is appreciated by both newcomers and long-established residents. Businesses also create new spaces for interactions. However, the effects of such spaces on local populations are debated in the international literature on the topic. Nonetheless, the importance of diversity and spaces for intercultural encounters is emphasised in planning studies (e.g., Iveson, K. 2000; Fincher, R. 2003; Fincher, R. *et al.* 2014), with some scholars paying special attention to the significant role that business venues such as urban markets play in this respect (Wood, P. *et al.* 2006). Other authors, however, are sceptical, especially with regard to planning for spaces for such encounters. Ahmadi, D. (2018) argues that in a diverse social environment, informal interactions only occur when shared activities and experiences exist among inhabitants. Hoekstra, M.S. and Dahlvik, J. (2018) point out that the success of such activities depends on several factors, such as the personal profiles of residents (e.g., educational level), local power relations, institutional configurations, and the infrastructure required to realise relevant initiatives. Based on our study, we can add that spaces of consumption have the potential to generate cross-cultural encounters, but lifestyles and consumption practices can be integrative and exclusive at the same time. Therefore, cooperation with local entrepreneurs in creating diverse spaces for encounters is vital in related planning activities.

In answer to the *third research question*, some policy recommendations are provided in this last section of the paper. First, urban policy makers should consider that locally-embedded small businesses, which are affordable to launch, play an important role in improving residents' quality of life and in fostering social cohesion. Therefore, attention should be paid to the protection and support of these relatively weak enterprises, which do not fit particularly well with the globalised economic mainstream, especially in neighbourhoods affected by gentrification. It is also important to note that there is considerable diversification among entrepreneurs in terms of age, lifestyle, or management strategy. Furthermore, categories of entrepreneurs are highly mixed nowadays. For instance, someone can simultaneously be an old-age pensioner and a part-time employee, or a single parent and a hobby or lifestyle entrepreneur – as our interviews have demonstrated. Such enterprises need differentiated and tailored policy solutions, which require new governance structures (Sutton, S.A. 2010). For example, instead of spontaneous, fully market-driven upgrading in gentrifying neighbourhoods, the solution may come in the form of 'socially sensible rehabilitation' (for instance, something similar to the Magdolna Quarter Programme in Józsefváros, Budapest – see Horváth, D. and Teller, N. 2008; Tosics, I. 2014; Czirfusz, M. *et al.* 2015), which can potentially be supplemented by sub-programmes focusing on small local enterprises.

Second, local economic development should be defined in multiple ways. Although, following Florida, J. (2002), it is mostly creative and technology-intensive industries that tend to be pushed to the forefront in policy discourses of diversity, there are some critiques towards this approach. First, categories such as creative enterprises are not homogeneous, and these businesses should be differentiated in policy making (see e.g., He, J. and Huang, X. 2018). Second, there are also a number of new paradigms that have recently emerged in studies of urban economy. Consequently, concepts such as green and circular economy (Su, B. *et al.* 2013), sharing economy (Davidson, N.M. and Infranca, J.J. 2015), or silver economy (Kubejko-Polańska, E. 2017) should be utilised by policy makers and other urban practitioners when formulating diversity-related initiatives for local economic development.

Third, in line with international literature (specifically, Thomas, J.M. and Darnton, J. 2006; Cysek-Pawlak, M.M. 2018) and based on our fieldwork, the term diversity should be defined in a broader way, instead of being limited to a few 'trendy' dimensions of social difference. In this respect, the concept of hyper-diversity (Tasan-Kok, T. *et al.* 2013) can serve as a conceptual framework, and it can also facilitate the development of analytical tools for urban policy and practice as regards lifestyles, consumption practices, and urban functions and services, among other things.

Finally, it is important to note that the interpretations of supposedly shared international concepts such as diversity are always context-dependent. According to our research findings, historical legacies in Budapest, Copenhagen, and Milan are decisive in this respect. While both in the northern and the southern European city, migration, for example, attracts more policy interest at the urban scale, in Budapest (and across Hungary), migration issues are seen primarily as elements in the rhetoric of the national government, with other dimensions of diversity such as ethnicity (i.e., Roma or Hungarian) or socio-economic deprivation appearing to attract greater interest. Therefore, future research should pay attention to local understandings of diversity to assist local actors in creating their own narratives of living with diversity.

***Acknowledgements*:** The empirical results presented in this study are derived from DIVERCITIES international research project. DIVERCITIES ('Governing Urban Diversity: Creating Social Cohesion, Social Mobility and Economic Performance in Today's Hyper-Diversified Cities', pr. n.: 319970) was a four-year long (2013–2017) project financed by the European Union's 7th Framework Programme for Research and Technological Development. This work of Lajos Boros was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

REFERENCES

Ahmadi, D. 2018. Diversity and social cohesion: the case of Jane-Finch, a highly diverse lower-income Toronto neighbourhood. *Urban Research & Practice* 11. (2): 139–158.

Allen, N. 2015. Understanding the importance of urban amenities: A case study from Auckland. *Buildings* 5. (1): 85–99.

Arrigoni, P. 2010. Via Padova. Tra cosmopolis e ordine pubblico. In *Milano Downtown. Azione Pubblica e Luoghi dell'Abitare.* Ed.: Bricocoli, M. and Savoldi, P., Milano, Et Al. Edizioni, 163–189.

Barberis, E., Angelucci, A., Jepson, R. and Kazepov, Y. 2017. *DIVERCITIES: Dealing with Urban Diversity. – The Case of Milan*.Utrecht, Utrecht University, Faculty of Geosciences.

Barberis, E. and Solano, G. 2018. Mixed embeddedness and migrant entrepreneurship: Hints on past and future directions. An introduction. *Sociologica – International Journal for Sociological Debate* 12. (2): 1–22.

Bellini, E., Ottaviano, G.I.P., Pinelli, D. and Prarolo, G. 2008. *Cultural Diversity and Economic Performance: Evidence from European Regions*. Hamburg, Hamburg Institute of International Economics.

Berényi, E.B. and Szabó, B. 2009. Housing preferences and the image of inner city neighbourhoods in Budapest. *Hungarian Geographical Bulletin* 58. (3): 201–214.

Blokland, T. and van Eijk, G. 2010. Do people who like diversity practice diversity in neighbourhood life? Neighbourhood use and the social networks of 'diversity-seekers' in a mixed neighbourhood in the Netherlands. *Journal of Ethnic and Migration Studies* 36. (2): 313–332.

Borck, R. 2007. Consumption and social life in cities: Evidence from Germany. *Urban Studies* 44. (11): 2105–2121.

Boros, L., Fabula, Sz., Horváth, D. and Kovács, Z. 2016. Urban diversity and the production of public space in Budapest. *Hungarian Geographical Bulletin* 65. (3): 209–224.

Camina, M.M. and Wood, M.J. 2009. Parallel lives: Towards a greater understanding of what mixed communities can offer. *Urban Studies* 46. (2): 251–274.

Chan, W.F. 2005. A gift of a pagoda, the presence of a prominent citizen and the possibilities of hospitality. *Environment and Planning D: Society and Space* 23. (1): 11–28.

Curley, A.M. 2010. Relocating the poor: Social capital and neighbourhood resources. *Journal of Urban Affairs* 32. (1): 79–103.

Cysek-Pawlak, M.M. 2018. Mixed use and diversity as a New Urbanism principle guiding the renewal of post-industrial districts. Case studies of the Paris Rive Gauche and the New Centre of Lodz. *Urban Development Issues* 57. (1): 53–62.

Czirfusz, M., Horváth, V., Jelinek, Cs., Pósfai, Zs. and Szabó, L. 2015. Gentrification and rescaling urban governance in Budapest-Józsefváros. *Intersections* 1. (4): 55–77.

Davidson, N.M. and Infranca, J.J. 2015. The sharing economy as an urban phenomenon. *Yale Law & Policy Review* 34. (2): 215–279.

Eraydin, A., Tasan-Kok, T. and Vranken, J. 2010. Diversity matters: Immigrant entrepreneurship and contribution of different forms of social integration in economic performance of cities. *European Planning Studies* 18. (4): 521–543.

Everts, J. 2010. Consuming and living the corner shop: belonging, remembering, socialising. *Social & Cultural Geography* 11. (8): 847–863.

Faist, T. 2009. Diversity: a new mode of incorporation? *Ethnic and Racial Studies* 32. (1): 171–190.

Fincher, R. 2003. Planning for cities of diversity, difference and encounter. Planning for cities of diversity, difference and encounter. *Australian Planner* 40. (1): 55–58.

Fincher, R., Iveson, K., Leitner, H. and Preston, V. 2014. Planning in the multicultural city: Celebrating diversity or reinforcing difference? *Progress in Planning* 92. (1): 1–55.

Florida, R. 2002. *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*. New York, Basic Books.

Foot, J. 1997. Migration and the 'miracle' at Milan. The neighbourhoods of Baggio, Barona, Bovisa and Comasina in the 1950s and 1960s. *International Journal of Historical Sociology* 10. (2): 184–213.

Gilroy, P. 2004. *After Empire: Melancholia or Convivial Culture?* London, Routledge.

Hall, S.M. 2011. High street adaptations: ethnicity, independent retail practices, and localism in London's urban margins. *Environment and Planning A: Economy and Space* 43. (11): 2571–2588.

Hatziprokopiou, P., Frangopoulos, Y. and Montagna, N. 2016. Migration and the city: Diversity, migrant economies and the urban space. *City* 20. (1): 52–60.

He, J. and Huang, X. 2018. Agglomeration, differentiation and creative milieux: A socioeconomic analysis of location behaviour of creative enterprises in Shanghai. *Urban Policy and Research* 36. (1): 79–96.

Hiebert, D., Rath, J. and Vertovec, S. 2014. *Urban Markets and Diversity: Toward a Research Agenda*. MMG Working Paper 14-06. Göttingen, Max Planck Institute for the Study of Religious and Ethnic Diversity.

Hoekstra, M.S. and Dahlvik, J. 2018. Neighbourhood participation in super-diverse contexts: comparing Amsterdam and Vienna. *Urban Research & Practice* 11. (4): 441–459.

Horváth, D. and Teller, N. 2008. An urban regeneration model: Local community participation in neighbourhood rehabilitation, planning, and implementation in Budapest's eighth district Magdolna Quarter. *Local Governance Brief* 9. (1): 47–52.

Iveson, K. 2000. Beyond designer diversity: Planners, public space and a critical politics of difference. *Urban Policy and Research* 18. (2): 219–238.

Jayne, M. 2006. Cultural geography, consumption and the city. *Geography* 91. (1): 34–42.

Jones, H., Neal, S., Mohan, G., Connell, K., Cochrane, A. and Bennett, K. 2015. Urban multi-culture and everyday encounters in semi-public, franchised café spaces. *Sociological Review* 63. (3): 644–661.

Kloosterman, R. and Rath, J. 2001. Immigrant entrepreneurs in advanced economies: Mixed embeddedness further explored. *Journal of Ethnic and Migration Studies* 27. (2): 189–201.

Kloosterman, R. and van der Leun, J.P. 1999. Just for starters: commercial gentrification by immigrant entrepreneurs in Amsterdam and Rotterdam neighbourhoods. *Housing Studies* 14. (5): 659–677.

Kubejko-Polańska, E. 2017. The role of local self-government in stimulating urban development in the context of the construction of age-friendly cities and the concept of Silver Economy. *Nierówności Społeczne a Wzrost Gospodarczy* 49. (1): 216–227.

Leadbeater, C. 2008. *The Difference Dividend: Why Immigration is Vital to Innovation*. London, NESTA.

Meissner, F. and Vertovec, S. 2015. Comparing superdiversity. *Ethnic and Racial Studies* 38. (4): 541–555.

Meltzer, R. and Schuetz, J. 2012. Bodegas or bagel shops? Neighbourhood differences in retail and household services. *Economic Development Quarterly* 26. (1): 73–94.

Municipality of Copenhagen. The Technical & Environmental Administration 2009. *Metropol for Mennesker* (Metropolis for People). Copenhagen, Municipality of Copenhagen.

Nathan, M. 2011. *The Economics of Super-Diversity: Findings from British Cities, 2001–2006*. Discussion Paper 68. London, SERC.

Nicholls, W. and Uitermark, J. 2016. Migrant cities: Place, power, and voice in the era of super diversity. *Journal of Ethnic and Migration Studies* 42. (6): 1–16.

Nzimande, N.P. and Fabula, Sz. 2020. Socially sustainable urban renewal in emerging economies: A comparison of Magdolna Quarter, Budapest, Hungary and Albert Park, Durban, South Africa. *Hungarian Geographical Bulletin* 69. (4): 383–400.

Pastore, F. and Ponzo, I. 2016. Introduction. In *Intergroup Relations and Migrant Integration in European Cities. Changing Neighbourhoods.* Eds.: Pastore, F. and Ponzo, I., Heidelberg, Springer, 1–18.

Peters, K. and De Haan, H. 2011. Everyday spaces of inter-ethnic interaction: the meaning of urban public spaces in the Netherlands. *Leisure/Loisir* 35. (2): 169–190.

Piekut, A. and Valentine, G. 2017. Spaces of encounter and attitudes towards difference: A comparative study of two European cities. *Social Science Research* 62. (1): 175–188.

Raco, M. 2018. Critical urban cosmopolitanism and the governance of urban diversity in European cities. *European Urban and Regional Studies* 25. (1): 8–23.

Raco, M. and Tasan-Kok, T. 2019. Governing urban diversity: Multi-scalar representations, local contexts, dissonant narratives. *European Urban and Regional Studies* 26. (3): 230–238.

Rath, J. and Swagerman, A. 2015. Promoting ethnic entrepreneurship in European cities: Sometimes ambitious, mostly absent, rarely addressing structural features. *International Migration* 54. (1): 152–166.

Rodríguez-Pose, A. and Storper, M. 2006. Better rules or stronger communities? On the social foundations of institutional change and its economic effects. *Economic Geography* 82. (1): 1–25.

Saxenian, A.L. 1999. *Silicon Valley's New Immigrant Entrepreneurs*. San Francisco (CA), Public Policy Institute of California.

Schiller, M. 2016. *European Cities, Municipal Organizations and Diversity. The New Politics of Difference*. London, Palgrave Macmillan.

Shaw, S.J. 2011. Marketing ethnoscapes as spaces of consumption: 'Banglatown – London's Curry Capital'. *Journal of Town & City Management* 1. (4): 381–395.

Skovgaard Nielsen, R., Beckman, A.W. and Andersen, H.T. 2015. Urban mangfoldighed som en styrke: Tilgangen til mangfoldighed i Københavns kommune (Urban diversity as a strength: The approach to diversity in Copenhagen Municipality). *Plan* 2015. (6): 50–57.

Skovgaard Nielsen, R. and Hedegaard Winther, A. 2019. The complexity of diversity in reality: Perceptions of urban diversity. *Urban Studies* 57. (1): online first. Doi: 10.1177/0042098019886737

Smith, M.K., Egedy, T., Csizmady, A., Jancsik, A., Olt, G. and Michalkó, G. 2018. Non-planning and tourism consumption in Budapest's inner city. *Tourism Geographies* 20. (3): 524–548.

Su, B., Heshmati, A., Geng, Y. and Yu, X. 2013. A review of the circular economy in China: Moving from rhetoric to implementation. *Journal of Cleaner Production* 42. (1): 215–227.

Sutton, S.A. 2010. Rethinking commercial revitalization: A neighbourhood small business perspective. *Economic Development Quarterly* 24. (4): 352–371.

Syrett, S. and Sepulveda, L. 2011. Realising diversity dividend: population diversity and economic development. *Environment and Planning A* 43. (2): 487–504.

Syrett, S. and Sepulveda, L. 2012. Urban governance and economic development in the diverse city. *European Urban and Regional Studies* 19. (3): 238–253.

Talen, E. 2010. The context of diversity: A study of six Chicago neighbourhoods. *Urban Studies* 47. (3): 486–513.

Tasan-Kok, T. and Vranken, J. 2008. From survival to competition? The socio-spatial evolution of immigrant entrepreneurs in Antwerp. In *Cities between Competitiveness and Cohesion: Discourses, Realities and Implementation*. Eds.: Ache, P., Andersen, H.T., Maloutas, T., Raco, M. and Tasan-Kok, T., Dordrecht, Springer, 151–168.

Tasan-Kok, T., van Kempen, R., Raco, M. and Bolt, G. 2013. *Towards Hyper-Diversified European Cities: A Critical Literature Review*. Utrecht, Utrecht University.

Tasan-Kok, T., Bolt, G., Plüss, L. and Schenkel, W. 2017. *A Handbook of Governing Hyper-Diverse Cities*. Utrecht, University of Utrecht, Faculty of Geosciences.

Thomas, J.M. and Darnton, J. 2006. Social diversity and economic development in the metropolis. *Journal of Planning Literature* 21. (2): 153–168.

Tosics, I. 2014. Housing renewal in Hungary: from socialist non-renovation through individual market actions to area-based public intervention. In *Renewing Europe's Housing*. Eds.: Turkington, R. and Watson, R., Bristol, Policy Press, 161–186.

Valentine, G. 2013. Living with difference: proximity and encounter in urban life. *Geography* 98. (1): 4–9.

Van Gent, W. and Musterd, S. 2016. Class, migrants, and the European city: Spatial impacts of structural changes in early twenty-first century. *Journal of Ethnic and Migration Studies* 42. (6): 893–912.

Van Kempen, R. 2006. The importance of globalisation. In *Cities and Globalisation: Exploring New Connections*. Eds.: Koekoek, A.F., van der Hammen, J.M., Velema, T.A. and Verbeet, M., Utrecht, Koninklijk Nederlands Aardrijkskundig Genootschap, 13–21.

Verga, P.L. and Vitrano, C. 2016. *Beyond the Rhetoric: The Emerging Configuration of the Padova–Monza Area in Milan* (online). Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3289874

Vertovec, S. 2007. Super-diversity and its implications. *Ethnic and Racial Studies* 30. (6): 1024–1054.

Vertovec, S. 2009. *Conceiving and Researching Diversity*. MMG Working Paper 09-01. Göttingen, Max Planck Institute for the Study of Religious and Ethnic Diversity.

Vertovec, S. 2010. Introduction: Depicting diversity. *Diversities* 12. (1): 1–3.

Vertovec, S. 2015. Introduction: Formulating diversity studies. In *Routledge International Handbook of Diversity Studies*. Ed.: Vertovec, S., London and New York, Routledge, 1–20.

Wood, P., Landry, C. and Bloomfield, J. 2006. *The Intercultural City. Making the Most of Diversity*. York, Joseph Rowntree Foundation.

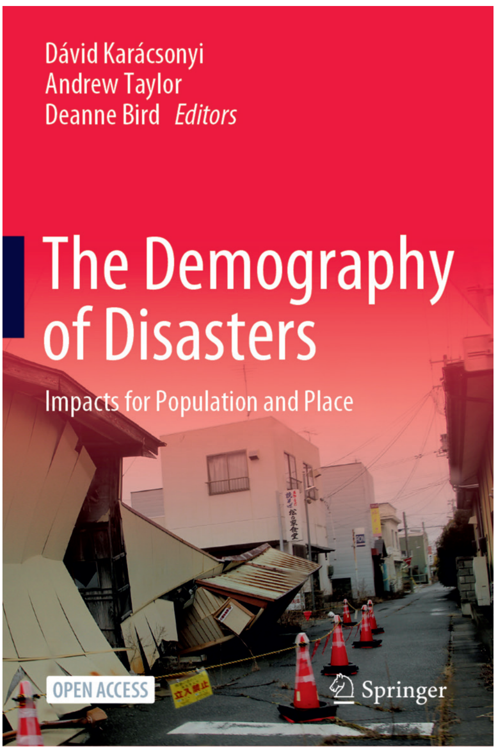
Zukin, S. and Kosta, E. 2004. Bourdieu off-Broadway: Managing distinction on a shopping block in the East Village. *City & Community* 3. (2): 101–114.

Zukin, S., Trujillo, V., Frase, P., Jackson, D., Recuber, T. and Walker, A. 2009. New retail capital and neighbourhood change: Boutiques and gentrification in New York City. *City & Community* 8. (1): 47–64.

BOOK REVIEW SECTION

Karácsonyi, D., Taylor, A. and Bird, D. (eds.): The Demography of Disasters: Impacts for Population and Place. Cham, Springer, 2021. 268 p.

The impact of disasters on the population can be considered in terms of community/city resilience to shocks and stresses, i.e. the ability to return to the previous state. However, there are more and more calls to look at disaster resilience not in terms of 'bouncing back,' but as everyday practices to cope with ongoing and changing everyday pressures (Andres, L. and Round, J. 2015). Bouncing back after a disaster is not satisfactory at the community level, as some disaster-affected people do not want a return to 'how things were,' but desire changes addressing former inequalities and dysfunctions (Vale, L.J. and Campanella, T. 2005). Moreover, resilience could be seen as a metaphor for change, not against change (DeVerteuil, G. and Golubchikov, O. 2016). The key ideas of this volume fully meet these calls. The editors aim to conceptualise the demography–disaster nexus in a wider perspective, beyond the natural hazards' 'statistical' impact on demography, in order to improve disaster policy and planning process. The volume contains 13 individual chapters, which highlight case studies from developed (Japan, USA, Australia, New Zealand, Sweden, Island) and post-Soviet (Ukraine, Russia) countries covering a variety of disasters (nuclear disaster, cyclone, hurricane, earthquake, volcanic eruption, wildfire, crop failure, mine fire, and heat-related stress and lifeline failure).



In the introductory and concluding chapters (Chapters 1 and 13), Karácsonyi, D. and Taylor, A. discuss paradigm shifts in the field of disaster studies which "is constantly emerging and reshaping" (p. 4), focusing on the demography–disaster interdependency in connection with disaster policies. The declared ambition to traverse the disaster–demography nexus from both 'non-routineness' (holistic) and 'social embeddedness' (vulnerability) perspectives (McEntire, D. 2013) is successfully implemented in this volume. In line with Perry, R.W. (2007), the editors consider disaster as the intersection of extreme natural hazard with the vulnerable human population. They follow Oliver-Smith, A. (2009), arguing that different social groups can be differently exposed to risks and they can suffer differently from the same hazardous events.

Karácsonyi, D. and Taylor, A. summarise seven intertwined disaster–demography subthemes. They justly note that this classification is subjective, and others may separate or merge some of the categories in different ways (p. 263). But this is unquestionably a great generalisation and a very helpful frame for further studies. This volume covers all distinguished approaches. However, it offers not a rigid 'approach–case' sequence, but diverse approaches rather overlap and get intertwined in every chapter.

Most of the chapters deals with the 'disaster impacts on population' approach, exploring death toll and the number of injured, post-disaster changes in population size and composition, migration responses, and health impacts. It has strong links to the non-routineness perspective and the holistic school. 'Migration and mass displacement' authors are distinguished as a separate approach, apparently the most visible and aware one in disaster–demography studies. It is considered here as planning and survival strategies adopted by people and authorities facing disasters regardless their character and related issues–community destruction, loss of/search for social cohesion, conflicts with hosting communities.

Studies of 'demography as root cause' are equally important in the disaster–demography nexus. It is linked to the 'social embeddedness' perspective and the vulnerability school. Age, gender, ethnic and social class composition are investigated to assess the demographic impact in, and vulnerability of, disaster-prone areas. And such influences are ambiguous. As the authors show, more disaster-vulnerable elderly people are the most likely to be post-disaster returners.

In many cases it is not easy to separate mutual disaster–demography impacts. So, Karácsonyi, D. and Taylor, A. distinguish the 'impact of and adaptation to climate change' subtheme. Thus, climate change-induced migration can be both a problem and a solution. Another approach related simultaneously to disaster root causes and consequences is 'urbanisation and urban vulnerability'. On the one hand, growing urbanisation can lead to the concentration of population in hazard-prone urban areas and hence put more people at risk, including more vulnerable groups. But from another side, post-disaster processes display further population concentration in cities and towns as more equipped places to disaster risks.

A lack of reliable data on the consequences of disasters has led to a search for substitution procedures to be used for disaster impact assessment, such as school enrolment or mobile phone location data presented in this volume. This enabled the authors to distinguish an 'applied demography approach' in disaster–demography studies. Finally, the 'spatial-geographical approach' related to spatially uneven vulnerability and resilience runs through the entire book.

Two chapters in the volume are devoted to the worst nuclear disasters in Chernobyl and Fukushima. Karácsonyi, D., Hanaoka, K. and Skryzhevska, Y. (Chapter 2) rely on the assumption of Oliver-Smith, A. (2013) that geographically and culturally distanced societies present analogous issues during similar disaster events. They argue that despite essentially different long-lasting demographic trends, differences in emergency measures (scales of decontamination works, accepted radiation thresholds or the approach to the organisation of permanent resettlement sites), both post-Chernobyl and post-Fukushima mass displacements caused much more significant demographic shifts than the radiation itself (p. 19). In both cases, the regional disaster impact resulted in a dramatic loss of population in the contaminated areas and a strong spatial shift towards urbanisation. Although the Chernobyl disaster did not change the general direction of regional population dynamics, it accelerated the negative demographic processes that, in combination with the outmigration and mass resettlement, resulted in "a huge hole in the demographic space of the region" (p. 31). Interestingly, the main negative demographic impact of the nuclear disaster was not the high mortality or morbidity, but rather the distortion of everyday life, growing uncertainties and various hardships in the new environment for evacuees. I completely agree with the authors that the most significant lesson from their study is that a poorly planned mass displacement can cause a larger economic loss than the disaster itself.

Both case studies reflect power relations and the role of local community participation in disaster recovery management, in particular how and why affected communities were excluded from decision-making during the disaster recovery process (by Okada, T., Cholii, S., Karácsonyi, D. and Matsumoto, M. – Chapter 11). In both cases, resettled people faced difficulties to integrate into their new local communities, despite support from local administrations. Some interviewees and media platforms reported a different degree of tension between evacuees and host communities. While Chernobyl evacuee suffered from the split, fragmentation or destroying of their community, Fukushima evacuees established their neighbourhood councils at each temporary housing unit, which proved efficient while negotiating and working with authorities. This study demonstrates the importance of socio-political systems and financial capacity, but uncertainty is commonly identified as a major challenge at a local-scale recovery following the nuclear disasters. The authors emphasise that the community should play an active role in disaster recovery as a key driver, instead of remaining passive receivers of services and information provided by the authorities (p. 213).

Chapter 3 (by Sharygin, E.) is aimed to understand the outcomes of wildfire disaster outmigration in California in a record fire season of 2017. The analysis focuses on impacts in Sonoma County, where the fire displaced the greatest number of residents. The results of this study show the moderate scale and spatial extent of the displacement, while the majority of the displaced did not move far, mostly within the same county. As the wildfire hazard increases, the author emphasises increasing demand for reliable methods to estimate population impacts. In this way, Sharygin, E. argues to use the 'school enrolment proxy method', based on the assumption that public education capturing data in a timely manner is more representative than other government programmes. Indisputably, the bias effect can be expected. However, he suggests that these data offer a superior balance of timeliness, completeness, and representativeness compared to the alternatives (p. 61).

In contrast to the dominating discussion on demography responses to disaster, Nefedova, T. (Chapter 4) offers to examine a converse relationship–demography as a cause of fire disaster. She suggests that human activities and forest legislation are root causes of forest fires around Moscow – in particular, carefree, impunity, deliberate burning to hide deforestation. Another root cause is the organisation of demographic space, especially the rapid rural depopulation of peripheral areas and the suburbanisation in urban cores. It has led to a combination of several fire risk factors previously subsidised by the state, but now abandoned agricultural lands are covered with high dry grass, growing logging instead of agriculture specialisation, and seasonal accumulation and incineration of garbage produced by overcrowding 'summurbanisers' from the city. Moreover, "the majority of peripheral villages are populated by old women and strongly drinking men" who are not capable of implementing even basic fire protection measures (p. 76). To trace the intensity of forest fires, Nefedova, T. uses media analysis. Although the media reports 'digest' is not quite full and reliable, it reflects general trends. Such an approach is promising and needs further in-depth researches.

Chapter 5 (by Carson, D.B., Carson, D.A., Axelsson, P., Sköld, P. and Sköld, G.) shifts the focus to sparsely populated areas and local conditions under which dramatic demographic responses to natural disasters occur. Additionally, to the 'eight Ds' explanation for sparsely populated areas development (Carson, D.B. and Carson, D.A. 2014), the authors introduce two new 'Ds' which reflect a potentially *disrupting* or *diverting impact* of natural disasters on demographic development. Two cases illustrate these impacts. The Great Deprivation crop failure in Northern Sweden during the 19th century caused temporary disruption in demographic development after which the pre-disaster pattern has resumed. Contrary to that, the cyclone caused flooding in the Northern Territory of Australia in 1998 led to longer lasting diversion to a new pattern clearly and substantially distinct from the pre-event state. The authors reveal both local urbanisation impact and consequences, when disaster impacts were less in higher urbanised areas, and affected areas became more urbanised after the disaster. The highlight, but also the weak point of this chapter, is the analysis of two case studies that occurred with an interval of more than a century in different parts of the world and had essentially different consequences. The authors' passage on natural disaster events labelling 'black swan' is rather unspoken as they underline later that such attributing is difficult, precisely because of the dynamic nature of populations in sparsely populated areas.

Bird, D. and Taylor, A. (Chapter 7) investigate the single-industry town of Morwell, Australia, which suffered from the Hazelwood mine fire disaster and, later, enterprise closure. They discuss demographic consequences of the disaster through the social capital concept, analysing cooperation among different groups of people and collective action to cope with the disaster impact. It was expected that the single-industry character of the town could strengthen demographic and socio-economic decline. Nevertheless, scholars revealed that the population size did not drop significantly, and the town showed a certain 'stoicism and resilience'. The lower than anticipated impacts they partly explain by the historical diversity of jobs, changing population composition, and the uncertainty of the label 'single-industry town'. However, the role of bonding and bridging social capital they see as another essential factor, when the population is collectively banded together around various community-led initiatives to produce a better future for their community (p. 147).

Zander, R.R., Richerzhagen, C. and Garnett, S.T. (Chapter 8) explore migration intention as a strategy of adaptation to climate change. Based on online survey results, they discuss the intention of people in different parts of Australia to move from their current place of residence to cooler places because of heat stress, as well as the temporal and geographical frames of this mobility. They revealed that the intention to move because of heat stress was affected by location, gender and mobility experience. Respondents living in the Northern Territories, and male and highly mobile people were more likely to intend to move because of heat stress. Instead, income, having children, workload and age did not have a significant impact. The latter was especially unexpected. While more than a third of those wanting to move because of heat stress did not know where they would move to, the most of them would cross the boundary of states (p. 162).

Singh, E.A. (Chapter 10) turns the attention of the readers to another side of disaster 'compounded impacts' showing through two case studies how natural hazards can cause lifeline infrastructure failure, which can become a disaster itself with demographic consequences. While extreme heat during the heat wave in South-eastern Australia collapsed region-wide electricity and rail transportation systems, the Eyjafjallajökull eruption in Iceland caused the closure of the European airspace and broke the supply chains that rely on airfreight for just-in-time deliveries and exports of perishable goods. The latter highlights that natural hazard impacts are not always confined to geographical or political borders. The impact on demography is not so clear, though the author talks about a direct impact when lifeline failure caused excess mortality (particularly in elderly age groups) and depends on the time it takes for the lifeline to return to operation. Singh, E.A. concludes that both responsible institutions and communities were "largely underprepared for an event of this magnitude" (p. 196). So, to improve urban-wide resilience to natural hazards, the author recommends improving communication, information sharing, collaboration and coordination between all stakeholders involved.

King, D. and Gurtner, Y. (Chapter 6) address post-disaster population decline and dislocation as an opportunity to re-appraise planning priorities, a chance to re-envision towns, cities or regions, to plan and manage them for 'a different community' (e.g. smaller, less dense, redesigned), and to produce a positive sense of place after the disaster for a sustainable future. The authors follow the idea of Hollander, J.B.

et al. (2009) on paradigm shifts to proactively plan for shrinkage and 'rightsizing' (i.e. planning for a different size and composition of community). They study three locations that have lost population following recent disasters in the USA (New Orleans), New Zealand (Christchurch) and Australia (Innisfail), damaged by a hurricane, earthquakes and cyclones, respectively. Because population movement after disaster has not been homogenous spatially, temporally and socially, and all cases have local specifics, the disaster impact and planning responses are different in terms of death toll, migration outflow, return rate, urban population decline and peri-urbanisation. King, D. and Gurtner, Y. conclude that the quality and good design of the post-disaster community is far more important than its demographic impacts or recovery (p. 120).

Chapter 9 deals with the intersection between gender, disaster resilience, and the design of the built environment. Barnes, J.L. discusses 'a male bias' in urban landscape and in disaster resilience when women and girls are often more marginalised and vulnerable to and after disasters, and tend to start off in worse conditions when a disaster occurs. Starting with the conceptualisation of women's disaster resilience, she delves into the questions of gender inequality covering women's transportation inconveniencies, lower access to safe public spaces, ignorance of women's specific health needs, and the lack of representation of women in leadership and decision-making roles. Barnes, J.L. asserts that listening to women's needs by including them into urban design processes can contribute to their disaster resilience. The analysis of individual case studies would significantly strengthen the author's argumentation.

Murao, O. (Chapter 12) shows that learning from past disaster recovery measures can be very useful to reduce disaster risks in the future. Considering cities as an artificial environment, he asserts that serious safety weaknesses remain unrecognised until the city faces a disaster (p. 234). That is why Murao, O. insists that past disasters and recoveries need to be examined carefully and the lessons learned have to be disseminated. Based on his own research experience from post-disaster recovery processes in cities with different social backgrounds in Taiwan, Turkey and Japan, the author discusses the effectiveness of urban recovery planning issues. One of his ideas is to represent the progress of recovery by creating "recovery curves" based on building construction data for the various building types. He shares experience in seeking collaborative relationships with local specialists, researchers, building good relationships with the local community and community hubs (such as restaurants in post-earthquake Chi-Chi, Taiwan).

The fascinating journey through the diversity of demography–disaster nexus studies makes the reader vulnerable to the desire to join this field of research. This volume is not organised into thematic sections, but it is not a problem, rather an advantage enabling free movement between the – thematically often interrelated – chapters. Despite many cases and quite comprehensive studies, the reader does not get lost in the details. On the contrary, one can easy step between the chapters and in the end gets a great overview in the form of seven approaches.

The impact of disasters on demography is obvious. But this volume often reveals unexpected sides and influences, as well as interlinks between places, communities, age groups, genders, and scales. Hence, for those who seek to understand the complicated nature of the disaster–demography nexus, it is advised to pay attention to the collection *The Demography of Disasters, Impacts for Population and Place*.

Kostyantyn Mezentsev[1]

REFERENCES

Andres, L. and Round, J. 2015. The role of 'persistent resilience' within everyday life and polity: households coping with marginality within the 'Big Society'. *Environment and Planning A: Economy and Space* 47. (3): 676–690.

Carson, D.B. and Carson, D.A. 2014. Local economies of mobility in sparsely populated areas: Cases from Australia's spine. *Journal of Rural Studies* 36. 340–349.

DeVerteuil, G. and Golubchikov, O. 2016. Can resilience be redeemed? *City* 20. (1): 143–151.

Hollander, J.B., Pallagst, K., Schwarz, T. and Popper, F.J. 2009. Planning shrinking cities. *Progress in Planning* 72. (4): 223–232.

McEntire, D. 2013. Understanding catastrophes. A discussion of causation, impacts, policy approaches, and organizational structures. In *Preparedness and Response for Catastrophic Disasters*. Eds.: Bissel, R., Jensen, S. and Feldman-Jensen, S., London, New York, CRC Press, 27–44.

Oliver-Smith, A. 2009. Climate change and population displacement: Disasters and diasporas in the twenty-first century. In *Anthropology and Climate Change: From Encounters to Actions*. Eds.: Crate, S.A. and Nuttal, M., Walnut Creek, Left Coast Press, 116–138.

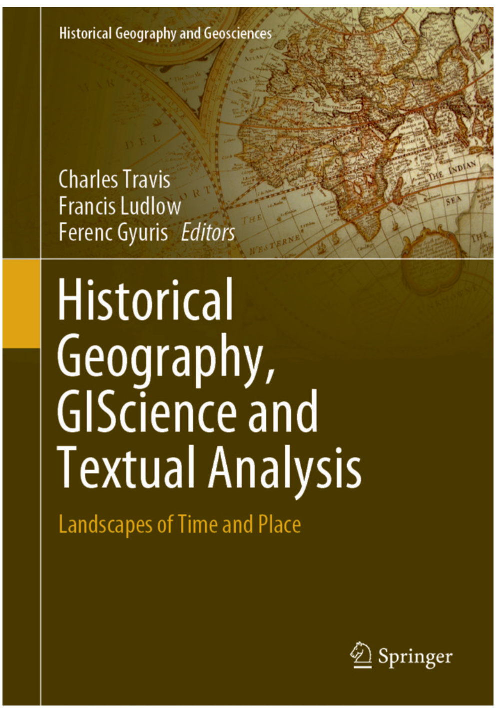
Perry, R.W. 2007. What is a disaster? In *Handbook of Disaster Research.* Eds.: Rodriguez, H., Quarantelli, E. and Dynes, R., New York, Springer, 1–15.

Vale, L.J. and Campanella, T. 2005. *The Resilient City: How Modern Cities Recover from Disaster*. New York, Oxford University Press.

[1] Department of Economic and Social Geography, Taras Shevchenko National University of Kyiv, Ukraine. E-mail: mezentsev@knu.ua

Travis, C., Ludlow, F. and Gyuris, F. (eds.): Historical Geography, GIScience and Textual Analysis. Landscapes of Time and Place. Cham, Springer, 2020. 272 p.

Historical geography was relatively slow to adopt methods and approaches of geographical information systems (GIS). As Gregory, I.N. and Haley, R.G. (2007) pointed out, even in the late 1990s the main texts describing the state of the discipline rarely mentioned this new field. This was happening despite the fact that the rapid development of technology and the appearance of more accessible desktop software saw the widespread incorporation of GIS into other disciplines. Fortunately, this have changed rapidly with the turn of the century with authors tackling the matter. Classic positions from that early period include Anne Knowles' (2002) *Past Time, Past Place: GIS for history* and Gregory, I.N. *et al.* (2001) *Geographical information and historical research: Current progress and future directions*. In the latter, the authors identified that the main advantages of using GIS are the ability to integrate data using its location, the ability to create maps and visualisations, and the possibility of using location as an explicit part of the analysis itself. This description gave the tone for the early period of Historical GIS in which GIS was perceived mainly as a tool. The first notable projects that resulted from this interdisciplinary marriage was *The Great Britain Historical GIS Project* (Gregory, I.N. *et al.* 2002) and *China Historical GIS* (Bol, P. and Ge, J. 2005). In the following years, Historical GIS became a lively discipline and many scholars took the challenge of incorporating GIS based methods in their research (Knowles, A.K. 2005; Gregory, I.N. and Healey, R.G. 2007). Recently there is a renewed interest and new approaches like spatial humanities (Gregory, I.N. and Geddes, A. 2014) and public participatory historical GIS (Lafreniere, D. *et al.* 2019) are being considered and applied. This is the rich landscape of thought and research practices into which this book appears.



The main aim of this book as expressed in the introductory chapter is to explore the possibilities of triangulating methods used in the fields of historical geography, geographic information science, and textual analysis. This is done in hope of transgressing interdisciplinary boundaries (or "methodological silos" in words of Charles Travis) to envision new ontologies and epistemologies that will help in understanding and modelling human and environmental phenomena. And the wide range of topics and methodologies presented in the chapters of this book let me believe that this is indeed, a valuable exercise with the potential of advancing our knowledge of the phenomena that are being the subject of intersecting fields of inquiry of those three disciplines.

The reviewed volume belongs to a relatively new Springer series called "Historical Geography and Geosciences." This is an interesting array of titles covering a wide range of topics related to spaces, places and their histories and geographies. This particular volume is a nice addition to the series portfolio, since its broad view on the matter means that a potential reader can enjoy finding many new takes on the intersection of history and geographical information systems and science. Its three editors are researchers well known in their respective fields. Charles Travis is Professor of Geography and Geographical Information Science at the Department of History at the University of Texas, Arlington. He is an expert in various applications of GIS in fields as diverse as humanities, environmental cartography and historical, literary and cultural geography. He has previously published books connecting the topics of history and GIS. Francis Ludlow is Professor of Medieval Environmental History at Trinity College Dublin. He is a leading expert on historical dynamics of climate, violence and conflict and he positions his research interests within a relatively new interdisciplinary field of climate history. Ferenc Gyuris is an Associate Professor of Geography at the Institute of Geography and Earth Sciences at Eötvös Loránd University, Budapest, with an interest and publications covering topics from regional sciences to geographies of Communism and post-Communist transition. The authors of the individual chapters present a wide range of expertise and stages of scientific career, which resulted in an interesting mix of methodological approaches and subjects of study. One might however note that apart of being predominantly male, they are also mainly affiliated within US universities with a small addition of Western European researchers. I wonder whether a more geographically diverse choice of voices would result in an ever more interesting view on this field of study.

Historical Geography, GIScience and Textual Analysis: Landscapes of Place and Time is separated into four parts consisting of four chapters each and an Introduction by Charles Travis. In the latter, the author guides the reader thorough interesting meanders of past and present tensions and paradigms that shaped the discipline of historical geography and the views on human and historical agency. We are learning about the cultural, spatial and computational turns as well as environmental determinism that have all influenced the current state of the intra- and interdisciplinary discourse. A significantly smaller part of the introduction is given to the GIS and textual analysis, mainly in relation to their integration potential that can lead to addressing research problems in all three disciplines. This triangulation manifesto is giving the tone to the rest of the book.

Part I (*Landscape, Time, Text*) almost directly exemplifies the main theme of this volume by demonstrating various blends of methods. Chapter 1 (*Ghost Cathedral of the Blackland Prairie*) by Charles Travis and Javier Reyes uses GIS database and three text maps to show how perceptions of landscape, identity and sense of place are built upon a specific locale. This chapter raises an important voice in the discussion about the problems that GIS have with subjective concepts of place. In Emily Lethbridge's Chapter 2 (*Digital Mapping and the Narrative Stratigraphy of Iceland*) describes methodological challenges and processes involved in creating Icelandic Saga Map, a digital mapping project aimed at linking Iceland's medieval text corpus with the country's physical geographies. We are also given theoretical insights coming from the results of the project, on the intricate and not obvious relations between Icelandic sagas and places. Chapter 3 with the catchy title *Dead Men Tell Tales: History and Science at Duffy's Cut* introduces us to a captivating story of Irish ghosts and homicide in Pennsylvania. William E. Watson, J. Francis Watson and Earl H. Schandelmeir give us an example of forensic investigation that combines geography, GIS and textual analysis to re-frame Irish immigrant historiographies. Chapter 4 (*Please Mention the Green Book: The Negro Motorist Green Book as Critical GIS*) by Ethan Bottone presents a novel approach to the analysis of the well-researched Green Book, a travel guide for Afro-Americans popular between 1936–1966. Reading of this material through the epistemologies of geographic information science reveals a spatialised history of racial discrimination and resistance and allows for a new look both at the past and present of Black Geographies.

In the following four chapters that together form Part II titled *Cultures, Networks and Mobilities,* the undertone of GIS grows much stronger and the power that it brings to the investigation of the past and present phenomena is explicitly visible. The first chapter by Damon Scott (*Queer Cartographies: Urban Redevelopment and the Changing Sexual Geography of Postwar San Francisco*) investigates the associative power of GIS, and shows how it can be used to excavate complicated spatial histories of stigmatised places of the post-war LGBTQ communities. This chapter is an interesting methodological study on the limitations of Critical GIS approach. The next chapter (*Revisiting the Walking City: A Geospatial Examination of the Journey to Work*) is authored by Don Lafraniere and Jason Gilliland. It is taking the readers through an almost classical and brilliantly executed journey through GIS informed historical analysis. The authors offer us a methodologically innovative approach that allowed them to explore daily mobilities of 1881 Ontario with surprising accuracy and insight, illustrated by well-designed maps and visualisations. The third chapter (*Corruption and Development of Atlanta Streetcar Lines in the Nineteenth Century: A Historical GIS Perspective*) by S. Wright Kennedy uses GIS to analyse new data sources, unveiling the previously unseen history of public transportation in Atlanta. *A Brother Orangeman the World Over": Migration and the Geography of the Orange Order in the United States* by Cory Wells and Charles Travis is the final chapter in this part of the book. It employs historical GIS methods to investigate the demographics of the Orange Order (a Protestant organisation) migrants' origins and destination.

In Part III (*Climate, Weather, Environment*) the approach presented is almost reversed. Here the geosciences play the leading role while historical and textual analysis methods are used to introduce socio-economic dimensions. Jase Bernhardt's chapter (*Mining Weather and Climate Data from the Diary of a Forty-Niner*) shows how literary sources can be used to extract and visually represent spatiotemporal patterns in meteorological conditions. In Chapter 10 (*Unmappable Variables: GIS and the Complicated Historical Geography of Water in the Rio Grande Project*) Daniel R. Beene and K. Maria D. Lane show the value of mixed methods approach by combining GIS and historical-critical physical geography. This allows to capture complex dimensions of the Rio Grande Project irrigation practices and its lasting ramifications. The next chapter is by Chris Hewitt (*Supplying the Conquest: A Geospatial Visualization and Interpretation of Available Environmental Resources at* *the Battle of Hastings in 1066*). It presents a fresh insight into the geographical and historical contexts of the battle by applying GIS analysis of environmental resources. Robert Legg, Francis Ludlow and Charles Travis in Chapter 12 titled *Mapping the Irish Rath (Ringfort): Landscape and Settlement Patterns in the Early Medieval Period* bring the geostatistical methods into the analysis of the spatial patterns of ringforts locations. They also present a methodological insight into mixing GIS and fieldwork methods.

The final part of this volume is titled *Place, Philology, History* and focuses mainly on the mapping of historical landscapes and explores the links between GIS and humanities. In the first chapter (*Mapping Power: Using HGIS and Linked Open Data to Study Ancient Greek Garrison Communities*) Ryan Horne introduces the reader to the possibilities and shortcoming of using HGIS and Linked Open Data to study ancient communities. It is an informative reading into the rapidly developing world of digital infrastructures of data that had recently matured enough to be considered valid research tools. In Chapter 14, Gordon Cromley and Chris Post are exploring the potential of humanities GIS to rethink geographical and historical processes. In *The Preservation of Paradox: Bismarck Towers as National Metaphor and Local Reality*, they present the results of kernel density estimates, geo-visualisations and exploratory data analysis applied to the network of Bismarck monuments. Chapter 15 (*Mapping the Historical Transformation of Beijing's Regional Naming System*) by Yong Yu presents a unique approach to place names, where their spatial distribution reflects changes in the social and political history of the region. The final chapter of the book (*Geographical Enrichment of Historical Landscapes: Spatial Integration, Geo-Narrative, Spatial Narrative, and Deep Mapping*) by May Yuan allows the reader to glimpse into the future of innovations and advances in Geographical Information Science and Technology (GIST). In the text, one can find not only discussions on unmanned aviation vehicle (UAV) surveys, virtual reality, and augmented reality but also a thorough review of cartographic and phenomenological views on landscape.

When we consider the chapters as a whole, we can see that this is a very thorough and up-to-date compilation of the various views on the exercise of inter- and transdisciplinary research. Connecting all the chapters is the feeling of transgressing boundaries – both disciplinary and methodological. I perceive this as a main strength and selling point of this volume. There are many edited compilations with a similar aim, to introduce a mixed method approach, but it is surprisingly rare to find one that give this proposition without much bias. Here the readers can see the very different viewpoints on the seemingly similar problems and there is no indication that history, geosciences, geography or cultural studies have been given a dominant voice. For me, this is a clear sign that this approach is needed to successfully tackle research problems of the landscapes of time and place. However, despite its aforementioned strengths, the book has some weaknesses as well. I must confess here that I see myself as a digital geographer with a strong GIS background and this brings a certain bias to the way I see this book and evaluate its contents. With that being said, here are the things that I think are weaker parts of this title.

First and foremost – the quality of maps. This issue raises to importance in my view due to the fact that GIS is one of the main selling points here. Therefore, I would like to see all the maps well designed. It is not that there are none, but among the well-thought and brilliantly executed cartographic visualisations that shine in some of the chapters there are also a couple of bad apples. Maps in the same time form a strong backbone of this book and its weakest point. Some of the maps look dated with their choice of mapping techniques. Some clearly infringe on the cartographic principles. There are examples of bad colour palettes and symbology, lack of figure-ground distinction, unnecessary map decorations and 3D visualisations. Since in most cases those are relatively minor mistakes and omissions could be improved easily, I think that this could have been done with a little bit more editing effort.

The second issue I have with this title is admittedly strictly related to my background and interests, but I think that it is something that would be noticeably missing for many geographers/GIS scientists reading this book. The thing I am missing here is a more in-depth methodological and interdisciplinary discussion on the coming together of history, geography and GIS. Especially it is not hard to see how in many chapters GIS is treated as a tool without taking into account the rich landscapes of theory that amassed during the evolution of this discipline. Given the editors' strong background, I have expected a little bit more. However, this does not take any value from the included chapters – just that it feels like an opportunity have been missed here to even further advance the field.

All in all, those weaknesses are small in comparison to the potential impact of this book. It can certainly be seen as an excellent source of inspiration and the description of the current state of the art – an update for a classic book by Gregory, I.N. and Ell, P.S. (2007). With its wide coverage of the potential interactions and intersections of history, geography and GIS, it gives an excellent overview of the possibilities waiting in this lively area of research. I would recommend it as a must read to anyone that dabbles with Historical GIS. Not only that, but it is worth considering to any early career researcher or postgrad student of history or geoscience as an example of the way we can mix and blend methods from different disciplines to gain deeper insights and understanding. For this alone, it is worth making acquaintance with this volume.

Acknowledgement: This work was supported by the National Science Centre, Poland, grant number 2019/33/B/HS4/00057.

Michał Rzeszewski[1]

REFERENCES

Bol, P. and Ge, J. 2005. China Historical GIS. *Historical Geography* 33. 150–152.

Gregory, I.N., Kemp, K.K. and Mostern, R. 2001. Geographical information and historical research: Current progress and future directions. *History and Computing* 13. (1): 7–23.

Gregory, I.N., Bennett, C., Gilham, V.L. and Southall, H.R. 2002. The Great Britain Historical GIS Project: from maps to changing human geography. *The Cartographic Journal* 39. (1): 37–49.

Gregory, I.N. and Ell, P.S. 2007. *Historical GIS: Technologies, Methodologies, and Scholarship.* Cambridge, Cambridge University Press.

Gregory, I.N. and Healey, R.G. 2007. Historical GIS: structuring, mapping and analysing geographies of the past. *Progress in Human Geography* 31. (5): 638–653.

Gregory, I.N. and Geddes, A. (eds.) 2014. *Toward Spatial Humanities: Historical GIS and Spatial History.* Bloomington, Indiana University Press.

Knowles, A.K. (ed.). 2002. *Past Time, Past Place: GIS for history.* Redlands, ESRI.

Knowles, A.K. 2005. Emerging trends in historical GIS. *Historical Geography* 33. 7–13.

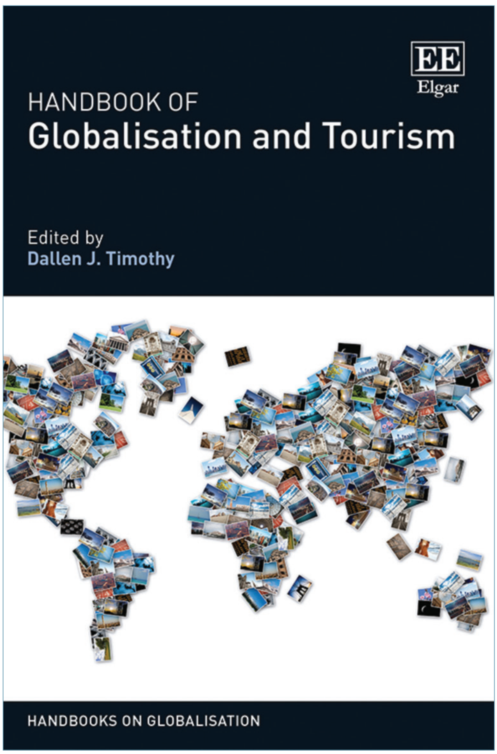
Lafreniere, D., Weidner, L., Trepal, D., Scarlett, S.F., Arnold, J., Pastel, R. and Williams, R. 2019. Public participatory historical GIS. *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 52. (3): 132–149.

[1] Faculty of Human Geography and Planning, Adam Mickiewicz University, Poznań, Poland. E-mail: mrz@amu.edu.pl

Timothy, D.J. (ed.): Handbook of Globalisation and Tourism. Cheltenham–Northampton, Edward Elgar, 2019. 341 p.

In 2020, the rapid spread of the COVID-19 pandemic made painfully evident the highs and lows of global interconnectedness for each inhabitant of the planet. New words such as lockdowns, home confinement, and social distancing were introduced to our tourism vocabulary in this *annus horribilis* for the industry. The collection of studies edited by Dallen J. Timothy on globalisation and tourism is antecedent to the pandemic and reveals to be an essential reading on the myriad of relations and impacts intertwined in and around tourism and on the sources of possible future challenges.

This edited volume is the fourth title belonging to the Elgar series on 'Handbooks on Globalisation.' Prior topics in the series include agriculture, development, and migration. The aim of the handbook series is to "provide an international and comprehensive overview of the debates and research positions in each key area of interest" (p. i). This volume on tourism, in fact, provides an extensive review of the meanings, implications and roles of tourism from a global perspective. The focus of the volume is to



"examine the ways in which tourism functions as a stimulator of, and conduit for, globalisation" (p. iii) by crediting tourism for being one of the most powerful engines to drive globalisation. Such power, as claimed in the volume, should be accompanied by responsibility, ethics, planning and good management.

The handbook is divided into six sections, which are equally balanced since they contain three to five chapters each. The illustration of the volume is not particularly rich, the volume lists only 14 figures, and five out of the nine tables are included in Chapter 14 on Global population dynamics. Infographics and maps would have been explicative to make global processes and implications for tourism visible. Subjects of particular interest to the readers of Hungarian Geographical Bulletin discussed in the volume are human mobility and the concept of home, geopolitics and security, cultural globalisation and transnational cultural routes, and the fluid meaning of place and placelessness. The volume argues that the meanings of borderlines, transition zones, cores and peripheries, virtual and cyber spaces evolve and change according to the role those cover in tourism. A general overview of globalisation and tourism is offered in the introduction written by the editor and built on a succinct historic perspective on human mobility.

Section 1 focusses on globalisation, its meanings and processes, and features four essays. In Chapter 2, Larry Dwyer and Nevenka Čavlek explore the role of multinational corporations (MNCs) and underline the change in the geographical perspective of MNS' capital investments shifting from North America and Europe to China and India. The authors discuss the impacts that MNCs generate in host countries. In more, the role of stakeholders such as tourism operators and tourists themselves is addressed in the context of MNS investments. In host countries, although profit-led interests of MNCs generate income and employment, corporations can induce negative social and environmental impacts and impoverish local communities. Tourism operators must acknowledge that the global marketplace allows MNCs to create vertically integrated businesses and handle mass tourism movements, while small and medium enterprises can only compete in niche markets. Chapter 3 by Stephen Wearing, Matthew McDonald, Greig Taylor and Tzach Ronen discusses the economic ideology of neoliberalism which has driven the global tourism industry for the past decades. The wide range of negative impacts of neoliberalism (free open market policies generating environmental, social and health damages) is addressed. The authors identify a solution in putting local communities in charge, delegating them the task to handle the enormous damage done in destinations. To reflect on neoliberalism, it must be noted here, that the COVID-19 pandemic disrupted these neoliberal market mechanisms. As Ioannides, D. and Gyimóthy, S. (2020) argue, "the crisis has brought us to a fork in the road – giving us the perfect opportunity to select a new direction and move forward by adopting a more sustainable path" (p. 624).

Local economic development and planning are the topics discussed in Chapter 4 by Christian M. Rogerson from the University of Johannesburg, South Africa. Cities in the Global North often leverage on the visitor economy and tourism to reposition themselves via place-based economic development. This trend has a parallel in the Global South, where new leisure spaces, 'the infrastructure of play' (p. 49), are built despite the different capabilities and capacities to implement sound planning strategies.

Section 2 gathers three essays on human mobility. The first one from Hall, Amore and Arvanitis critically analyses the globalising force of human mobilities by introducing the concept of metagovernance and raises concern about the macro issues of contemporary tourism. The authors call for a new form of tourism mobility governance to enhance sustainability, though the approach and steps needed to implement it are left for future research. Allan M. Williams claims in Chapter 6 on migration, tourism and globalisation that the importance of distance and proximity has been accentuated by globalisation and has driven visiting friends and relatives (VFR) tourism.

Section 3 entitled 'Geopolitics, security and conflict' includes six essays. Hazel Tucker from the University of Otago reflects on the tourism legacies of colonialism starting from colonial core-periphery relationships and concluding with counter-narratives offered by tourism. In Chapter 9, Dallen J. Timothy examines the role of tourism in the creation and development of multinational alliances. Chapter 10 entitled 'Biological invasion, biosecurity, tourism and globalisation' by Michael C. Hall is particularly timely and of outmost significance. Hall's analysis reveals how nature-based tourism is both directly and indirectly connected to the spread of pathogens in remote areas. But most of all, this chapter raises concerns about individual, national and transnational responsibilities related to the long-term cost of biological invasions in new/old environments. In Chapter 11 by Bruce Prideaux, the impact of terrorism on global tourism is approached by three perspectives: terrorism as a risk, its impact on tourism, and possible responses. Prideaux claims that tourism destinations that elaborate crisis management strategies must take into account the importance of managing fake news and its widespread consequences. Wantanee Suntikul provides an overview on war heritage tourism and memorial in Chapter 12 on tourism and war. She discusses the popularity of visiting battlefields of real-time war sites and guided tours like the 'Assad tour' in Syria. The phenomenon is not new, in 1854 in the Crimean War tourists followed closely the siege of Sevastopol (Irimiás, A. 2014). Recently, mass and social media have played a pivotal role to amplify the spectacle of real-time war tourism. In Chapter 13 entitled 'Tourism, peace and global stability,' the cultural geographer Alon Gelbman explains how sport and heritage tourism have a symbolic role in developing peaceful relations between countries in conflict.

Section 4 deals with the topic of population and environmental challenges and draws on four essays. Richard Sharpley investigates the implications of population dynamics on global tourism focussing on the management of resources from a neo-Malthusian perspective and addressing new trends like the so-called silver-haired tourism. Chapter 15 by Will Stovall, James Higham, and Janet Stephenson on the anthropogenic climate change and tourism, highlights the negative impacts of the global aviation industry by addressing the shortfalls of outdated governance measures and mitigation strategies. The authors believe that the only way to meet the sustainability goals is a collective commitment to reduce gas emissions. Brent W. Ritchie and Yawei Jiang in Chapter 16 entitled 'Tourism, globalisation, and natural disasters' focus on the developing countries and regions, where ecosystems are particularly vulnerable. The authors urge for taking a global perspective in research on tourism disaster management rather than employing case studies. The implementation of transnational disaster governance and global collaboration is identified as essential to tourism disaster management. The COVID-19 pandemic made crystal clear that no countries can be safe and prosperous without a transnational common understanding of sustainability. Chapter 17 written by colleagues from the University of Botswana and from the Okavango Research Institute analyses the impacts of global tourism on ecosystem management. In particular, the authors express serious concerns about the exploitation and degradation of resources and ecosystems. Current corporate responsibility strategies fail to provide a sustainable approach to mitigate ecosystem damage and to improve local residents' living standards, let alone wellbeing.

Section 5 'Innovation and technology' includes five essays. In Chapter 18, Mike Peters and François Vellas investigate the interdependencies between globalisation and innovation, keeping in mind the geographical differences and the peculiarities of community versus corporate-oriented destinations. The authors call for further research on the growth strategies of small and medium-sized enterprises (SMEs). In Central Eastern European countries, the topic of internationalisation and the role of innovation in tourism SMEs is less studied although it is of key relevance in sustainable tourism management. Chapter 19, written by David T. Duval and John Macilree, a former advisor of the New Zealand Treasury and Ministry of Transport, is an exquisite contribution on the assessment of transport innovation by addressing the issues of technology, commerce and policy. The authors claim that technological innovation should go hand in hand with new regulatory and policy approaches to support regional development. Claudia tom Dieck and Dai-In Han reflect on the links between tourism and augmented reality from the co-creation and value creation perspective in Chapter 20. In Chapter 21, Marianna Sigala investigates the radical influence of social media on the tourism experience and tourist behaviour. The chapter provides a balanced perspective on the positive and negative impacts of social media networks on tourism. Sigala also questions whether tourists honestly rely on user generated content when consumers are well aware of the illusory travel visuals and fake nature of selfies. Chapter 22 by Kevin Hannam concludes Section 5. Hannam calls for an interdisciplinary analysis of mobility and the development of smart cities.

Section 6 is entitled 'Cultural issues and contemporary mobility trends' and includes five essays dealing with topics such as religious tourism, pop culture tourism, volunteer, medical and last chance tourism. Each chapter is delivered by an international expert of the topic. Daniel H. Olsen critically addresses in Chapter 23 the managerial issues linked to spirituality and pilgrimage in our globalised world. In Chapter 24, Sue Beeton provides an overview of the issues, trends and implications of pop culture (movies, music, fashion, TV-series etc.) on tourism, with a focus on tourists. Jacob Henry, a cultural geographer and a former volunteer tourist, along with Mary Mostafanezhad from the University of Hawaii deliver Chapter 25 entitled 'The geopolitics of volunteer tourism.' The authors claim that critical geopolitics (feminist/everyday, environmental, and imperial) offer the approach to understand the transnational and humanitarian interactions in popular forms of volunteer tourism such as teaching, conservation, and infrastructure. I think that in Central and Eastern European countries we could benefit by employing the feminist approach. In Hungary, some neglected and underdeveloped regions see the intervention of elite volunteer domestic tourists, and the feminist approach would provide insights to the 'spatialized imaginary of aspiration.' Chapter 26 by John Connell discusses medical mobility and tourism with a focus on 'reverse globalisation' that countries of the Global South turn to be medical tourism destinations. The rapid rise of medical tourism, for its fragile and fluid nature, challenges its management in Asian countries. To conclude the global excursus of tourism, Chapter 27 by Harvey Lemelin and Paul Whipp fills a caveat about the consequences of inefficient, ill-managed and short-sighted planning and business strategies. It is imperative that the Great Barrier Reef in Australia or the glaciers of New Zealand should not turn to be 'last chance tourism destinations.' Chapter 28 is the concluding one by Dallen J. Timothy on the historic roots and future paths of globalisation and tourism. The editor claims for new approaches in considering the implications of technological innovation, changing mobility paradigms and cultural globalisation. He advises that not only hyperconnected destinations but 'placeless spaces' also need to be drawn on the map of global tourism.

To conclude this review, I think the strong and meticulous editorship makes the book a solid composition and a goldmine for references. Each chapter adopts a global perspective and issues are considered for their widespread economic, social, environmental and human implications. The volume is not only another advocate for sustainable tourism. Rather it provides a critical and clear statement on the positive and negative impacts of global tourism and on the absolute need of collaboration, social and individual responsibility. The COVID-19 pandemic has shown how fragile the tourism industry is. In the Mediterranean regions, criminal organisations are already active to purchase tourism resorts, hotels and small and medium-sized enterprises. As the volume claims, transnational governance and policy should be more rapid and efficient to tackle problems and issues, as any issue has global consequences. Every chapter concludes with some practical and managerial implications, although these were rarely based on cutting-edge research, rather included some general recommendations on sustainable tourism. This is not the weakness of the volume, but the weakness of academia. More research involving stakeholders like local residents, policy-makers, industry representatives, SMEs etc. is paramount to explore new paths in globalisation and tourism. This edited volume is a highly recommended source for policy-makers, academics, undergraduate and postgraduate students, volunteer, pop culture and Instagram tourists.

Acknowledgement: Project no TKP2020-NKA-02 has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the Research Excellence Program funding scheme.

Anna Irimiás[1]

REFERENCES

Ioannides, D. and Gyimóthy, S. 2020. The COVID-19 crisis as an opportunity for escaping the unsustainable global tourism path. *Tourism Geographies* 22. (3): 624–632.

Irimiás, A. 2014. Review on 'Tourism and War' by Butler, R. & Suntikul, W. (Eds.). Routledge (Taylor & Francis Group) London and New York, 2013. *Tourism Management* 42. 260–261.

[1] Corvinus University of Budapest, Budapest, Hungary. E-mail: anna.irimias@uni-corvinus.hu

Manuscript reviewers

2018–2020

The editors of the Hungarian Geographical Bulletin would like to thank the following experts who have offered their assistance in reviewing manuscript submissions to our journal issues between Number 1 in 2018 and Number 4 in 2020. Their efforts and useful comments have been of great service for the authors and the journal.

ANGILERI, Sylvia Eleonora (Palermo)
BAJMÓCY, Péter (Szeged)
BALOGH, Péter (Budapest)
BALTEANU, Dan (Bucharest)
BARCZA, Zoltán (Budapest)
BEKE, Szilvia (Szeged)
BENEDEK, József (Cluj-Napoca)
BÍRÓ, Borbála (Budapest)
BONTJE, Marco (Amsterdam)
CENTERI, Csaba (Budapest)
ĆORLUKA, Goran (Split)
CZIGÁNY, Szabolcs (Pécs)
CSAPÓ, János (Pécs)
DEÁK, Balázs (Budapest)
DEÁK, Márton (Budapest)
DRAGICEVIC, Slavoljub (Belgrade)
FARSANG, Andrea (Szeged)
GÁL, Tamás (Szeged)
GARCÍA-ARNAY, Ángel (Zaragoza)
GAVRILOV, Milivoj B. (Novi Sad)
GYURIS, Ferenc (Budapest)
HÄIDER, Martin (Munich)
HARMAT, Ádám (Budapest)
HOFIERKA, Jaro (Košice)
HOUSKOVA, Beata (Bratislava)
HRUŠKA, Vladan (Ústí nad Labem)
IRIMIÁS, Anna (Budapest)
JAKAB, Gergely (Budapest)
KARÁCSONYI, Dávid (Darwin)
KERN, Zoltán (Budapest)
KERTÉSZ, Ádám (Budapest)
KEVE, Gábor (Budapest)
KISS, András (Budapest)
KISS, Éva (Budapest)
KOK, Herman (London)
KOLOSSVÁRY, Endre (Budapest)
KOVÁCS, Tibor (Eger)
KUBEŠ, Jan (České Budějovice)
KULCSÁR, Balázs (Debrecen)
LABANCZ, Viktória (Gödöllő)
LANGE, Bastian (Leipzig)
LÁSZLÓ, Elemér (Debrecen)
LÁSZLÓ, Péter (Budapest)
LENKA, Lisá (Prague)
LEWIS, Quinn W (Bloomington)
LÓCZY, Dénes (Pécs)
MADARI, Beata (Brasília)
MAKÓ, András (Budapest)
MANTEL, Stephan (Wageningen)
MÁRK, László (Gyula)
MATLOVIČ, René (Bratislava)
MCINTOSH, Richard William (Debrecen)
MEZENTSEV, Konstyantyn (Kiev)
MICHALKÓ, Gábor (Budapest)
MIKA, János (Eger)
MILEVSKI, Ivica (Skopje)
MILOSEVIC, Dragan (Novi Sad)
MITKUS, Tomas (Vilnius)
NÉGYESI, Gábor (Debrecen)
NICOSIA, Enrico (Macerata)
NOVÁK, Tibor (Debrecen)
ORANJE, Mark (Pretoria)
PACHURA, Piotr (Częstochowa)
PARAJKA, Juraj (Vienna)
PÁSZTOR, László (Budapest)
PENIZEK, Vit (Prague)
PÉNZES, János (Debrecen)
PICHLER-MILANOVIĆ, Nataša (Ljubljana)
POPJAKOVÁ, Dagmar (Banská Bystrica)
REID, Neil (Toledo)
REMENYIK, Bulcsú (Budapest)
REPE, Blaz (Ljubjana)
RUSZKICZAY-RÜDIGER, Zsófia (Budapest)
SAVIC, Steven (Novi Sad)
SCHAD, Peter (München)
SCHWARZ, Ulrich (Vienna)
ŠIMON, Martin (Prague)
SINGH, Sudhir Kumar (Allahabad)
SIPOS, György (Szeged)
SIWEK, Tadeusz (Ostrava)
SKOKANOVÁ, Hana (Brno)
SLACH, Ondrej (Ostrava)
SMITH, Melanie (Budapest)
SZABÓ, György (Debrecen)
SZABÓ, Péter (Brno)
SZABÓ, Szilárd (Debrecen)
SZALAI, Zoltán (Budapest)
SZEMETHY, László (Pécs)
SZILASSI, Péter (Szeged)
TORMA, Csaba (Budapest)
TUROK, Ivan N. (Pretoria)
VACCA, Andrea (Cagliari)
VON SUCHODOLETZ, Hans (Leipzig)
WINTER, Johannes (Munich)
ZELENAKOVA, Martina (Košice)
ZIED, Hej-Amor (Sfax)
ZIZALA, Daniel (Prague)

GUIDELINES FOR AUTHORS

Hungarian Geographical Bulletin (formerly Földrajzi Értesítő) is a double-blind peer-reviewed English-language quarterly journal publishing open access **original scientific works** in the field of physical and human geography, methodology and analyses in geography, GIS, environmental assessment, regional studies, geographical research in Hungary and Central Europe. In the regular and special issues also discussion papers, chronicles and book reviews can be published.

Manuscript requirements

We accept most word processing formats, but MSWord files are preferred. Submissions should be single spaced and use 12pt font, and any track changes must be removed. The paper completed with abstract, keywords, text, figures, tables and references should not exceed **6,000 words**.

The Cover Page of the article should only include the following information: title; author names; a footnote with the affiliations, postal and e-mail addresses of the authors in the correct order; a list of 4 to 8 keywords; any acknowledgements.

An abstract of up to **300 words** must be included in the submitted manuscript. It should state briefly and clearly the purpose and setting of the research, methodological backgrounds, the principal findings and major conclusions.

Figures and tables

Submit each illustration as a separate file. Figures and tables should be referred in the text. Numbering of figures and tables should be consecutively in accordance with their appearance in the text. Lettering and sizing of original artwork should be uniform. Convert the images to TIF or JPEG with an appropriate resolution: for colour or grayscale photographs or vector drawings (min. 300 dpi); bitmapped line drawings (min.1000 dpi); combinations bitmapped line/photographs (min. 500 dpi). Please do not supply files that are optimised for screen use (e.g., GIF, BMP, PICT, WPG). Size the illustrations close to the desired dimensions of the printed version. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article.

REFERENCES

Please ensure that every reference cited in the text is also present in the reference list (and vice versa).

Reference style

Text: In the text refer to the author's name (small capitals with initials) and year of publication. References should be arranged first chronologically and then further sorted alphabetically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', placed after the year of publication.
Examples: (Ridgewell, A.J. 2002; Maher, B.A. *et al.* 2010) or Ridgewell, A.J. (2002); Maher, B.A. *et al.* (2010).

Journal papers:
Aagaard, T., Orford, J. and Murray, A.S. 2007. Environmental controls on coastal dune formation; Skallingen Spit, Denmark. *Geomorphology* 83. (1): 29–47.

Books:
Pye, K. 1987. *Aeolian Dust and Dust Deposits.* London, Academic Press.

Book chapters:
Kovács, J. and Varga, Gy. 2013. Loess. In *Encyclopedia of Natural Hazards.* Ed.: Bobrowsky, P., Frankfurt, Springer, 637–638.

Book reviews

Book reviews should be between 2,000 and 3,000 words (including references).

Submission

Submission to this journal occurs online. Please submit your article via http://ojs3.mtak.hu/index.php/hungeobull/about/submissions.

All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail.

Publisher:
Research Centre for Astronomy and Earth Sciences
9400 Sopron, Csatkai Endre u. 6–8., Hungary

Editorial office:
Geographical Institute, Research Centre for Astronomy and Earth Sciences
1112 Budapest, Budaörsi út 45., Hungary
Phone, fax: +36 1 309 2628
E-mail: geobull@mtafki.hu, kovacs.zoltan@csfk.mta.hu
Distribution: Gabriella Petz, petz.gabriella@csfk.mta.hu
Full text is available at https://ojs3.mtak.hu/index.php/hungeobull

Typography: Eszter Garai-Édler
Technical staff: Fanni Koczó, Anikó Kovács, Gáspár Mezei

Cover design: Anna Redl
Printed by: Pannónia Nyomda Kft.

HU ISSN 2064–5031
HU E-ISSN 2064–5147

Distributed by the Geographical Institute, Research Centre for Astronomy and Earth Sciences

Subscription directly at the Geographical Institute, Research Centre for Astronomy and Earth Sciences (H-1112 Budapest, Budaörsi út 45), by postal order or transfer to the account IBAN: HU24 10032000-01730841-00000000. Individual copies can be purchased in the library of the Institute at the above address.