ANDRÁS IGARI

Regional Differences of the Spread of the Coronavirus in Central Europe

Abstract

The Coronavirus pandemic has had a severe impact on a worldwide scale, including on Central Europe, and was characterised by considerable territorial disparities. The aim of this article is to present a statistical analysis of pandemic data to show which regions in Central Europe were the most and least affected by the COVID-19 in each period of the pandemic, since the beginning of the first wave – February 2020 – until the end of the third wave – Summer 2021 –, with a particular focus on the geographical reasons behind the differences. The paper found that cities and tourist regions were heavily affected in the initial phase of each wave due to their prominent role in human mobility; however, over time these disparities disappeared and the vulnerability of each region became the determining factor in mortality which affected rather the rural and peripheral regions in Central Europe.

Keywords: COVID-19, Central Europe, Spatial Diffusion; Epidemic Diffusion, Health Inequalities

JEL-code: I14, I18, O33, P46, P48

INTRODUCTION

The novel Coronavirus pandemic has had a severe global impact but various countries and regions have been affected in a different time and measure. These geographical disparities highlight the need for analysing the spatial characteristics of diffusion and exploring the main factors which facilitate or inhibit the spread of disease. Mobility of population in global networks play a basic role in the spread of epidemics which could affect the spatial pattern of the diffusion: diseases appear firstly in main transportation hubs (usually this means the largest cities and main tourist regions), secondly in lower-level centres and finally in the countryside. However, the later epidemiological situation could be affected by many other factors: social and demographic characteristics of the population, preparedness of the health care system, policy responses etc. It also depends on the temporal factor: different regional differences could be observable in different time frames.

This article is aiming to show the spatiotemporal pattern of the spread of the pandemic and to detect possible affecting geographic factors - regarding Central Europe. First, spatial diffusion models and the spatial characteristics of epidemic spread are presented, based on the literature. This is followed by a description of the research methodology and the spatial and temporal framework of the analysis, showing the challenges in using pandemic data. The body of the article can be divided into two main parts: while the first examines the spatiotemporal pattern of COVID-19 diffusion and the possible explanatory factors (regional typologies, mobility indicators), the second looks at the regional differences of pandemic indicators (number of cases, mortality) of each wave separately and analyses the impact of possible geographical characteristics on them. Finally, the paper concludes with the spatial characteristics of the spread of COVID-19 in Central Europe.

1. SPATIAL DIFFUSION MODELS OF EPIDEMICS

To understand the spatiality of epidemic spread the so-called spatial diffusion model of Torsten Hägerstrand (1967) plays an important role. Although it mainly focuses on the diffusion of innovations, its main findings can also be applied to epidemic diffusion research: on one hand, spreading pandemics occur in waves, and on the other hand, the geographical position has a fundamental influence on when a wave reaches a given area. The main stages of spatial diffusion waves are the following:

- Primary / initial phase: the beginning of diffusion, only in some centres the phenomenon is still present
- Diffusion phase: the real diffusion, when the phenomenon spreads out from the centres and causes strong regional differences
- Densification phase: in this phase, the number of people affected by the phenomenon increases everywhere, thus reducing regional disparities
- Saturation phase: the diffusion wave slows down and differences continue to decrease.

The spatial pattern of diffusion of phenomena (including epidemics) can be basically classified into two main types, based on regional science theories. One of these is the so-called contiguous-type diffusion, where the spatial pattern of diffusion is based on geographical proximity. The phenomenon first appears in the areas geographically closest to the origin point, then in their neighbours and so on. In the other, so-called hierarchical-type diffusion, the role of certain hubs (usually main cities at the top of the settlement hierarchy) is prominent: the phenomenon spreads first to major centres and then downwards in the settlement hierarchy (Hägerstrand, 1967; Morrill et al., 1988; Nikodémus, 1991; Haggett, 2006; Nemes Nagy, 2009).

What sets human-to-human epidemics apart from most spatial diffusion processes is that human mobility plays a prominent, direct role in them. Individuals carry the virus, which in most cases requires direct contact for transmission. This is why research regarding the role of mobility and the transport networks in spatial diffusion, at a global, national, regional or even municipal-local level, is of paramount importance. However, the diffusion of an epidemy (and the spatial pattern of it) can be influenced by many other special factors. The spatial pattern of diffusion depends essentially on the mode of transmission of the disease:

different spatial patterns could be characteristic in the case of diseases transmitted by droplet transmission (e.g. COVID-19, all diseases associated with coronaviruses or influenza viruses etc.), sexually transmitted diseases (e.g. HIV, syphilis), infected waterborne diseases (e.g. cholera) and animal-borne diseases (e.g. malaria) (Childs et al., 2015). Location of the outbreak is also an important influencing factor; in most cases it is the place where zoonosis, i.e. the transmission of the disease from animals to humans, has occurred. Finally, the time course of the disease (how long it takes for symptoms to appear, how long one is infectious, recovery/death time, etc.), the mortality rate and the likelihood of transmission can also influence it.

Recently, a number of studies and analyses have focused on the spatial differences in the spatial spread of the COVID-19 pandemic at a Hungarian (Kiss, 2020; Uzzoli et al., 2021), Central European (Igari, 2021; Kovalcsik et al., 2021) and international level (Amdaoud et al., 2021; Bourdin et al., 2021; ESPON, 2020; Franch-Pardo, 2020; Rodríguez-Pose–Burlina, 2021). Furthermore, significant attention has been paid to the impact of mobility in spatial diffusion of the pandemic: Chen et al. (2020) investigated the impact of emigration from Wuhan on the spread of the COVID-19 within China, while Kincses and Tóth (2020) examined the links between international migration patterns and the emergence of the pandemic in Europe. There has also been important research on the role of mobility links and networks in the spread of the pandemic: Bogoch et al. (2020) estimated the expected infection levels in the cities most strongly linked to Wuhan from the number of international air routes, at a global level, while Gatto et al. (2020) modelled the role of transport networks in the spread of the pandemic in Italy. In the research of Brockmann and Helbing (2020) the role of the international air transport network in epidemic spread was examined - his research exploring the relationship between mobility networks and epidemic spread started almost two decades ago (Hufnagel et al., 2004; Belik et al., 2011; Brockmann–Helbing, 2013; Iannelli et al., 2017). Although, not topically created, but also relevant is the work of Balcan et al. (2010), who created a global epidemic prediction model using population data, mobility data and epidemic predictions - the so-called GLEAM-model.

Some researchers analyse relationships between people to model the spread of the pandemic (Lennert, 2021). These include agent-based models, in which individual people (actors - agents) “decide” according to given rules: they move in space and time, interacting with each other. Furthermore, a number of other spatially interpretable models have been used to investigate the spread of the pandemic (e.g. Giuliani et al., 2020; Munshi et al., 2020; O’Sullivan et al., 2020), which were designed to outline the expected effects of specific actions based on the available information. In addition to these methods, the COVID-19 pandemic has brought an explosion of research regarding the relationship of mobility and epidemic diffusion, with the huge amount and variety of data available, updated daily, allowing near real-time analysis on various spatial scales. Data from individual’s mobile phones plays a major role in these researches, allowing individual mobility patterns and inter-personal connections to emerge: Kuchler et al. (2020) investigated the relationship between social media contacts and case rates in sample areas in New York State and Lombardy, Gao et al. (2020) looked at the impact of closures on mobility at the US level, while Chan et al. (2020) used Google's COVID-19 Community Mobility Reports to examine this at a global level.

2. METHODOLOGY OF THE RESEARCH

This chapter presents the used indicators and methods, as well as the spatial and temporal framework of the paper. To *describe the spatial diffusion*, the data of Number of Reported Cases was downloaded from the official government Coronavirus-related websites (see in Annex 1) on a weekly basis.[1] The indicator of the Weekly New Reported Cases could be calculated from this data. However, in addition to the change in the number of cases, the article tries to show the *impact of the COVID-19 on human lives* through the Number of Reported COVID-19 Deaths – collected also from the official government Coronavirus-related websites on a weekly basis – and the regional level weekly Excess Mortality data based on Eurostat. The Excess Mortality could be described as "an unusual mortality increase during a specific period, in a given population." (Eurostat, 2021a). It is calculated by measuring the number of deaths from all causes in a given period with the average number of deaths in the same period in the last 5 years. However, to interpret the indicator of Excess Mortality, it should be noted that the weekly number of deaths in the region ranged between 19–25 thousand people in the 2015–2019 period in average: in January–February, on average, 5 thousand more people die in the region each week than in the summer period. For this reason (and other causes of death), Excess Mortality should be used with caveats for small variations, but for larger outliers it gives a better indication of the impact on lives over the period than the indicator of Number of Reported COVID-19 Deaths. (For more about the use of the indicator of Excess Mortality, see Ferenci [2022].) All of these pandemic indicators are summarised and analysed at NUTS 3 level, although for the Number of Reported COVID-19 Deaths and Excess Mortality – in several cases – the data was not available in this territorial level. Furthermore, all data are used in relative measure (per 100,000 inhabitants) so that the values for regions and countries can be compared.

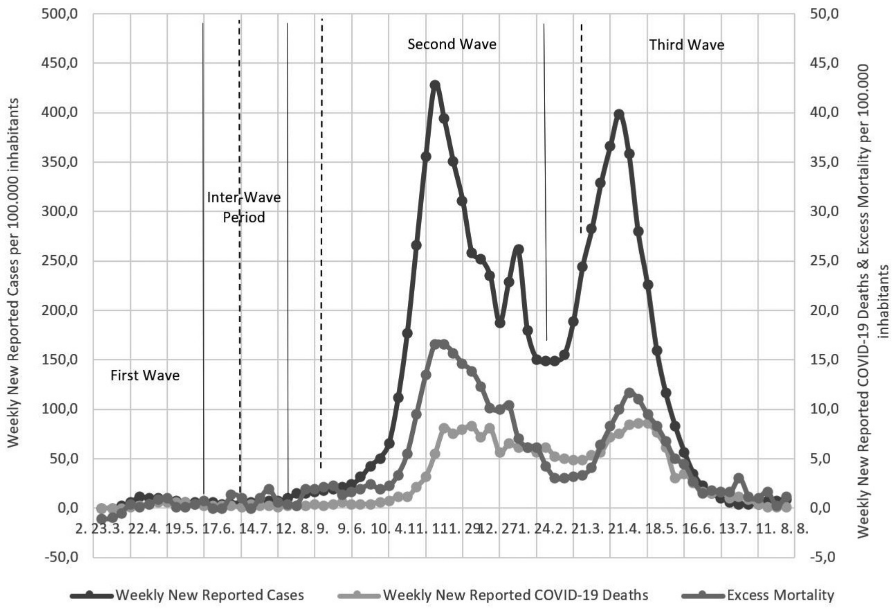
It must be noted, however, that while applying these indicators there are many *challenges in using pandemic data*. Firstly, testing capacity plays an important role in the Number of Reported Cases and in the Number of Reported COVID-19 Deaths. In all reported countries, there have been weeks when more than 20% of the tests performed were positive; it is well above the WHO recommended threshold (5%), meaning that the reliability of the resulting data is

[1] Date of data download: every Monday, the most recent data available for Sunday.

low and many cases remain hidden. There are also significant differences in the methodologies of pandemic data used by countries: while the recording of the Number of Reported Cases follows a broadly uniform methodology, there are significant methodological differences among countries in the recording of Number of Reported COVID-19 Deaths making interpretation of this indicator uncertain; therefore, the indicator of Excess Mortality is also used for this article. Finally, the spatial detail of data publication also varies from country to country, and it has changed many times over the last year.

The *spatial frame* of this research includes countries of Central Europe such as: Austria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia. The NUTS 3 level regions of these countries were the basis for the analysis: both pandemic and other types of data were downloaded focusing on this territorial level - if they were available. The *time frame* of the research is between the date of the first COVID-19 case reported in Central Europe – 25th February 2020 – and the end date for data collection of Number of Reported COVID-19 Cases is 4th July 2021. It is important to note that the waves in case-fatality rates are on average four weeks late - this is also reflected in the Central European data (as Figure 1 shows) and for Excess Mortality, which means that the data collection of mortality related data ends on 1st August 2021.

Figure 1 Weekly COVID-19 related data in Central Europe, from 24th February 2020, until 1st August, 2021



Source: Edited by author, based on official Coronavirus databases, 2021; Eurostat, 2021b

It was also an important task to *separate each wave in time* (even if it is not obvious to determine this exactly by day/week) so that each period can be analysed separately. In total, 3 + 1 periods were identified: the three waves and the Inter-Wave Period during the summer of 2020. It seemed important to analyse the latter separately because the spatial relevance of the epidemic diffusion in this period was different from that of each wave, and because the linking of data from this period to the First or Second Wave is difficult (at which date we determine the switch between waves) or may mislead the analysis. Overall, the following periods have been defined (the periods for the Number of Reported COVID-19 Deaths and Excess Mortality are indicated in brackets; Figure 1 also shows the separation of each period: the solid line shows the separation by number of cases, the dashed line shows the separation by mortality related indicators):

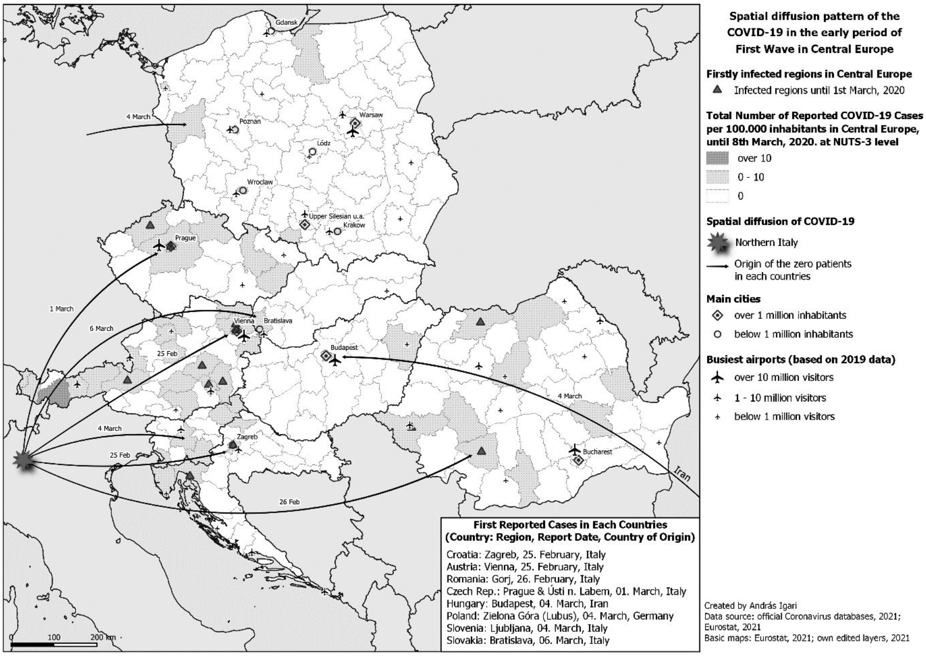
- First Wave: 25th February, 2020 – 17th May, 2020 (12th March, 2020 – 14th June, 2020)
- Inter-Wave Period: 17th May, 2020 – 19th July, 2020 (14th June, 2020 – 16th August, 2020)
- Second Wave: 19th July, 2020 – 31st January, 2021 (16th August, 2020 – 28th February, 2021)
- Third Wave: 31st January, 2021 – 4th July, 2021 (28th February, 2021 – 1st August, 2021)

3. SPATIAL DIFFUSION PATTERNS OF COVID-19 WAVES IN CENTRAL EUROPE

In Central Europe, the first cases were reported on the 25th of February 2020 in Zagreb and Vienna, but the virus was probably present in the region weeks earlier. This was followed by further reported cases in Croatia, Austria and Romania, and then in the next week in other countries (for the first infected regions and the possible links of the spread of the disease, see Figure 2). COVID-19 spread essentially throughout the region in March; the last infected region was Harghita County on the 2nd April, 2020.

The spatial pattern of the COVID-19 diffusion during the *First Wave* was influenced by several factors: on the one hand, the disease appeared first in the south-western part of Central Europe, linked to the hotspot in Northern Italy and then spread east and northwards. According to current knowledge, in 6 of the 8 countries in Central Europe the first reported cases connected to Northern Italy. Tourists, students and commuters travelling by air were therefore important transmitters of the outbreak. Regions with international airports (usually capitals and other major cities) were relatively early in the emergence of the virus. Regions with medium or big airports (more than 1 million visitors) were infected 3 days earlier than the regions with small airports (less than 1 million visitors) and 6 and half days before regions without airports, on average within each country. As Figure 2 shows, the first cases were found in the capital in 6 out of 8 countries, while by 8th March the virus had appeared in most major cities and conurbations in the region, with only a few reports from rural areas. This means that hierarchical diffusion prevailed in Central Europe in the initial phase of the First Wave. Tourism also played an important role, in case of Tyrol, a major beneficiary of winter tourism, becoming the first hotspot in Central Europe. On their return home migrant workers also triggered several early chains of infection (mostly in Poland, Romania and Hungary), as did daily commuting, which contributed to the early spread of the pandemic, both in the agglomerations of large cities and in border regions.

Figure 2 Spatial Diffusion of the COVID-19 in the early period of First Wave, in Central Europe



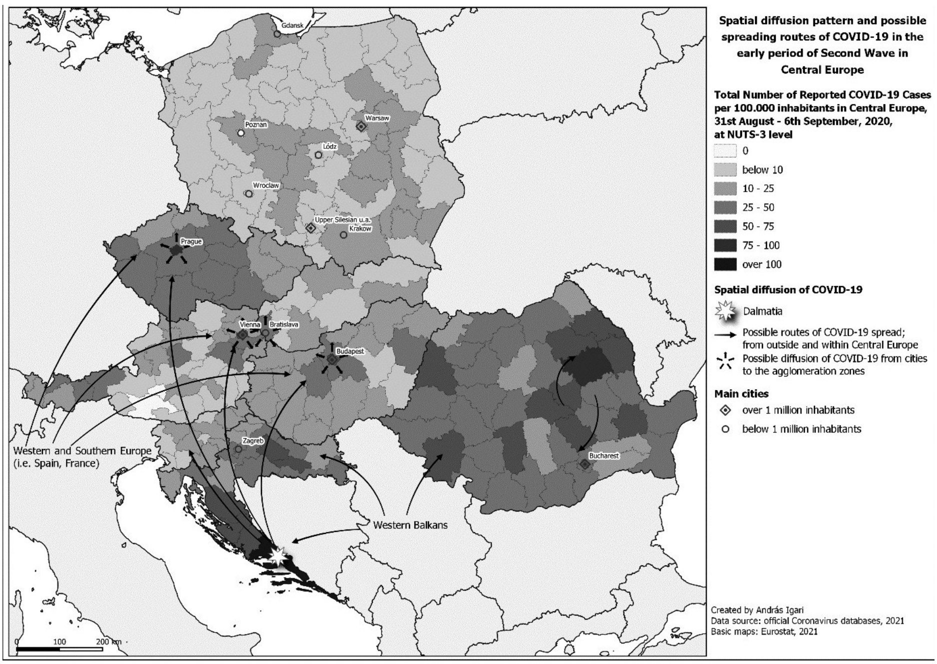
Source: Edited by author, based on official Coronavirus databases, 2021

The First Wave reached its peak very quickly and at a very low level compared to later waves; decline in the Number of Reported Cases already started in early April. This was mainly due to the fact that most countries in the region took strict measures (e.g. declaring a state of emergency, closing borders, closing certain services and shops, restricting events and gatherings) early on after COVID-19 had emerged, taking advantage of the fact that the outbreak reached the region a few weeks later than in Western Europe.

The First Wave was followed by a calmer period during summer in 2020, the *Inter-Wave Period* when the diffusion of COVID-19 was mostly stopped, but COVID-related infections and deaths still happened. However, these did not occur as a wave throughout the region, but were mainly linked to random hotspots, with the highest incidence in the regions of Wallachia and Southern Transylvania in Romania and Silesia in Poland, and later spreading to Moravian-Silesian Region in the Czech Republic (this highlights the fact that the pandemic was able to diffuse across borders in closely connected cross-border regions). The emergence of hotspots linked to specific institutions was still observed. The decline was indicated by the fact that all countries (except Romania and Poland) have seen a decrease in cases and deaths (the latter also in Poland).

Increased contact numbers during the Inter-Wave Period and a partial recovery of cross-border migration led to an intensification of the pandemic in July and August, triggering the *Second Wave* of it. Local hotspots gained strength and new hotspots emerged with a similar spatial pattern to the First Wave: international tourism made Dalmatia the main hotspot in the region by August, while in several countries (Austria, the Czech Republic, Hungary, Slovakia) the number of infected people increased firstly in the capitals and then in their agglomerations, again indicating a hierarchical pattern of diffusion (Figure 3).

Figure 3 Spatial Diffusion of COVID-19 in the early period of Second Wave, in Central Europe



Source: Edited by author, based on official Coronavirus databases, 2021

But there were no more similarities between First and Second Wave; during the autumn the pandemic exploded in Central Europe, with most countries' testing capacity unable to keep up: the peak was the week between 2–8th November, when 421 thousand Weekly New Cases were reported in Central Europe, while one in three tests were positive - presumably leaving many cases undetected. The main hotspots were in the Czech Republic and Slovenia, with weeks when 1% of the population in some regions was newly infected per week.

A further major difference is that while the First Wave of the pandemic ran roughly in parallel in the countries of the region, the Second Wave was much more volatile. The pandemic broke out in different weeks in different countries: at the very beginning of autumn, the Second Wave of the pandemic started rapidly in the regions of the Czech Republic, Southern Poland and Austria, and when it was halted by mid-November with the closures, the Croatian and Hungarian counties took the lead, but from mid-December onwards, the counties of the Czech Republic (the second wave had double-peaked in this country, due to the early withdrawal of the restrictions) and Slovenia were again the most infected.

The *Third Wave* was linked to the emergence of the British (Alpha) variant which arrived in the highly infected population in January 2021. This indicates that the circumstances of the start of this wave were very different from those of the previous two waves. While there were naturally no cases in Central Europe before the First Wave and only a low level of infection rate in most of the region during the Inter-Wave Period before the Second Wave, the start of the Third Wave coincided with the end of the Second Wave. Therefore, at the beginning of the Third Wave, the previous spatial pattern, i.e. the prominence of cities, was no longer present; although it is likely that the first cases associated with British (Alpha) variant were also present mainly in cities, in the absence of detailed data (presenting the variants separately), these cases cannot be separated from the cases related to the Second Wave.

Based on the data available so far, the spatiotemporal pattern of the Third Wave can be described as similar to that of the Second Wave in autumn: countries were severely affected at different time periods. In February, the Czech Republic, in March Hungary and Poland, and in April Croatia and Slovenia became the main hotspots. From May onwards, there was a significant decline observable and at the end of June, the Number of Weekly New Cases were similar as in the Inter-Wave Period. In part it is probably due to increasing vaccination rates: 5% of the population in the region received the full vaccination package at the end of March, 10% at the end of April, 19% at the end of May and one third at the end of June.

4. GEOGRAPHICAL FEATURES AFFECTING THE REGIONAL DIFFERENCES OF COVID-19

The impact of the pandemic's effect on human lives has become one of the most important issues of the past year and a half, both from a professional and a public perspective. This chapter attempts to provide a nuanced picture regarding the degree of exposure to the pandemic (totally and by waves) concerning certain Central European regions using the indicators presented in Chapter 2 and presenting geographical characteristics that may have influenced the differences.

Comparing the periods, huge differences were detectible between the first two periods (First Wave and Inter-Wave Period) and the Second and Third Waves. As Table 1 shows the difference between the weekly numbers of the Second and Third Wave was ten-thirty times higher than the First Wave and the Inter-Wave Period. The largest differences were in the Number of Reported Cases, but there was also a significant difference in the Number of Reported COVID-19 Deaths and Excess Mortality.

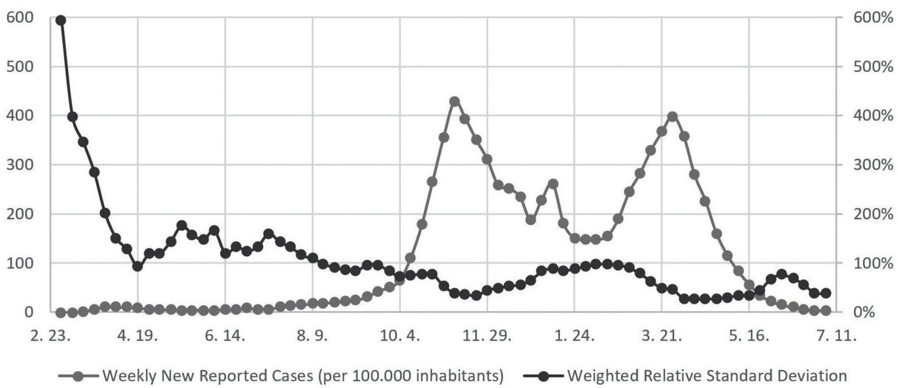
Table 1 Total and Weekly average number of COVID-19 related indicators by the different time periods

		First Wave (12 weeks)	Inter-Wave Period (9 weeks)	Second Wave (28 weeks)	Third Wave (22 weeks)	TOTAL (71 weeks)
Number of Reported Cases	Total	69,177	55,547	4,538,884	3,430,039	8,093,647
	Weekly average	5,765	6,172	162,103	155,911	113,995
Number of Reported COVID-19 Deaths	Total	4,393	2,400	118,279	80,986	206,058
	Weekly average	366	267	4,224	3,681	2,902
Excess Mortality	Total	6,544	9,953	198,786	101,392	316,676
	Weekly average	545	1,106	7,085	4,609	4,460

Source: Edited by author, based on official Coronavirus databases, 2021; Eurostat, 2021b

Furthermore, it is also observed that the spatial differences of the pandemic indicators change over time. As shown in Figure 4, the spatial disparity (the Weighted Relative Standard Deviation) in the Number of Reported Cases (per 100 thousand inhabitants) was the highest in the first week of the pandemic, from which point it decreased to around 100%. It fluctuated between 100–200% in the summer of 2020 and has decreased again since the Second Wave started. In general, the spatial inequalities were relatively high in the initial phase of each wave, because the Number of Reported Cases only increased in a few hotspots at first. Then the differences began to decrease: the lowest differences were not at the peak of each wave, but in the following few weeks, as by then the outbreak hotspots started to decline, while the decline was not so marked in the other, less affected regions. Finally, during the waning phase of the waves (as well as during the summer, Inter-Wave Period), the differences again increased; although most regions had very low values at this time, some regions still had an above average value.

Figure 4 Weekly New Reported Cases in Central Europe and the Weighted Relative Standard Deviation of it in NUTS 3 (Poland: NUTS 2) level, 25th February, 2020–4th July, 2021



Source: Edited by author, based on official Coronavirus databases, 2021

If we compare the individual periods, we also find that during the First Wave and the 2020 Inter-Wave Period there were higher spatial differences than during the Second and Third Waves, both at a Central European level and in each country. In the following, I will show the regional pattern of it and the regional characteristics which can influence that.

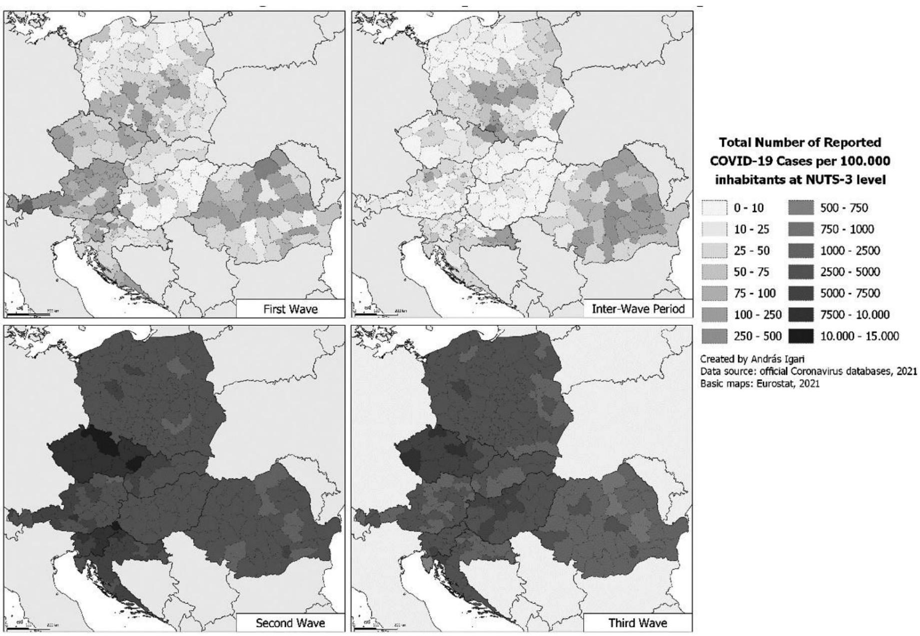
A closer look at the *spatial pattern of Number of Reported Cases* in each period reveals significant differences (Figure 5). Evaluating data available on the First Wave, we can detect very large spatial disparities. In fact, only a few regional hotspots emerged for specific reasons: in Tyrol, due to the winter tourism and the late closures, and in Suceava (Romania) because of the poor management of the pandemic by the county hospital which resulted in high rates. Furthermore, the hierarchical pattern – that characterised the diffusion of the pandemic at the beginning of the First Wave – has eased, but most countries continued to have infection levels above average in capital regions (regions of Prague, Budapest and Bratislava having the highest infection levels in their countries) and urban areas had 1.5 times higher infection levels than other regions.

When comparing the First Wave and the 2020 Inter-Wave Period, there were not significant differences in the average Number of Reported Cases, but the type of inequality indicates how the two periods diverged: the national level inequality of the First Wave appeared slightly higher (57% and 55%), while regional level inequality of the 2020 Inter-Wave Period were substantially higher (117% and 149%). However, the urban-rural disparities have essentially disappeared, and differences among regional hotspots and other areas became more noticeable. This originated more from insufficient protection in these regions than from geographic location or the easing of the first wave restrictions. The vulnerability of border areas should also be highlighted. At the end of the First Wave, countries reopened their borders (cross-border commuting was allowed by most countries during the First Wave, but with significant restrictions) and in several cases new hotspots were found in regions along the borderline with intensive links to previous hotspots on the other side.

During the initial phase of the Second Wave of the pandemic, regional disparities in the Number of Reported COVID-19 Cases increased again, but by the end of this wave, these values had decreased significantly. On one hand this is due to the differences among countries having been reduced (although the Czech Republic and Slovenia had high values, the other countries were not far behind); on the other hand, the differences within countries have essentially disappeared. Thus, the previously existing urban-rural differences were no longer significant (Kovalcsik et al. [2021] also indicates the disappearance of urban-rural difference in Central Europe, but there the focus was more on the shift of the pandemic's centre of gravity from Western part of the region (Germany) to the Eastern part).

Finally, there were only minor changes in spatial differences during the Third Wave: differences among countries remained, but in most countries the deviation among regions increased slightly (except in Austria and Slovenia). These disparities were partly along the regional typologies presented above. Poland and Romania continued to have high levels of urban infection rate (although this was probably due to spatial disparities in testing capacity), while in Croatia, the Dalmatian areas again became above average. However, these differences were not significant, so that the influence of regional typologies could not be identified. All in all, there has been a levelling off in the Number of Reported COVID-19 Cases over time and the initial regional disparities (cities, urban regions, tourist areas) have disappeared over time. As a result, by 4th July 2021, the disparities in infection rates were relatively low and were mainly due to differences among countries rather than among types of regions.

Figure 5 Regional pattern of Number of Reported COVID-19 Cases per 100.000 inhabitants during the examined time periods, in Central Europe

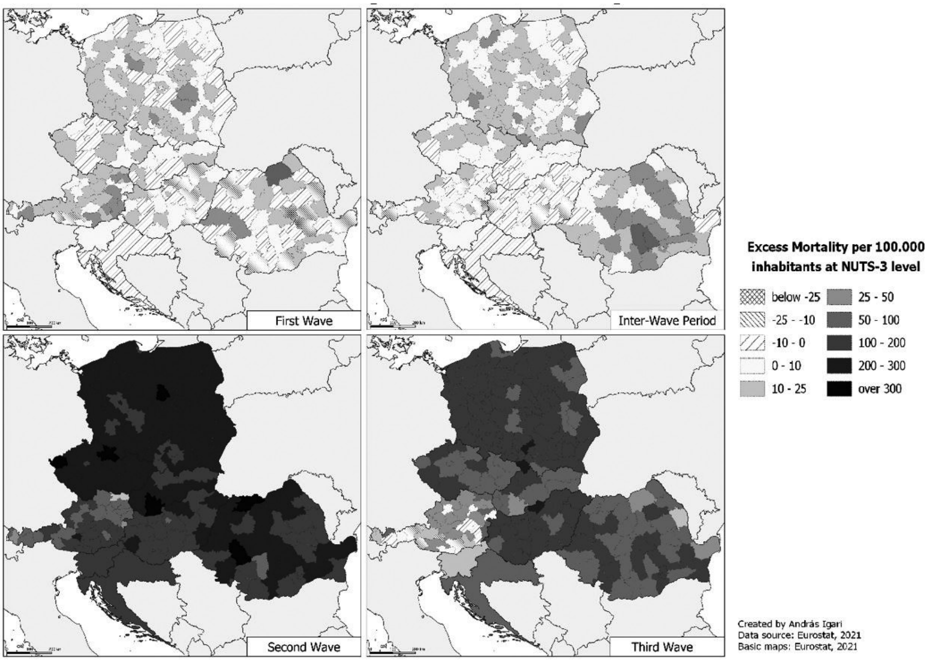


Source: Edited by author, based on official Coronavirus databases, 2021

Turning to *spatial disparities of mortality*, in many aspects different spatial patterns emerge. Both indicators' (Reported COVID-19 Deaths, Excess Mortality) spatial patterns have changed significantly over time. In the case of the First Wave, the highest COVID-19 Death Rates and Excess Mortality Rates were associated with the main hotspots: Suceava, Tyrol and Styria. In addition, in most countries, metropolitan and predominantly urban regions had above average mortality rates, due to their relatively high infection rates. However, the moderate impact of the pandemic is reflected in the negative Excess Mortality in Croatia and in some other regions. It was the same case in the 2020 Inter-Wave Period, with Hungary and Croatia having lower number of deaths than the average of the last five years. In contrast, above-average Excess Mortality Rates were found in Romania and Poland, partly overlapping with the local hotspots (Figure 6).

The Second Wave was characterised by a levelling off in terms of Reported Cases Rates, but by a more severe impact on deaths (including both indicators examined) in rural areas: in all countries of Central Europe, the mortality rates of predominantly urban and metropolitan regions were below average, despite the fact that the average infection rate was not lower in these regions. This may have been due to better health care in urban areas and lower vulnerability of the population living there (Balás et al., 2020; ESPON 2020; Guzzi et al., 2020; Kovács–Uzzoli, 2020; Uzzoli et al., 2020; Vinci et al., 2020). Finally, during the Third Wave, although infection levels were close to those of the Second Wave, mortality rates were slightly lower; presumably due in part to the onset of vaccination. During the Third Wave, the urban-rural differences disappeared in most countries, except in the Czech Republic, Slovakia and Hungary, where the mortality rates in the capital regions were below the national level. However, the differences among countries increased again, for several possible reasons: different vaccination levels in each country, different treatment of the pandemic wave, and possibly data management issues (the temporal separation of the Second and Third Waves is difficult). Poland and Hungary were hardest hit by the Third Wave, while several regions in Austria already had negative Excess Mortality Rate (Figure 6).

Figure 6 Regional pattern of Excess Mortality per 100.000 inhabitants during the examined time periods, in Central Europe



Edited by author, based on Eurostat, 2021b.

All in all, the chapter finds that while there was a levelling off over time in the Number of Reported COVID-19 Cases, the Excess Mortality Rate was below average in urban areas and metropolitan regions while in some peripheral regions it was well above average. This was the case in the Second Wave but these differences disappeared again by the Third Wave and urban-rural disparities are not significant. Analysing the pandemic as a whole, the highest Excess Mortality Rates were in Poland and the Czech Republic (above 350 per 100,000 inhabitants), while in Austria they remained particularly low (below 150). I also found that although urban areas had slightly lower Excess Mortality Rates than other regions, this is only so evidenced in a few countries: in the Czech Republic, Hungary and Slovakia, the capital had the lowest Excess Mortality Rate, while in Poland urban regions had better than average rates (e.g. Gdansk-Gdynia, Krakow). In contrast, Bucharest and Vienna had Excess Mortality Rates very close to the national averages for Romania and Austria.

5. CONCLUSIONS

The article analysed the spread of the COVID-19 pandemic in Central Europe until the end of the Third Wave. It focused on the spatial pattern of COVID-19 diffusion and regional disparities concerning pandemic data for each period. The aim was also to examine possible geographical factors and how they influenced the spatial diffusion of the pandemic. As a result of this research, it can be concluded that although the spatial pattern of each wave and period was different, certain geographical characteristics were present as influencing factors in several cases. The main findings are shown in Table 2.

Table 2 Characteristics and main affecting factors of each time period of COVID-19 spread in Central Europe

Characteristics / Periods		First Wave	Inter-Wave Period	Second Wave	Third Wave
Initial status and affecting factors	Infection level at the beginning of period	-	Low	Low	High
	Touristic season at the beginning of the period	Winter	-	Summer	-
	Characteristics of government actions	Timely, rigorous	Mitigation measures	Delayed action	Delayed action (some cases are preceded by mitigations)
Spatial pattern of...	the infections in the early part of the period	Hierarchical (hotspots: cities, winter tourist regions)	Random hotspots (Contiguous-type diffusion)	Hierarchical (hotspots: summer tourist regions, cities)	Difficult to determine - coincides with the end of the Second Wave
	the infections for the whole period	Slightly hierarchical	Random hotspots	Balanced	Balanced
	the mortality for the whole period	Slightly hierarchical	Random hotspots	Below average in cities	Differences among countries dominate
The severity of the epidemiological situation for the period as a whole		Low	Low	High	High-medium

Source: Own compilation

The paper found that transport hubs and tourist areas played a prominent role in the spread of each wave of the pandemic; therefore, the initial phase of the First and Second Waves were linked to major cities (with main transportation hubs) and the two main tourist regions of Central Europe; Tyrol and Dalmatia. However, for each period as a whole, the spatial pattern of infection and mortality depended on the severity and temporal frame of the pandemic situation in that period, which were strongly influenced by government measures. Thus, when strict and timely measures were taken by governments to slow the spread of the pandemic, the areas most affected initially (cities, tourist regions) and regions linked to random events (where local hotspots emerged) remained the most affected for the whole period (First Wave). Conversely, when action was delayed, the pandemic spread throughout the whole region, balancing the infection levels and reducing differences among and within countries. At the same time, as the urban-rural differences in infection rates disappeared, the cities were in a relatively favourable position in terms of mortality, thanks to their better health care and generally higher resilience (Second Wave). Finally, when the high infection levels were accompanied by slightly lower mortality rates - presumably due in part to the start of vaccination - the urban-rural differences disappeared in most countries, but the differences among countries increased again (Third Wave).

All in all, although urban-rural differences and tourist regions have a significant impact on the spread of the pandemic, government policies and the conditions at the start of a wave can have a major influence on which characteristics emerge. At the time of writing this essay, the Fourth Wave of the pandemic has not yet started in most countries of Central Europe. Although cities and summer tourist regions are expected to be particularly affected in the initial phase of this wave, in contrast to previous periods, most countries in Central Europe have a high level of vaccination (around 40-50% of the population is fully vaccinated; except Romania), which could also significantly influence the spatial pattern of spread regarding the new wave. There are also significant spatial disparities in this case, with urban areas in most countries having higher vaccination rate than rural areas, while the most vulnerable peripheral zones often have the lowest coverage. Changes in the resilience of different regions (and the emergence of new virus variants) can have a significant impact on the pattern of transmission. Further spatial analysis of this dynamically changed situation is an important task that can contribute to effective protection against the pandemic.

ACKNOWLEDGEMENT

I would like to extend my gratitude to the CEO of Hétfa Research Institute, Mr. András Csite PhD, who gave me an opportunity to do the *Weekly progress report on the spread of the Coronavirus pandemic in Eastern-Central Europe* (commissioned by the State Secretariat for National Policy of the Prime Minister's Office) which provided the database and preliminary results that were the basis of this research. I would also like to express special thanks to my supervisors, Mr. Ákos Jakobi PhD and Mr. Pál Szabó PhD (Eötvös Loránd University, Faculty of Science, Department of Regional Science) for helping me write this paper and to the editors for their valuable comments.

Nemzeti Kutatási, Fejlesztési És Innovációs Hivatal — Új Nemzeti Kiválóság Program — Innovációs és Technológiai Minisztérium

Supported by the ÚNKP-21-3 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund.

REFERENCES

- Amdaoud, M.–Arcuri, G.–Levratto, N. (2021) Are regions equal in adversity? A spatial analysis of spread and dynamics of COVID-19 in Europe. *The European Journal of Health Economics*, 22, 4, pp. 629–642. DOI: 10.1007/s10198-021-01280-6
- Balás, G.–Csite, A.–Igari, A.–Lőcsei, H. (2020): *Melyik Magyar járásokat veszélyeztethetik leginkább a nyaralójukba leköltözők?* HÉTFA Kutatóintézet, Budapest https://hetfa.hu/wp-content/uploads/2020/04/%C3%BCd%C3%BCl%C5%91k%C3%B6rzetek_mortalit%C3%A1s_j%C3%A1rv%C3%A1ny_H%C3%89TFA.pdf Downloaded: 17. 08. 2021.
- Balcan, D.–Gonçalves, B.–Hu, H.–Ramasco, J. J.–Colizza, V.–Vespignani, A. (2010) Modeling the spatial spread of infectious diseases: The Global Epidemic and Mobility computational model. *Journal of Computational Science*, 1, 3, pp. 132–145. DOI: 10.1016/j.jocs.2010.07.002
- Belik, V.–Geisel, T.–Brockmann, D. (2011) Natural Human Mobility Patterns and Spatial Spread of Infectious Diseases. *Physical Review X*, 1, DOI: 011001 10.1103/PhysRevX.1.011001
- Bogoch, I. I.–Watts, A.–Thomas-Bachli, A.–Huber, C.–Kraemer, M. U.–Khan, K. (2020) Potential for global spread of a novel coronavirus from China. *Journal of travel medicine*, 27, 2. DOI: taaa011 10.1093/jtm/taaa011
- Bourdin D.–Jeanne, L.– Nadou, F.–Noiret, G. (2021) Does lockdown work? A spatial analysis of the spread and concentration of COVID-19 in Italy. *Regional Studies*. 55, 7, pp. 1182–1193. DOI: 10.1080/00343404.2021.1887471
- Brockmann, D.–Helbing D. (2013) The Hidden Geometry of Complex, Network-Driven Contagion Phenomena. *Science*, 342, 6164, pp. 1337–1342. DOI: 10.1126/science.1245200
- Brockmann, D.–Helbing D. (2020) *Spreading Routes on a Global Scale*. Research on Complex Sytems, Berlin. https://rocs.hu-berlin.de/project/viz-event-horizon/ Downloaded: 17. 08. 2021.
- Chan, H. F.–Skali, A.–Torgler, B. (2020) *A Global Dataset of Human Mobility*. Center for Research in Economics, Management and the Arts (CREMA), Zürich.

• Chen, Z.–Zhang, Q.–Lu, Y.–Guo, Z.–Zhang, X.–Zhang, W.–Guo, C.–Liao, C.–Li, Q.–Han, X.–Lu, J. (2020). Distribution of the COVID-19 epidemic and correlation with population emigration from Wuhan, China. *Chinese Medical Journal*, 133, 9, pp. DOI: 1044–1050. 10.1097/CM9.0000000000000782
• Childs, L. M.–Abuelezam, N. N.–Dye, C.–Gupta, S.–Murray, M. B.–Williams, B. G.–Buckee C. O. (2015): Modelling challenges in context: Lessons from malaria, HIV, and tuberculosis. *Epidemics*, 10, pp. 102–107. DOI: 10.1016/j.epidem.2015.02.002
• ESPON (2020) *Geography of COVID-19 outbreak and first policy answers in European regions and cities – Policy Brief*. EPON EGTC, Luxembourg
• Eurostat (2021a) *Excess mortality – statistics*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Excess_mortality_-_statistics Downloaded: 23. 08. 2021.
• Eurostat (2021b) *Deaths by week, sex, 5-year age group and NUTS 3 region (demo_r_mweek3)*. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_mweek3&lang=en Downloaded: 21. 12. 2021.
• Ferenci T. (2022): *Többlethalálozási adatok európai összevetésben*. https://github.com/tamas-ferenci/ExcessMortEUR Downloaded: 25. 01. 2022.
• Franch-Pardo, I.–Napoletano, B. M.–Rosete-Verges, F.–Billa, L. (2020) Spatial analysis and GIS in the study of COVID-19. A review. *Science of The Total Environment*, 739. DOI: 10.1016/j.scitotenv.2020.140033
• Gao, S.–Rao, J.–Kang, Y.–Liang, Y.–Kruse, J. (2020) Mapping county-level mobility pattern changes in the United States in response to COVID-19. *SIGSPATIAL Special*, 12, 1, pp. 16–26. DOI: 10.1145/3404820.3404824
• Gatto, M.–Bertuzzo, E.–Mari, L.–Miccoli, S.–Carraro, L.–Casagrandi, R.–Rinaldo, A. (2020) Spread and dynamics of the COVID-19 epidemic in Italy: Effects of emergency containment measures. *Proceedings of the National Academy of Sciences of the USA*, 117, 19, pp. 10484–10491. DOI: 10.1073/pnas.2004978117
• Giuliani, D.–Dickson, M. M.–Espa, G.–Santi, F. (2020) Modelling and predicting the spatio-temporal spread of COVID-19 in Italy. *BMC Infectious Diseases*, 20, 700. DOI: 10.1186/s12879-020-05415-7
• Guzzi, P. H.–Tradigo, G.–Veltri, P. (2020) Spatio-Temporal Resource Mapping for Intensive Care Units at Regional Level for COVID-19 Emergency in Italy. *International Journal of Environmental Research and Public Health*, 17, 10, p. 3344. DOI: 10.3390/ijerph17103344
• Hägerstrand, T. (1967) *Innovation diffusion as a spatial process*. University of Chicago Press, Chicago
• Haggett, P. (2006) *Geográfia: globális szintézis*. Typotex, Budapest
• Hufnagel, L.–Brockmann, D.–Geisel, T. (2004) Forecast and control of epidemics in a globalized world. *Proceedings of the National Academy of Sciences*, 101, 42, pp. 15124–15129. DOI: 10.1073/pnas.0308344101
• Ianelli, F.–Koher, A.–Brockmann, D.–Hövel, P.–Sokolov I. M. (2017) Effective distances for epidemics spreading on complex networks. *Physical Review E*, 95, 1. arXiv:1608.06201 DOI: 10.1103/PhysRevE.95.012313
• Igari, A. (2021): *Koronavírus: íme a térkép, így terjed a járvány Közép-Európában*. HÉTFA Kutatóintézet, Budapest https://hetfa.hu/wp-content/uploads/2021/02/Koronavirus_KozepEuropa_Hetfa_Igari.pdf Downloaded: 30. 01. 2022.

• Kincses, Á.–Tóth, G. (2020) How coronavirus spread in Europe over time: national probabilities based on migration networks. *Regional Statistics*, 10, 2, 228–231. DOI: 10.15196/RS100210
• Kiss, J. P. (2020): A magyar koronavírus-térkép – és ami abból következik. *HVG*. https://hvg.hu/tudomany/20200408_magyar_koronavirus_terkep_jarvany_teruleti_eloszlas_adatok Downloaded: 30. 01. 2022.
• Kovács, S. Zs.–Uzzoli, A. (2020) A koronavírus-járvány jelenlegi és várható egészségkockázatainak területi különbségei Magyarországon. *Tér és Társadalom*, 34, 2, 155–170. DOI: 10.17649/TET.34.2.3265
• Kovalcsik, T.–Boros, L.–Pál, V. (2021) A COVID-19-járvány első két hullámának területisége Közép-Európában. *Területi Statisztika,* 61, 3, 263–290. DOI: 10.15196/TS610301
• Kuchler, T.–Russel, D.–Stroebel, J. (2020) *The geographic spread of COVID-19 correlates with the structure of social networks as measured by Facebook*. National Bureau of Economic Research, Cambridge (MA). https://www.nber.org/system/files/working_papers/w26990/w26990.pdf Downloaded: 23. 08. 2021. DOI: 10.3386/w26990
• Lennert, J. (2021) A SARS-CoV-2 vírus magyarországi terjedésének ágens alapú modellezése – az első járványhullám tapasztalatai. *Tér és Társadalom,* 35 3, 3–32. DOI: 10.17649/TET.35.3.3341
• Morril, R.–Gale, G. L.–Thrall, G. I. (1988) *Spatial diffusion*. Reprint. Edited by Grant Ian Thrall. WVU Research Repository, 2020.
• Munshi, J.–Roy, I.–Balasubramanian, G. (2020) *Spatiotemporal dynamics in demography-sensitive disease transmission: COVID-19 spread in NY as a case study*. arXiv. https://arxiv.org/ftp/arxiv/papers/2005/2005.01001.pdf
• Nemes Nagy, J. (2009) *Terek, helyek, régiók – A regionális tudomány alapjai*. Akadémia Kiadó, Budapest. DOI: 10.1556/9789630598644
• Nikodémus A. (1991) A térbeli diffúzió problémája és alkalmazási lehetőségei. *Földrajzi Értesítő*, 40, 1–2, 7–24.
• O'Sullivan, D.–Gahegan, M.–Exeter, D. J.–Adams, B. (2020) Spatially explicit models for exploring COVID-19 lockdown strategies. *Transaction in GIS*, 24, 4, pp. 967–1000. DOI: 10.1111/tgis.12660
• Rodríguez-Pose, A.–Burlina, C. (2021) Institutions and the uneven geography of the first wave of the COVID-19 pandemic. Journal of Regional Science, pp. 1–25. DOI: 10.1111/jors.12541
• Uzzoli, A.–Egri, Z.–Szilágyi, D.–Pál, V. (2020) Does better availability mean better accessibility? Spatial inequalities in the care of acute myocardial infarction in Hungary. *Hungarian Geographical Bulletin,* 69, 4, pp. 401–418. DOI: 10.15201/hungeobull.69.4.5
• Uzzoli, A.–Kovács, S. Zs.–Páger, B.–Szabó, T. (2021) A hazai COVID–19-járványhullámok területi különbségei. *Területi Statisztika,* 61, 3, pp. 291–319. DOI: 10.15196/TS610302
• Vinci, D. L.–Polidori, C.–Polidori, P. (2020) The healthcare and pharmaceutical vulnerability emerging from the new Coronavirus outbreak. *European Journal of Hospital Pharmacy*, 27, 3, pp. 129–130. DOI: 10.1136/ejhpharm-2020-002278

ANNEX

Annex 1 COVID-19 related websites in Central European countries

Country	Governmental websites of territorial data	Available territorial level of the different indicators	
		Reported COVID-19 Cases	Reported Covid-19 Deaths
Hungary	https://koronavirus.gov.hu/	NUTS 3	Budapest - Countryside
Austria	https://covid19-dashboard.ages.at/?l=en	LAU	LAU
Slovakia	https://covid-19.nczisk.sk/sk	LAU	NUTS 0
Romania	https://stirioficiale.ro/informatii	NUTS 3	NUTS 0 (NUTS 3 from informal source)
Croatia	https://www.koronavirus.hr/	NUTS 3	NUTS 3
Slovenia	https://www.nijz.si/sl/dnevno-spreml-janje-okuzb-s-sars-cov-2-covid-19	LAU	NUTS 3
Czech Rep.	https://onemocneni-aktualne.mzcr.cz/covid-19	LAU	LAU
Poland	https://www.gov.pl/web/koronawirus/wykaz-zarazen-koronawirusem-sars-cov-2	LAU	LAU

Source: Own compilation