Eastern Journal of European Studies
DOI: 10.47743/ejes-2024-0112 • JUNE 2024 • VOLUME 15, ISSUE 1

The role of socioeconomic variables in the regional inequalities of COVID-19 mortality in Hungary

Balázs Páger [a;b], **Csaba G. Tóth**✉ [a;c], **Annamária Uzzoli** [d]
[a] HUN-REN Centre for Economic and Regional Studies, Hungary; [b] University of Vienna, Austria; [c] Corvinus Institute for Advanced Studies, Hungary; [d] HUN-REN Research Centre for Astronomy and Earth Sciences, Hungary

Abstract
Hungary is one of the five countries in the World which were most affected by the pandemic in terms of registered COVID-19 mortality up to 2023. Our research aims to identify those socioeconomic variables that explain the geographical distribution of registered district-level COVID-19 mortality in Hungary. Using OLS and spatial regression, we found that the higher share of elderly people and respiratory death rate were associated with a more severe mortality burden. Educational attainment was negatively associated with COVID-19 mortality. Variables related to healthcare access were not found to be significantly associated with district-level COVID-19 mortality. Our results indicated that the spatial term of COVID-19 mortality is significant. Positive spatial autocorrelation can be observed in some less developed districts and a few inner peripheral areas where COVID-19 mortality was relatively high, and relatively developed areas like the agglomeration area of the capital in which COVID-19 mortality was low.

Keywords: COVID-19, socio-spatial inequality, spatial autocorrelation, district-level, Hungary

Introduction

The Coronavirus disease 2019 (COVID-19), caused by the novel coronavirus (SARS-CoV-2), spread to almost all countries in the world in the spring of 2020. On March 11, 2020, the World Health Organization (WHO) declared the global pandemic outbreak of the novel coronavirus, and the global emergency status for COVID-19 was maintained until the 5th of May, 2023. The pandemic led to increased mortality worldwide, and severely affected healthcare, economies, governments, and societies. The multiple effects have been profound and long-term, and the consequences will remain with us for at least the next couple of years.

✉ Csaba G. Tóth, Research Fellow, HUN-REN Centre for Economic and Regional Studies, Institute of Economics, Budapest, Hungary and Corvinus Institute for Advanced Studies, Budapest, Hungary; email: toth.gcsaba@krtk.hun-ren.hu

Even though many papers investigating the factors influencing the spatial distribution of COVID-19 mortality have been published in recent years, the low variation of the surveyed regions must be emphasized. A large number of studies analyzing subnational areas of a certain country focused on the United States. Other studies investigated the course of the pandemic in developed countries (England, Germany, Italy) or countries with large territories (Brazil, Russia, China). Therefore, most of our pandemic-related knowledge has reflected the process occurred in these geographical regions, whereas only a few empirical studies gathered information from other regions, such as Central and Eastern European (CEE) countries. For example, Nazia et al. (2022) published a comprehensive literature survey on the spatial analyses of COVID-19, reviewing the results of 154 studies from Africa, Asia, North America, South America, Europe, the Mediterranean, and the Middle East, but no research from CEE countries was included. Still, these countries were among those which experienced the highest death toll due to COVID-19 over the pandemic period.

Even though there are some studies analysing the spatial dimension of COVID-19 in CEE countries (Muntele, 2022; Parysek & Mierzejewska, 2021; Sleszinsky, 2021), and others described the mortality burden of the pandemic (Klimovský & Nemec, 2021; Petrovic et al., 2021), we still have very limited knowledge about the factors and variables that influenced the spatial distribution of COVID-19 mortality in this area (e.g., Sobczak & Pawliczak, 2022). The CEE countries were mildly affected by the novel coronavirus infection, and mortality rates during the first wave in the spring of 2020 were lower compared to those in Western European countries (Röst et al., 2020); however, from the second wave on, this area was affected more severely by the pandemic, and the CEE countries experienced much more intensive outbreaks starting in the autumn of 2020 (Kovalcsik et al., 2021). The third epidemic wave caused the most serious effects on CEE countries, resulting in high COVID-19 death rates and a severe health crisis (Urbanovics et al., 2021). Within the CEE area, Hungary was one of the most disadvantaged, having the fourth highest confirmed population-related COVID-19 mortality worldwide up until 2023[1], as the cumulative number of COVID-19 deaths was 48,751 by the end of March 2023. The country's mortality rate caused by COVID-19 was 2.2%, which was one of the highest rates in Europe. Moreover, this mortality rate considerably exceeded the European average in the earlier phases of the pandemic (e.g., during the second, the third and the fourth epidemic wave). Hungary registered the highest COVID-related mortality rate among European countries in 2021: it was the second highest after the Czech Republic in the spring and became the first after the summer. In addition, the registered Covid-19 mortality rate was the fourth highest in the world in the spring and summer of 2021.

[1] WHO COVID-19 Dashboard. Geneva: World Health Organization, 2020. Available online: https://covid19.who.int/ Downloaded: 05.05.2023.

This study provides deeper insight into the COVID-19 mortality situation in Hungary during the first two years of the pandemic. Our research aims to identify the socioeconomic (SES) factors that can explain the geographical distribution of the registered district-level mortality burden of the pandemic. It is worth emphasizing that this is explorative research providing a general description of the spatial distribution of the death toll caused by COVID-19 instead of focusing on the role of specific factors. Our statistical analysis has been conducted at the micro-regional level, covering 175 districts of Hungary from 4 March 2020 - the outbreak of the pandemic in Hungary - until 31 January 2022.

Our primary objective is to identify the spatial pattern of COVID-19 mortality in Hungary and to analyze its socioeconomic explanatory variables. In this way, we address two gaps in the literature. On the one hand, the spatial pattern of COVID-19 mortality in Hungary has not yet been analyzed in detail and, on the other hand, there are only a few studies in the literature that looked at the COVID-19 mortality patterns in Central and Eastern European (CEE) countries; yet, these countries are among those with the highest population-adjusted COVID-19 mortality rates in the world. To elucidate the features of Hungarian COVID-19 mortality, our analysis is based on the following research questions:

1. Which variables influence COVID-19 mortality and to what extent?
2. What is the spatial pattern of COVID-19 mortality in Hungary?
3. Does spatiality influence the impact of variables on COVID-19 mortality?

Using ordinary least squares (OLS) and spatial regression analyses, we identified three socioeconomic variables associated with the spread of COVID-19 deaths in Hungary. The share of the population above 65 years of age, which captures an important demographic dimension of a given area, is positively related to the district-level mortality rate during the pandemic. The same result can be discovered for the respiratory death rate, which reflects the health risk of a population. The third variable is educational attainment, which refers to the income status of a society. Districts with a high share of the population above 20 years of age with tertiary educational attainment tends to have lower COVID-19 mortality rates. Our research also shed light on the case of the variables related to access to healthcare, as we do not find a significant association with district-level COVID-19 mortality. This result is in contrast with a large proportion of the literature. In addition, the results suggest that the spatial term of COVID-19 mortality is significant; COVID-19 seems to have a spatial autoregressive (SAR) effect, and the values of a district might influence the values of its neighbouring districts.

The paper is structured into the following chapters. The first chapter provides an overview of recent studies focused on empirical findings related to measuring the dimensions and variables of COVID-19 mortality. Then, the chapter "Theoretical framework and database" introduces our datasets and the third chapter describes the methodology of our research. The fourth chapter presents the most important results and empirical evidence. Finally, the chapter "Discussion and conclusions" is focused on concluding remarks and on emphasizing the policy implications.

1. Literature

Over the past three years, many authors and studies examined the relationship between COVID-19 mortality and different socioeconomic characteristics, such as age, gender, disability, ethnicity, deprivation, occupation, and unemployment; however, these studies paid less attention to exploring the links between COVID-19 mortality and spatiality (Chen & Krieger, 2021; Daras et al., 2021; Munford et al., 2022; Wali & Frank, 2021). Geographical inequalities in COVID-19 mortality have been studied in various global contexts, and it has been reported that people of low socioeconomic status (SES) have higher mortality rates than those of high SES (Bambra et al., 2020; McGowen & Bambra, 2022; Munford et al., 2022). Overall, most of these studies reported area-level evidence (e.g., neighbourhood, town, city, municipality, or region) socioeconomic inequalities in COVID-19 mortality (Khobragade & Kadam, 2021; Griffith et al., 2022; Santos et al., 2022).

According to international antecedents, many variables are used to evaluate the features of COVID-19 mortality and its regional distribution, which can be classified into several main dimensions: demography, health risk, access to healthcare, income status, and the dimension related to the pandemic.

The bulk of the research investigating the spatial distribution of pandemic-related death found that the share of older people is one of the most crucial demographic factors affecting the mortality impact of COVID-19 (Lima et al., 2021; Tang et al., 2022; Urban & Nakada, 2021). Regardless of where the age limits are drawn (e.g., 65 years or above) (Perone, 2021) or which age groups are focused on (Kim et al., 2021), most of the studies found that the age structure of the population was significant at all periods. Moreover, the presence of minorities in a population, especially minor ethnic groups, was usually associated with high mortality (Congdon, 2021; Sun et al., 2021).

Many other demographic variables were included in different studies; however, their association with the mortality burden of the pandemic is not straightforward. This can be explained by using different explanatory variables in the models and the variation in the survey periods, geographical areas, and methodologies between studies. The effect of population density is significant, according to Urban and Nakada (2021) and Benita and Gasca-Sanchez (2021), while Grekousis et al. (2022a) and Praharaj et al. (2022) reported less convincing results. The gender ratio and household size were also included in several investigations to explore the factors associated with the different geographical patterns of COVID-19 mortality; however, the results seemed to be controversial in both cases. Some studies found that these two factors are related to COVID-19 mortality (Tchicaya et al., 2021; Urban & Nakada, 2021), while others did not find a significant relationship

(Grekousis et al., 2022b; Sun et al., 2021). In addition, some studies attempted to use urbanization (Ehlert, 2021), population size (Sannigrahi et al., 2020), or population growth (Middya & Roy, 2021) to explain regional differences in COVID-19 mortality.

To measure the dimension of access to healthcare, most studies used the number of physicians per capita, which has a significant relationship with the mortality burden of COVID-19. Perone (2021) and Ehlert (2021) reported that a higher number of physicians was associated with a lower level of mortality, while Tchicaya et al. (2021) reported an inverse relationship. The findings of this paper can also be explained by the fact that healthcare workers in many countries were redirected from areas less impacted by the pandemic to regions with more serious difficulties. The direction of the relationship is clearer in the case of nursing home capacity. The increased number of nursing home beds (Kathe & Wani, 2021), the greater share of inhabitants (Kandula & Shamanm, 2021), and the lower number of personnel working in a nursing home (Ehlert, 2021) were associated with a higher mortality burden of the pandemic. Studies focusing on specific indicators rather than composite indexes (e.g., health system performance indexes or Human Development Index) often used the number of hospital beds (Kathe & Wani, 2021) and the density of hospitals (Sun et al., 2021) to evaluate access to healthcare, with mixed results.

Regarding the dimension of health risk, average life expectancy at birth should be considered separately from other, more specific indicators. Life expectancy as a composite index depends on the health condition of a population; it is also linked to other socioeconomic, environmental, and cultural factors that affect longevity. Some studies (Petti & Cowling., 2020; Sannigrahi et al., 2020) investigating the pandemic's first period (typically the first wave) reported a positive relationship between average life expectancy at birth and COVID-19 mortality. In other studies (Cifuentes-Faura, 2021), life expectancy proved to be insignificant. However, as time passed, the results shifted, and later published studies (like Papadopulos et al., 2022) rather found a significant negative relationship between life expectancy and COVID-19 mortality.

According to the empirical literature, among the specific variables related to health risk, two seem to have a key role in shaping the mortality burden of COVID-19. The share of people struggling with obesity (Benita & Gasca-Sanchez, 2021; Praharaj et al., 2022) is significantly associated with the mortality burden of the pandemic. Morshed and Sarkar (2021) found that the obesity rate was one of the three common factors (including hospital beds and the share of people over 65 years of age) that influenced the number of COVID-19 deaths in the 50 most affected countries. The other factor related to health risk that has a strong association with COVID-19 mortality is the share of people with diabetes. Of the studies that considered this factor, the majority found it to be significantly associated with COVID-19 mortality (Kandula & Shamanm, 2021; Tchicaya et al., 2021). In addition, the share of people with heart disease (Grekousis et al., 2022a) and indicators related to smoking prevalence (Ozyilmaz et al., 2022) were included in several analyses to explain the geographical differences in COVID-19 mortality.

The importance of certain variables related to income status is even less clear than the other dimensions, which may be due to the strong correlations between the related variables. Taking income level into account is often a successful strategy (Kim et al., 2021; Sannigrahi et al., 2020) and the same is true for education. Morshed and Sarkar (2021) and Grekousis et al. (2022b) reported that a higher education level was associated with lower COVID-19 mortality. According to a literature survey by Nazia et al. (2022), the unemployment rate had a negative relationship with the number of deaths, while Kotov et al. (2022) and Kim et al. (2021) considered the share of specific sectors (e.g., retail and service) in the labour market. In addition, the prevalence of commuting (Grekousis et al., 2022b), social security insurance (Yu et al., 2022), poverty (Sannigrahi et al., 2020), and income inequality (Benita & Gasca-Sanchez, 2021) were often used to measure the impact of income status.

Studies covering a relatively large geographical area or access to specific meteorological data placed considerable importance on the environment, especially air pollution, when explaining the regional differences in COVID-19 mortality. Díaz Ramírez et al. (2022) and Middya & Roy (2021) highlighted the role of PM2.5 (traffic-related air pollutants with a diameter of less than 2.5 μm) on the mortality burden of the pandemic, while Perone (2021) and Yu et al. (2022) referred to humidity to explain the geographical distribution of COVID-19 mortality.

A couple of studies from CEE countries show the same characteristics between those variables identified in the mortality rate in Hungary and in these CEE countries. For example, the evolution of excess mortality rate had many similarities between Hungary and CEE countries (e.g., Karlinsky & Kobak, 2021, Tóth, 2022). The other important similarity is that relatively few studies examined the role of those variables which can influence the spatial distribution of COVID-19 mortality in the CEE region and in Hungary (e.g., Sobczak & Pawliczak, 2022). It is generally true, to antecedents from CEE, that the country-level approach to examine the mortality burden of COVID-19 in CEE has taken Europe-specific comparison (e.g. Hajdu et al. 2024; Szysz & Torój, 2023).

In Hungary, only few studies described the COVID-19 mortality in the context of socioeconomic or regional inequalities because the majority of the most important antecedents focused mainly on demographic (age, gender) or health risk factors (comorbidity) (e.g., Bíró et al., 2021; Elek et al., 2022; Gombos et al., 2020; Kemenesi et al. 2020;). Some studies were based on estimating excess mortality (e.g., Bogos et al., 2021, Ferenci, 2021; Tóth, 2022), while others modeled COVID-19 mortality rates with variables describing the general health status and the state of healthcare (e.g., Hajdu & Krekó, 2022; Horváth et al., 2022; Merkely et al., 2020). Several studies highlighted that excess mortality roughly corresponds to the reported number of deaths in Hungary (Ferenci & Tóth, 2022), and other findings indicated that the high number of nurses had a significant negative effect on COVID-19 mortality (Kovács & Vánus, 2022). Studies investigating the effect of socioeconomic conditions on the COVID-19 mortality reported an inverse association between trends in novel coronavirus morbidity and mortality. This suggests that individuals living in socioeconomically disadvantaged regions had a lower risk of being identified as a confirmed COVID-19 case but had a higher risk of death, indicating the existence and burden of inequity (Oroszi et al., 2022a, 2022b). However, it is important to note that lower recorded morbidity in disadvantaged regions might also be affected by less reliable characteristics of Hungarian epidemiological indicators as there have not been any exact data on the number of polymerase chain reaction (PCR) tests according to their regional distribution (Uzzoli et al., 2021). Among Hungarian antecedents, there is an additional focus on investigating the association between morbidity, mortality, and vaccination (Vokó et al., 2021, 2022). For example, one study identified that vaccination coverage was higher in large cities and less deprived areas during the third wave, and the proportion of individuals who received the basic vaccination series exceeded the national average in more deprived areas only in the fourth wave, except for districts with the highest rate in Roma populations (Juhász et al., 2022).

2. Theoretical framework and database

This paper is mainly based on quantitative methods but the theoretical framework of our research was developed through literature review. One of the main lessons from the literature is that identifying the variables that contribute to regional COVID-19 mortality is a complex process. Of course, certain variables are more often applied than others, and their impact on the COVID-19 mortality was shown to be significant more often than others. However, no consensus has emerged on an optimal set of variables that explains much of the regional distribution of COVID-19 mortality. This can be explained by the strong correlation between the factors shaping the mortality burden of the pandemic, which leads to significant cointegration in the modeling process. Furthermore, the limited exploration of research papers combining territorial characteristics, economic factors and medical prowess is another possible explanation.

To review the potential variables and their connections, the variables were structured along the same dimensions, which were also interpreted in the literature as primary determinants of the COVID-19 mortality. These dimensions are demography, access to healthcare, health risks, income status, and the so-called pandemic-related dimension, which includes the variables regarding COVID-19 infection, COVID-19 death, and vaccination cases.

Based on the literature review, we have developed the concept of the study, which includes five dimensions that might indirectly or directly impact COVID-19 mortality in the Hungarian districts, according to our research questions. To validate the indirect and direct impact of these dimensions on the COVID-19 mortality in Hungary, we sought the relevant variables for each dimension (Table 1).

Table 1. Examined dimensions and variables of COVID-19 mortality in Hungary

Dimension	Abbreviated name of the variable	Full name of the variable	Source	Date/Period	Spatial level
Dependent variable	COVID-19_mortality	Number of COVID-19-deaths per 1,000 people	National Health Insurance Fund of Hungary	Period from 04/03/2020 to 31/01/2022	district
Demographic	D_popperc65	Proportion of the population 65 years and older compared to the total population (%)	Hungarian Central Statistical Office (HCSO)	Date: 31/12/2019	district
Health risk	H_respiratory_mortality	Number of deaths from respiratory diseases per 100,000 population	HCSO	2019	district
	H_diabetes_morbidity	Prevalence of diabetes[1] in the percentage of people aged 30 years or over	Databank of Centre for Economic and Regional Studies (Hungary)	2017	district
	H_circulatory_mortality	Circulatory mortality per 10,000 population aged 65 years and older	HCSO	2019	district
	H_life_exp	Average life expectancy at birth (years)	Own calculation applying the data of HCSO	2019	district
Income status	I_univ_grad	Rate of university graduates in the percentage of people aged 20 years or over	Microcensus data of HCSO	2016	district
	I_job_seek	The proportion of job seekers aged 15-64 years at the end of the year	HCSO	2019	district
Access to healthcare	A_dist	Rapid accessibility of the road to the nearest city with county rights (in hours)	Own calculation	Calculation performed on 20/04/2021	municipality aggregated to district level
	A_vacantGP	Percentage of vacant general practitioner posts within the district	National Health Insurance Fund of Hungary	2019	district
	A_small_mcp	Rate of the population living in municipalities with less than 1,000 inhabitants	Own calculation applying the data of HCSO	2019	district
COVID-19 (pandemic-related)	C_ln(infect)	COVID-19 infections per 100,000 people	National Public Health Center of Hungary	Period: from 04/03/2020 to 31/12/2021	district
	C_vacc	Vaccination rate among the infected people compared to the total district population	National Public Health Center of Hungary	Date: 31/12/2021	district

Note: [1] At least two instances of at least 800 HUF (2 EURs) spent on diabetes-related medicines in a year.
Source: authors' representation

Our quantitative examination was conducted on secondary data. Several sources were used to collect data on the COVID-19 mortality and the social and health conditions of the population. The analyzed data were obtained from official sources (e.g., Hungarian Central Statistical Office [HCSO] - www.ksh.hu, National Pandemic Website - koronavirus.gov.hu, National Public Health Center of Hungary - https://www.nnk.gov.hu/). The data were collected on 175 areas, comprising Budapest and the 174 districts of Hungary. This spatial level allowed us to conduct a fine-grained analysis that could also reflect intra-regional disparities; however, it limited the pool of potential indicators as fewer measures were available at this spatial level.

The Hungarian epidemiological data were mainly published at the national level. The sub-national level - e.g., micro-regional level - data of some essential pandemic-related variables, such as the number of COVID-19 tests, were not published in Hungary. Therefore, only three variables were reported at the micro-regional level. These variables refer to the pandemic-related dimension of our analysis regarding infection, mortality, and vaccination. To calculate the proportion of crude pandemic-related variables per 1,000 inhabitants, we used the population data published by the HCSO.

The data on the COVID-19 mortality covered the period between 4 March 2020 and 31 January 2022, which aligns with the temporal distribution of the first four epidemic waves in Hungary. The confirmed number of COVID-19 deaths during this period covered 85% of the total death burden of the pandemic up to 1 April 2023. Because the first confirmed COVID-19 cases were announced in Hungary on 4 March 2020, this date denotes the starting date of the Hungarian epidemic and of our analysis. The closing date of our analysis refers to the date of the last officially announced epidemiological data at the micro-regional level (31 January 2022).

3. Methods

This paper adopted an approach based on the traditional estimation technique such as ordinary least squares and it also used the spatial autocorrelation (see, e.g., Stach, 2021). Our statistical investigation had two aims: firstly, we aimed to explore which dimensions, and secondly, within each dimension, which variables might have a significant impact on COVID-19 mortality in Hungary. Therefore, we formulated a baseline ordinary least squares (OLS) regression model that included the COVID-19 mortality rate as the dependent variable and the explanatory variables, which were also connected to the five determined dimensions (in the name of the variable, the first letter - "D," "H," "A," "I," and "C" - refers to the dimension to which a variable belongs).

$$\begin{aligned} Mort = \beta_0 &+ D\_perc65 * \beta_1 + H\_resp\_d * \beta_2 + H\_diab * \beta_3 + H\_circ\_d * \beta_4 \\ &+ H\_life\_exp * \beta_5 + I\_univ * \beta_6 + I\_job\_seek * \beta_7 + A\_dist * \beta_8 \\ &+ A\_dist^2 * \beta_9 + A\_vacantGP * \beta_{10} + (infect) * \beta_{12} + C\_vacc * \beta_{13} \\ &+ \varepsilon \end{aligned}$$

In the case of distance, we added the squared term of this variable to the OLS model to control for its non-linear relationships with the COVID-19 mortality. We used robust standard errors in each model to overcome heteroskedasticity within the model. After running the models, we conducted additional diagnostic tests on multicollinearity and heteroskedasticity.

To investigate whether spatial autocorrelation among the districts could be detected in the residuals of the OLS regression model variants, referring to Anselin (2005), we performed Moran's I test. The results indicated that the third research question could be investigated by applying a spatial econometric model. Therefore, we performed Lagrange Multiplier tests to determine which spatial model fits the best in our case. The results of these tests indicated that we should use the spatial autoregressive (SAR) model to control the spatial effects of the dependent variable.

$$Mort = \beta_0 + \rho WMort + D\_perc65 * \beta_1 + H\_resp\_d * \beta_2 + H\_diab * \beta_3 + H\_circ\_d * \beta_4 + H\_life\_exp * \beta_5 + I\_univ * \beta_6 + I\_job\_seek * \beta_7 + A\_dist * \beta_8 + A\_dist^2 * \beta_9 + A\_vacantGP * \beta_{10} + (infect) * \beta_{12} + C\_vacc * \beta_{13} + \varepsilon$$

In the case of the spatial model, we set up a contiguity first-order row-standardized spatial weight matrix among the 175 districts. The coefficients of the spatial model were calculated by using maximum likelihood estimation.

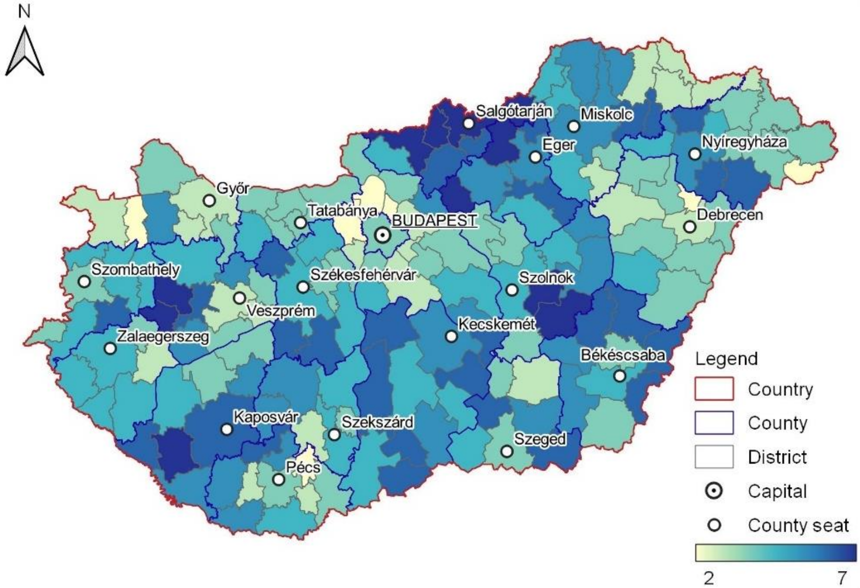
3. Results

First, we summarized here the most important milestones of the COVID-19 pandemic in Hungary, and we also highlighted the relevant features in the spatial pattern of the COVID-19 mortality within the country.

The first two confirmed COVID-19 cases were announced in Hungary on 4 March 2020. According to the government's official website (koronavirus.gov.hu), the first COVID-19 death was reported on 15 March 2020 (Gombos et al., 2020). The first recovered patient left the hospital on 12 March 2020 (Kovács & Vánus, 2022). On 11 March 2020, the Hungarian government declared a state of epidemic emergency that lasted until 18 June 2020, and the state of emergency was reinstated on 11 November 2020. The second announced state of emergency was extended several times and was valid until 31 May 2022. Between March 2020 and December 2022, six epidemic waves were recorded in Hungary. In total, 2,185,816 COVID-19 cases were confirmed in Hungary until 31 December 2022, when the official Hungarian pandemic announcements were discontinued. The total number of deaths due to COVID-19 was 48,495, while the number of recovered cases was 2,123,750 at the end of 2022. Vaccinations began at the end of 2020; however, mass vaccination was introduced only in April and May 2021. The first booster was introduced at the beginning of August 2021, and the second booster became available in January 2022. The governmental announcement indicated that the cumulative vaccine uptake rate of the primary course was 63.9% in Hungary on 31 December 2022, while the rate of uptake was 40.2% for the first booster and 3.9% for the second booster.

Figure 1 shows that the key features of COVID-19 mortality have marked regional differences within the country. The lowest rates of pandemic-related death appeared in the capital city (Budapest), its agglomeration, and the county seats, while the highest mortality rates were reported in the Eastern part of the country and along the Southern borderline. It can primarily be explained by the marked differentiation between the Eastern and Western parts of Hungary according to socioeconomic inequalities. It means that there are more districts with better values of SES in the Western part of the country, while the most advantageous districts are located in and around Budapest and in the Northwestern part of the country. The entire Eastern part of Hungary is generally in a very disadvantageous position due to SES. There are only some districts in this Eastern part which show better values, especially in county seats. Moreover, along the Southern borderline, the number of people in multiple disadvantaged positions is very high, and thus, they struggle with significantly high deprivation. Overall, the regional distribution of COVID-19 deaths represents a centre-periphery and a Western-Eastern spatial pattern.

Figure 1. Confirmed COVID-19 deaths per thousand inhabitants in the districts of Hungary (LAU) between 4 March 2020 and 31 January 2022.



Source: www.ksh.hu, koronavirus.gov.hu, https://www.nnk.gov.hu/
Source: authors' representation

According to what was explained in the previous sections, we analyzed the role of socioeconomic variables in the COVID-19 mortality in Hungary by OLS regression. The OLS regression provided a comprehensive description of the main variables associated with the regional distribution of the mortality burden of COVID-19. We identified three socioeconomic variables that proved significant in almost all models (Table 2). The share of the population above 65 years of age and the respiratory death rate were positively related to the district-level mortality rate during the pandemic. Districts with a higher share of the population over 20 years of age with tertiary educational attainment tended to have lower COVID-19 mortality rates. The robustness of this finding suggests that these three variables play a key role in understanding the driving forces of the pandemic. The explanatory power of the models captured by the R-square ranged from 0.39 to 0.44, which supports the relevance of our findings.

Table 2. The results of the OLS regression model variants

DV: COVID-19_mortality	**m1**	**m2**	**m3**	**m4**	**m5**	**m6**
D_Popperc_65	9.852*** (3.34)	8.881*** (3.15)	10.981*** (3.69)	9.390*** (3.13)		10.788*** (3.67)
H_respiratory_mortality	0.004** (2.13)	0.005*** (2.65)	0.004** (2.45)	0.004** (2.12)	0.005*** (2.68)	
H_diabetes_morbidity	21.985 (1.25)	27.208 (1.57)	23.150 (1.26)	18.813 (1.05)	49.996*** (2.91)	27.867 (1.56)
H_circulatory_mortality	0.000 (0.95)	0.000 (1.63)	0.001 (1.05)	0.000 (0.98)	0.001 (1.24)	0.000 (0.70)
H_Life_exp	-0.092 (1.51)		-0.096 (1.49)	-0.112* (1.82)	-0.032 (0.51)	-0.139** (2.29)
I_univ_grad	-2.572* (1.87)	-2.979** (2.22)	-2.554* (1.8)	-2.800** (2.03)	-2.365* (1.66)	-2.149 (1.55)
I_job_seek	3.788 (1.40)	4.849* (1.85)	1.833 (0.63)	3.811 (1.36)	2.128 (0.77)	4.651* (1.71)
A_distance	-0.028 (0.04)	-0.005 (0.01)	-0.122 (0.16)	-0.054 (0.08)	-0.105 (0.15)	0.172 (0.25)
A_distance^2	-0.584 (0.91)	-0.578 (0.88)	-0.644 (0.94)	-0.489 (0.80)	-0.464 (0.71)	-0.750 (1.12)
A_vacantGP	0.339 (0.41)	0.486 (0.59)	0.344 (0.39)	0.482 (0.57)	0.683 (0.81)	0.225 (0.28)
A_small_mcp	-0.421 (0.98)	-0.481 (1.14)	-0.341 (0.76)	-0.234 (0.54)	-0.180 (0.43)	-0.410 (0.94)
C_ln(infect)	1.909*** (3.11)	1.919*** (3.12)		1.503*** (2.77)	2.120*** (3.31)	2.034*** (3.28)
C_vacc	-29.908 (1.64)	-33.2* (1.84)	-6.892 (0.44)		-25.030 (1.31)	-28.116 (1.46)
Constant	-9.245 (1.34)	-16.560*** (2.98)	8.204 (1.61)	-4.496 (0.70)	-15.298** (2.18)	-7.065 (1.01)
R-squared	0.439	0.432	0.395	0.426	0.396	0.423
Adjusted R-squared	0.393	0.390	0.350	0.384	0.352	0.380
N	175	175	175	175	175	175
F	13.607	14.642	11.171	14.180	11.489	13.792
p	0.000	0.000	0.000	0.000	0.000	0.000
Moran test for spatial dependence	7.80***	8.32***	9.44***	6.20**	11.44***	8.11***

Note: * - sig. at 0.1 level, ** - sig. at 0.05 level, *** - sig. at 0.01 level; t-values in parentheses
Source: authors' calculations

The confirmed COVID-19 infection rate of a certain district is a special variable. While all other factors have a stochastic relationship with COVID-19 death, being infected is a precondition for dying of COVID-19. However, the systemic underreporting of infection, which was suggested by several studies (Oroszi et al., 2022a; Uzzoli et al., 2021), should be considered. In the baseline model (m1), the registered infection rate was also included among the explanatory variables, and we identified a strong positive relationship with COVID-19 mortality. Assuming this variable does not contain any bias, this model specification revealed the relationship between the case fatality rate and the other socioeconomic variables. However, it is worth noting that the significance of age structure, respiratory death rate, and education are left unchanged without considering the infection rate (m3).

In addition to the aforementioned variables, other variables proved significant in the different model specifications. The share of the population with diabetes was significant if we did not control for the age structure (m5), which can be explained by the age-specific nature of this non-communicable disease. The association between the vaccination rate and the COVID-19 mortality was negative in all cases and was significant only when life expectancy was excluded (m2). The lack of a strong relationship can be explained by the nature of the database we used, which did not contain information to distinguish between mortality before and after the appearance of the vaccines. This is a significant drawback of papers dealing with the topic. Furthermore, it is reasonable that the vaccination rate became significant when life expectancy was excluded, as the latter is a comprehensive indicator with strong co-movement with the willingness to be vaccinated.

By extending the interpretation to the analysis of the different dimensions, we obtained a more general view of the relative importance of the various fields in the contribution of district-level COVID-19 mortality in Hungary. The *demographic* dimension captured by the share of elderly inhabitants was especially important. The dimension of *health risk* was also substantial in understanding the geographical pattern of COVID-19 mortality, of which the role of respiratory mortality rate was key factor. In addition, the prevalence of diabetes and life expectancy as a composite variable were associated with the mortality burden of the pandemic. The dimension of *access to healthcare* was less relevant in explaining district-level differences in COVID-19 mortality, as none of the associated variables were significant in either model. The *income status* dimension proved to be particularly important, especially the level of education. In addition, there was a model specification (m6) in which the proportion of registered job seekers in the working-age (15-64 years) population was significant. Within the *pandemic-related dimension,* the role of the registered infection rate was clear, while the vaccination rate was significant in one model specification (m2).

The Moran test values for all linear model variants referred to a significant spatial autocorrelation in the error terms. Therefore, we conducted different diagnostic tests to discover which spatial model fit the best to our case. The results confirmed that including the spatial autocorrelation of the dependent variable was a valid assumption (Table 3). Therefore, we ran the spatial model that was introduced in the Methodology section.

Table 3. Results of the spatial regression model variants

DV: COVID-19_mortality	m1	m2	m3	m4	m5	m6
D_Popperc_65	6.404** (2.35)	5.680** (2.17)	7.062** (2.53)	6.089** (2.20)		7.158*** (2.62)
H_respiratory_mortality	0.003** (2.11)	0.004** (2.52)	0.004** (2.39)	0.003** (1.97)	0.004** (2.41)	
H_diabetes_morbidity	25.524 (1.50)	28.942* (1.73)	26.837 (1.53)	21.665 (1.25)	42.579*** (2.73)	30.880* (1.81)
H_circulatory_mortality	0.001 (1.23)	0.001* (1.82)	0.001 (1.32)	0.001 (1.24)	0.001 (1.42)	0.000 (0.98)
H_Life_exp	-0.060 (0.95)		-0.059 (0.92)	-0.084 (1.33)	-0.018 (0.30)	-0.101* (1.66)
I_univ_grad	-2.037 (1.49)	-2.277* (1.7)	-1.973 (1.41)	-2.331* (1.69)	-1.817 (1.32)	-1.644 (1.20)
I_job_seek	1.787 (0.71)	2.396 (0.98)	-0.064 (0.03)	1.938 (0.75)	0.447 (0.18)	2.511 (0.99)
A_distance	0.032 (0.04)	0.048 (0.06)	-0.044 (0.05)	-0.002 (0.00)	-0.003 (0.00)	0.212 (0.26)
A_distance^2	-0.506 (0.69)	-0.500 (0.68)	-0.550 (0.72)	-0.402 (0.54)	-0.421 (0.57)	-0.653 (0.88)
A_vacantGP	-0.198 (0.28)	-0.122 (0.17)	-0.242 (0.33)	-0.000 (0.00)	-0.095 (0.13)	-0.313 (0.43)
A_small_mcp	-0.302 (0.82)	-0.336 (0.92)	-0.223 (0.59)	-0.095 (0.26)	-0.139 (0.38)	-0.290 (0.78)
C_ln(infect)	1.656*** (3.35)	1.654*** (3.34)		1.205*** (2.60)	1.733*** (3.48)	1.761*** (3.54)
C_vacc	-34.599** (2.36)	-36.848** (2.55)	-15.327 (1.11)		-32.603** (2.21)	-33.107** (2.24)
Constant	-10.286 (1.54)	-14.950*** (3.30)	4.548 (0.88)	-4.773 (0.75)	-14.022** (2.14)	-8.358 (1.25)
W_Spatial COVID-19_mortality	0.374*** (3.85)	0.386*** (4.02)	0.407*** (4.21)	0.351*** (3.56)	0.443*** (4.91)	0.383*** (3.94)
Pseudo R-squared	0.444	0.439	0.398	0.435	0.413	0.428
N	175	175	175	175	175	175
chi2	166.49	165.16	146.71	155.06	158.65	158.22
p	0.000	0.000	0.000	0.000	0.000	0.000

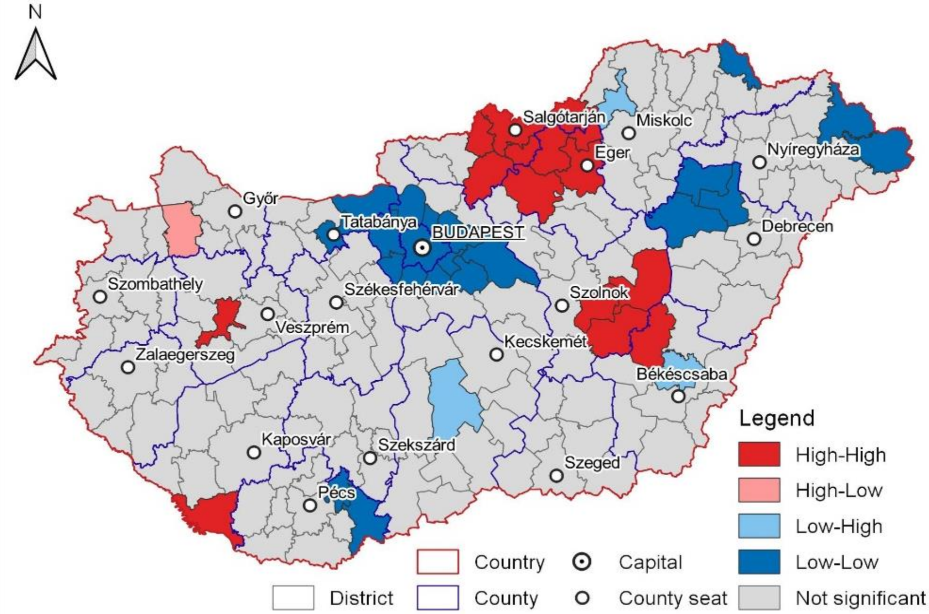
Note: * - sig. at 0.1 level, ** - sig. at 0.05 level, *** - sig. at 0.01 level; t-values in parentheses
Source: authors' calculations

The results suggest that the spatial term of COVID-19 mortality is significant, that is, COVID-19 seems to have a SAR effect, and the values of an area might influence the values of its neighbouring districts. As we analyzed different model variations from the full model (m1) to different modified combinations of the variables (m2 to m6), the spatial term of our dependent variable remained significant. This suggests that the neighbourhood effect of COVID-19 mortality was relatively robust and significant in all model variations. The finding on the spatiality of the dependent variable was also confirmed by the results of the Wald test. Furthermore, the results of the spatial regression analysis suggested that most factors that proved to be significant in the OLS regression retained their importance when we ran the SAR model. However, some differences were discovered. On the one hand, the education-related variable became even less significant compared with the OLS results; on the other hand, diabetes morbidity was more significant in certain model variations. However, we can conclude that the spatial model strengthens our findings regarding the variables influencing the COVID-19 mortality in Hungary.

As noted in the first part of the paper, the broader relationship between SES and geographical site in COVID-19 mortality was previously reported (e.g., Bambra et al., 2020; Congdon, 2021; Nazia et al., 2022). Some of these studies highlighted the prioritizing role of neighbouring areas with a high risk of COVID-19 morbidity and mortality (e.g., Stier et al., 2021; Wrigly-Field et al., 2021; Rizaldi et al., 2022). Specifically, the urban-rural context is often highlighted in the most relevant antecedents; regarding spatial characteristics, a higher risk of COVID-19 mortality is most apparent in urban or metropolitan areas, while lower mortality risk is concentrated in rural areas (e.g., Kulu & Dorey, 2020). This may be due to the effect induced by population density. Furthermore, studies on COVID-19 mortality and its spatial distribution consider both SES-based and place-based explanatory variables. Regarding these results, we found that the most robust SES variables differed significantly between different areas or clusters of neighborhoods. These neighborhood-level inequalities in COVID-19 mortality were examined in our spatial autocorrelation analysis. From our point of view, as we can see in Figure 2, the neighbourhood-based approach is more useful to achieve a deeper understanding of the socio-spatial inequalities of the COVID-19 mortality (e.g., Blair et al., 2022; Edward, 2021).

Regarding spatiality, the model results confirmed that the COVID-19 mortality is spatially dependent (Figure 2). Reviewing the degree and direction of this phenomenon among the districts, positive spatial autocorrelation was observed among less developed districts, like the Northern part of Hungary and a few inner peripheral areas where the COVID-19 mortality was relatively high (high-high), while in relatively developed areas, like the agglomerated area of Budapest (low-low), the COVID-19 mortality was low. The negative spatial autocorrelation can also be explained by the general pattern of development; however, other variables might also play a considerable role in these cases. As we conducted the spatial regression models, the spatial lag coefficient of the dependent variable remained significant despite controlling for different health risks and SES variables. We believe that this impact might be rooted in access to healthcare. However, this dimension is relatively difficult to capture as there is a lack of officially available district-level data on the number of health personnel and hospital beds.

Figure 2. Spatial autocorrelation of COVID-19 mortality in the districts of Hungary (LAU)



Note: high-high and low-low areas refer to positive spatial autocorrelation meaning the data values of neighbouring territorial units are similar to each other, i.e. high values are next to high values or low values are besides low values. High-low and low-high compositions refer to a negative spatial autocorrelation with the neighbouring districts showing that neighbouring areas are significantly different (next to high value areas, there are low value areas and vice versa).
Source: authors' representation

Overall, the literature review on the novel coronavirus pandemic strengthened the role of both SES-based and place-based health risk variables in COVID-19 mortality. In addition, our analysis revealed the significant impacts of income status, health risks, and demographic variables on the COVID-19 mortality in Hungary. These findings highlight the importance of long-term epidemiological measures. If a higher proportion of elderly, low-income populations and people with poor health is detected in certain neighbourhoods, further local public health measures are required to protect these vulnerable social groups.

Conclusions

We have found robust evidence of the unequal spatial effects of the novel coronavirus pandemic. Identifying the key socioeconomic variables associated with the COVID-19 mortality enabled us to compare the experience of a CEE country with that of the rest of the world, as documented in the literature. Generally, the Hungarian districts with large populations of elderly residents were more likely to have higher COVID-19 mortality rates than other districts. This result supports the broad consensus on the age-specific risk of the pandemic (Lima et al., 2021; Perone, 2021).

In addition, we have found that districts with poor health conditions were likely to have high COVID-19 mortality rates in 2020 and 2021. Due to data limitations, we could not consider obesity in the health risk dimension; however, we included diabetes, which was an important factor, according to the literature. Diabetes was significant only in one model specification, while the mortality rate of respiratory disease was a significant factor regardless of the model specification. This finding is in line with the findings of Ozyilmaz et al. (2022), who reported a limited but increasing effect of smoking on the number of COVID-19 cases.

It is worth mentioning that, in Hungary, as well as in CEE countries, poor health conditions are affected by the “Central and Eastern European health paradox”. This is a typical public health situation in this European region that describes marked differences between the general health status of the populations of Western and Eastern Europe (Cornia & Paniccia, 2000; Kopp et al., 2007). The essence of this phenomenon is that the population’s health status is worse than justified by the level of economic development in CEE countries. For example, the rate of premature death is higher, the average life expectancy at birth is lower, and the main health indicators are worse compared with Western European countries (Egri & Tánczos, 2015). Traditionally, unhealthy lifestyles and their consequences play a key role in producing poor health conditions in CEE countries, including Hungary (WHO, 2013). The health paradox results in significant health inequalities among European countries and within CEE countries, and the further increase in these inequalities represents a challenge for the European countries in the future (Forster et al., 2018; Lebihan, 2023). Health inequalities are associated with significant socio-spatial inequalities in CEE countries and Hungary which have implications on access to healthcare, especially among low-income populations (Levesque et al., 2013; Uzzoli et al., 2020).

Our results also highlight the protective roles of a high level of education and a good labour market position, which is in line with the main findings in the literature (Grekousis et al., 2022b; Kim et al., 2021). In addition, our findings support the importance of the income status dimension, which includes, in a broad sense, relevant skills, social networks, and relative financial capacities that could play a crucial role in protection against the pandemic. It may also be relevant in relation to the access to remote jobs.

In contrast to a large share of the literature, regarding the variables related to access to healthcare, our results were not significant. Because most of the variables used to measure this dimension were based on distance and settlement sizes, we cannot exclude measurement bias. However, the percentage of vacant general practitioner (GP) posts, which was also considered, usually precisely captures the level of healthcare infrastructure. We must note that there are contradictory results in the literature on the association between access to healthcare and COVID-19 death rates; several studies found no significant association, especially regarding the availability of healthcare resources (e.g., Karmakal et al., 2021; Mattiuzzi et al., 2021), while others found that specific health resources (e.g., number of intensive care beds or GPs) were associated with COVID-19 mortality (e.g., Ndayishimiye et al., 2022; Tchicaya et al., 2021). Our result can be explained by the similar level of healthcare infrastructure across Hungary; more accurately, we can assume that the consecutive waves of the pandemic overloaded the healthcare system to the same degree across the country. In addition, the reallocation of health personnel after the COVID-19 outbreak could have compensated for the geographical differences in access to healthcare.

Our results suggest that the COVID-19 pandemic represents a health burden in certain population subgroups. The neighbourhoods with a high proportion of elderly citizens, low-income populations, and people with poor health were inequitably affected by COVID-19 death. These findings can help inform public health efforts to further protect populations that are more vulnerable to COVID-19-specific health risks in Hungary.

Furthermore, our results also suggest that, in addition to the SES variables, the multilevel interconnections among these have an important role in the COVID-19 mortality. Moreover, it is important to consider the multi-dimensional spatial effects because COVID-19 is highly infectious and can influence the mortality outcomes of geographically proximal areas. The spatial differentiations of SES are important for explaining that a district’s COVID-19 mortality effects the districts that it borders.

Overall, we emphasize that there were remarkable regional differences in the spatial effects of SES on the COVID-19 mortality. Namely, there was strong spatial evidence between the COVID-19 mortality rate of neighbouring areas and the robust SES variables of neighbouring areas.

References

Anselin, L. (2005). *Exploring Spatial Data with GeoDa: A Workbook*. https://geodacenter.github.io/docs/geodaworkbook.pdf

Bambra, C., Riordan, R., Ford, J., & Matthews, F. (2020). The COVID-19 pandemic and health inequalities. *Journal of Epidemiology and Community*, *74*(11), 964-968. https://doi.org/10.1136/jech-2020-214401

Benita, F., & Gasca-Sanchez, F. (2021). The main factors influencing COVID-19 spread and deaths in Mexico: A comparison between phases I and II. *Applied Geography*, *134*, 102523. https://doi.org/10.1016/j.apgeog.2021.102523

Bíró, A., Branyiczki, R., & Elek, P. (2021). Time patterns of precautionary health behaviours during an easing phase of the COVID-19 pandemic in Europe. *European Journal of Ageing*, *19*, 837-848. https://doi.org/10.1007/s10433-021-00636-4

Blair, A., Pan, S., Subedi, R., Yang, F.-J., Aitken, N., & Steensma, C. (2022). Social inequalities in COVID-19 mortality by area and individual-level characteristics in Canada, January to July/August 2020: Results from two national data integrations. *Canada Communicable Disease Report*, *48*(1), 27-38. https://doi.org/10.14745/ccdr.v48i01a05

Bogos, K., Kiss, Z., Kerpel-Fronius, A., Temesi, G., Elek, J., Madurka, I., Cselkó, Z., Csányi, P., Abonyi-Toth, Z., Rokszin, G., Barcza, Z., & Moldvay, J. (2021). Different trends in excess mortality in a Central European country compared to main European regions in the year of the Covid-19 pandemic (2020): a Hungarian analysis. *Pathology and Oncology Research*, *27*, 1609774. https://doi.org/10.3389/pore.2021.1609774

Chen, J. T., & Krieger, N. (2021). Revealing the unequal burden of COVID-19 by income, race/ethnicity, and household crowding: US county versus zip code analyses. *Journal of Public Health Management and Practice*, *27*(1), S46-S56. https://doi.org/10.1097/PHH.0000000000001263

Cifuentes-Faura, J. (2021). COVID-19 mortality rate and its incidence in Latin America: Dependence on demographic and economic variables. International *Journal of Environmental Research and Public Health*, *18*(13), 6900. https://doi.org/10.3390/ijerph18136900

Congdon, P. (2021). COVID-19 Mortality in English Neighborhoods: The Relative Role of Socioeconomic and Environmental Factors. *J - Multisciplinary Scientific Journal*, *4*(2), 131-146. https://doi.org/10.3390/j4020011

Cornia, G. A., & Panicciá, R. (2000). *The Transition Mortality Crisis: Evidence, Interpretation and Policy Responses*. New York: Oxford University Press.

Daras, K., Alexiou, A., Rose, T. C., Buchan, I., Taylor-Robinson, D., & Barr, B. (2021). How does vulnerability to COVID-19 vary between communities in England? Developing a Small Area Vulnerability Index (SAVI). *Journal of Epidemiology and Community Health*, *75*(8), 729-734. http://dx.doi.org/10.1136/jech-2020-215227

Díaz Ramírez, M., Veneri, P., & Lembcke, A. C. (2022). Where did it hit harder? Understanding the geography of excess mortality during the COVID-19 pandemic. *Journal of Regional Science*, *62*(3), 889-908. https://doi.org/10.1111/jors.12595

Edward, N. (2021). *COVID-19 deaths among immigrants: Evidence from the early months of the pandemic*. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/45-28-0001/2021001/article/00017-eng.htm

Egri, Z., & Tánczos, T. (2015). Socioeconomic and spatial correlations of the Eastern European health paradox in Hungary. *Deturope*, *7*(2), 138-156. https://doi.org/10.32725/det.2015.020

Ehlert, A. (2021). The socio-economic determinants of COVID-19: A spatial analysis of German county level data. *Socio-Economic Planning Sciences*, *78*, 101083. https://doi.org/10.1016/j.seps.2021.101083

Elek, P., Fadgyas-Freyler, P., Váradi, B., Mayer, B., & Zemplényi, A. (2022). Effects of lower screening activity during the COVID-19 pandemic on breast cancer patient pathways: Evidence from the age cut-off of organized screening. *Health Policy*, *126*(8), 763-769. https://doi.org/10.1016/j.healthpol.2022.05.013

Ferenci, T. (2021). Different approaches to quantify years of life lost from COVID 19. *European Journal of Epidemiology*, *36*, 589-597. https://doi.org/10.1101/2021.05.13.21257193

Ferenci, T., & Tóth, C. G. (2022). Kulcsfontosságú járványügyi paraméterek meghatározása a COVID-19 pandémia során: a többlethalálozás példája. [Estimation of key parameters during the COVID-19 pandemic: the case of excess mortality]. *Népegészségügy*, *99*(1), 42-52.

Forster, T., Kentikelenis, A., & Bambra, C. (2018). *Health inequalities in Europe: setting the stage for progressive policy action*. Dublin: TASC.

Gombos, K., Herczeg, R., Erőss, B., Kovács, S. Z., Uzzoli, A., Nagy, T., Kiss, S., Szakács, Z., Imrei, M., Szentesi, A., Nagy, A., Fabian, A., Hegyi, P., & Gyenesei,, A. (2020). Translating scientific knowledge to government decision makers has crucial importance in the management of the COVID-19 pandemic. *Population Health Management*, *24*(1), 35-45. https://doi.org/10.1089/pop.2020.0159

Grekousis, G., Feng, Z., Marakakis, I., Lu, Y., & Wang, R. (2022a). Ranking the importance of demographic, socioeconomic, and underlying health factors on US COVID-19 deaths: A geographical random forest approach. *Health and Place*, *74*. https://doi.org/10.1016/j.healthplace.2022.102744

Grekousis, G., Lu, Y., & Wang, R. (2022b). Exploring the socioeconomic drivers of COVID-19 mortality across various spatial regimes. *Geographical Journal*, *18*(82), 245-260. https://doi.org/10.1111/geoj.12436

Griffith, G. J., Owen, G., Manley, D., Howe, L. D., & Smith, G. D. (2022). Continuing inequalities in COVID-19 mortality in England and Wales, and the changing importance of regional, over local, deprivation. *Health and Place*, *76*, 102848. https://doi.org/10.1016/j.healthplace.2022.102848

Hajdu, T., & Krekó, J. (2022). Koronavírus-esetszámok és -halálozás. [Coronavirus cases and deaths]. In D. Horn & A.M. Bartal (Eds.) *Fehér Könyv a COVID-19-járvány társadalmi-gazdasági hatásairól* (pp. 13-22). Budapest: KRTK KTI.

Hajdu, T., Krekó, J. & Tóth, C.G. (2024). Inequalities in regional excess mortality and life expectancy during the COVID-19 pandemic in Europe. *Scientific Reports*, *14*, 3835. https://doi.org/10.1038/s41598-024-54366-5

Horváth, J. K., Komlós, K., Krisztalovics, K., Röst, G., & Oroszi, B. (2022). A COVID-19 világjárvány első két éve Magyarországon. [The first two years of the COVID-19 pandemic in Hungary]. *Népegészségügy*, *99*(1), 6-19.

Juhász, A., Nagy, Cs., Oroszi, B., & Ádány, R. (2022). A COVID-19 megbetegedés, halálozás és oltottság alakulása és összefüggése a társadalmi-gazdasági helyzettel a 2-4. járványhullámok idején Magyarországon. [Spatial distribution of COVID-19 morbidity, mortality, and vaccination coverage and their association with the socioeconomic status during the 2nd-4th pandemic waves in Hungary]. *Népegészségügy*, *99*(1), 92-104.

Kandula, S., & Shaman, J. (2021). Investigating associations between COVID-19 mortality and population-level health and socioeconomic indicators in the United States: A modeling study. *PLoS Medicine*, *18*(7), 1-17. https://doi.org/10.1371/journal.pmed.1003693

Karlinsky, A. & Kobak, D. (2021). Tracking excess mortality across countries during the COVID-19 pandemic with the world mortality dataset. *ELife*, *10*, e71974. https://doi.org/10.7554/eLife.69336

Karmakar, M., Lantz, P. M., & Tipirneni, R. (2021). Association of social and demographic factors with COVID-19 incidence and death rates in the US. *JAMA Network Open*, *4*(1), e2036462.

Kathe, N. J., & Wani, R. J., (2021). Determinants of covid-19 case fatality rate in the united states: Spatial analysis over one year of the pandemic. *Journal of Health Economics and Outcomes Research*, *8*(1), 51-62. https://doi.org/10.36469/JHEOR.2021.22978

Kemenesi, G., Kornya, L., Tóth, G. E., Kurucz, K., Zeghbib, S., Somogyi, B. A., Zöldi, V., Urbán, P., Herczeg, R., & Jakab, F. (2020). Nursing homes and the elderly regarding the COVID-19 pandemic: situation report from Hungary. *GeroScience*, *42*, 1093-1099. https://doi.org/10.1007/s11357-020-00195-z

Khobragade, A. W., & Kadam, D. D. (2021). Spatial mapping and socio-demographic determinants of COVID-19 mortality in India. *Journal of Family Medicine and Primary Care*, *10*(11), 4200-4204. https://doi.org/10.4103/jfmpc.jfmpc_903_21

Kim, B., Rundle, A. G., Goodwin, A. T. S., Morrison, C. N., Branas, C. C., El-Sadr, W., & Duncan, D. T. (2021). COVID-19 testing, case, and death rates and spatial socio-demographics in New York City: An ecological analysis as of June 2020. *Health and Place*, *68*, 102539. https://doi.org/10.1016/j.healthplace.2021.102539

Klimovsky, D., Nemec, J., & Bouckaert, G. (2021). The COVID-19 Pandemic in the Czech Republic and Slovakia. *Scientific Papers of the University of Pardubice. Series D: Faculty of Economics and Administration*, *29*(1). https://doi.org/10.46585/sp29011320

Kopp, M., Skrabski, Á., Székely, A., Stauder, A., & Williams, R. (2007). Chronic stress and social changes, socioeconomic determination of chronic stress. *Annals of the New York Academy of Sciences*, *1113*, 325-338. https://doi.org/10.1196/annals.1391.006

Kotov, E. A., Goncharov, R. V., Kulchitsky, Y. V., Molodtsova, V. A., & Nikitin, B. V. (2022). Spatial Modelling of Key Regional-Level Factors of Covid-19 Mortality In Russia. *Geography, Environment, Sustainability*, *15*(2), 71-83. https://doi.org/10.24057/2071-9388-2021-076

Kovács, L., & Vánus, K. (2022). A hazai koronavírus-halálozás járási különbségeinek összefüggései az egészségügyi ellátással. [The relation between the differences of Coronavirus related deaths in the districts of Hungary and health services]. *Területi Statisztika*, *62*(3), 253-289. https://doi.org/10.15196/TS620301

Kovalcsik, T, Boros, L., & Pál, V. (2021). A COVID-19-járvány első két hullámának területisége Közép-Európában [The spatiality of the first two wawes of the COVID-19 pandemic in Central-Europe]. *Területi Statisztika*, *61*(3), 263-290. https://www.ksh.hu/statszemle_archive/terstat/2021/2021_03/ts610301.pdf

Kulu, H., & Dorey, P. (2021). Infection rates from Covid-19 in Great Britain by geographical units: A model-based estimation from mortality data. *Health and Place*, *67*, 102460. https://doi.org/10.1016/j.healthplace.2020.102460

Lebihan, L. (2023). Minimum wages and health: evidence from European countries. International *Journal of Health Economics and Management*, *23*, 85-107. https://doi.org/10.1007/s10754-022-09340-x

Levesque, J-F., Harris, M. F., & Grant, R. (2013). Patient-centred access to health care: conceptualizing access at the interface of health systems and populations. *International Journal for Equity in Health*, *12*(18), 1-9. https://doi.org/10.1186/1475-9276-12-18

Lima, E. E.C.D., Gayawan, E., Baptista, E. A., & Queiroz, B. L. (2021). Spatial pattern of COVID-19 deaths and infections in small areas of Brazil. *PLoS ONE*, *16*(2). https://doi.org/10.1371/journal.pone.0246808

Mattiuzzi, C., Lippi, G., & Henry, B. M. (2021). Healthcare indicators associated with COVID-19 death rates in the European Union. *Public Health*, *193*, 41-42. https://doi.org/10.1016/j.puhe.2021.01.027

McGowan, V., & Bambra, C. (2022). COVID-19 mortality and deprivation: pandemic, syndemic and endemic health inequalities. *Lancet Public Health*, *7*(11), e966-e975. https://doi.org/10.1016/S2468-2667(22)00223-7

Merkely, B., Szabó, A. J., Kosztin, A., Berényi, E., Sebestyén, A., Lengyel, Cs., Merkely, G., Karády, J., Varkonyi, I., Papp, C., Miseta, A., Betlehem, J., Burian, K., Csoka, I., Vasarhelyi, B., Ludwig, E., Prinz, G., Sinko, J., Hanko, B., Varga, P., Fulop, G.A., Mag, K., & Voko, Z. (2020). Novel coronavirus epidemic in the Hungarian population, a cross-sectional nationwide survey to support the exit policy in Hungary. *GeroScience*, *42*(4), 1063-1074. https://doi.org/10.1007/s11357-020-00226-9

Middya, A. I., & Roy, S. (2021). Geographically varying relationships of COVID-19 mortality with different factors in India. *Scientific Reports*, *11*(1), 1-12. https://doi.org/10.1038/s41598-021-86987-5

Morshed, M. M., & Sarkar, S. K. (2021). Common factors of COVID-19 cases and deaths among the most affected 50 countries. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, *15*(5), 102247. https://doi.org/10.1016/j.dsx.2021.102247

Munford, L., Khavandi, S., & Bambra, C. (2022). COVID-19 and deprivation amplification: An ecological study of geographical inequalities in mortality in England. *Health and Place*, *78*. https://doi.org/10.1016/j.healthplace.2022.102933

Muntele, I. (2022). Spatial Patterns and Drivers in the Evolution of Covid-19 Pandemic in Romania (March 2020-June 2021). *Analele Universităţii Din Oradea Seria Geografie*, *32*(1), 1-15. https://doi.org/10.30892/auog.321101-875

Nazia, N., Butt, Z. A., Bedard, M. L., Tang, W. C., Sehar, H., & Law, J. (2022). Methods Used in the Spatial and Spatiotemporal Analysis of COVID-19 Epidemiology: A Systematic Review. *International Journal of Environmental Research and Public Health*, *19*(14). https://doi.org/10.3390/ijerph19148267

Ndayishimiye, C., Sowada, C., Dyjach, P., Stasiak, A., Middleton, J., Lopes, H., & Dubas-Jakóbczyk, K. (2022). Associations between the COVID-19 Pandemic and Hospital Infrastructure Adaptation and Planning-A Scoping Review. *International Journal of Environmental Research and Public Health*, *19*(13), 8195. https://doi.org/10.3390/ijerph19138195

Oroszi, B., Juhász, A., Nagy, C., Horváth, J. K., Komlós, K. E., Túri, G., McKee, M., & Ádány, R. (2022a). Characteristics of the Third COVID-19 Pandemic Wave with Special Focus on Socioeconomic Inequalities in Morbidity, Mortality and the Uptake of COVID-19 Vaccination in Hungary. *Journal of Personal Medicine*, *12*, 388. https://doi.org/10.3390/jpm12030388

Oroszi, B., Juhász, A., Nagy, Cs., Horváth, J. K., McKee, M., & Ádány, R. (2022b). A COVID-19 járvánnyal összefüggő megbetegedések és halálozások egyenlőtlen terhei, valamint összefüggésük a társadalmi-gazdasági helyzettel Magyarországon a második járványhullám alatt. [Unequal burden of COVID-19 in Hungary: a geographical and socioeconomic analysis of the second wave of the pandemic]. *Népegészségügy*, *99*(1), 76-91.

Ozyilmaz, A., Bayraktar, Y., Toprak, M., Isik, E., Guloglu, T., Aydin, S., Olgun, M. F., & Younis, M. (2022). Socio-Economic, Demographic and Health Determinants of the COVID-19 Outbreak. *Healthcare* (*Switzerland*), *10*(4). https://doi.org/10.3390/healthcare10040748

Papadopoulos, V. P., Emmanouilidou, A., Yerou, M., Panagaris, S., Souleiman, C., Varela, D., Avramidou, P., Melissopoulou, E., Pappas, C., Iliadou, Z., Piperopoulos, I., Somadis, V., Partsalidis, A., Metaxa, E., Feresiadis, I., & Filippou, D. (2022). SARS-CoV-2 Vaccination Coverage and Key Public Health Indicators May Explain Disparities in COVID-19 Country-Specific Case Fatality Rate Within European Economic Area. *Cureus*, *14*(3). https://doi.org/10.7759/cureus.22989

Parysek, J., & Mierzejewska, L. (2021). Spatio-temporal analysis of the development of the COVID-19 epidemic (pandemic) in Poland: First phase of development. *Geographia Polonica*, *94*(3), 325-354. https://doi.org/10.7163/GPol.0208

Perone, G. (2021). The determinants of COVID-19 case fatality rate (CFR) in the Italian regions and provinces: An analysis of environmental, demographic, and healthcare factors. *Science of the Total Environment*, *755*, 142523. https://doi.org/10.1016/j.scitotenv.2020.142523

Petrovič, F., Vilinová, K., & Hilbert, R. (2021). Analysis of hazard rate of municipalities in Slovakia in terms of Covid-19. I*nternational Journal of Environmental Research and Public Health*, *18*(17). https://doi.org/10.3390/ijerph18179082

Petti, S., & Cowling, B. J. (2020). Ecologic association between influenza and COVID-19 mortality rates in European countries. *Epidemiology and Infection*, *148*(e209), 1-7. https://doi.org/10.1017/S0950268820002125

Praharaj, S., Kaur, H., & Wentz, E. (2022). The Spatial Association of Demographic and Population Health Characteristics with COVID-19 Prevalence Across Districts in India. *Geographical Analysis*, *55*(3), 427-449. https://doi.org/10.1111/gean.12336

Rizaldi, A. A., Xie, S., Hubbard, R. A., & Himes, B. E. (2022). Neighborhood Characteristics and COVID-19 Incidence and Mortality in Southeastern *Pennsylvania. AMIA Summits on Translational Science Proceedings, 2022,* 422-431.

Röst, G., Bartha, F. A., Bogya, N., Boldog. P., Dénes, A., Ferenci, T., Horváth, K.J., Juhász, A., Nagy, C., Tekeli, T., Vizi. Z., & Oroszi, B. (2020). Early phase of the COVID-19 outbreak in Hungary and post-lockdown scenarios. *Viruses*, *12*(7). https://doi.org/10.3390/v12070708

Sannigrahi, S., Pilla, F., Basu, B., & Basu, A. S. (2020). The overall mortality caused by COVID-19 in the European region is highly associated with demographic composition: A spatial regression-based approach. *Sustainable Cities and Society*, *62*, 102418. https://doi.org/10.1016/j.scs.2020.102418

Sannigrahi, S., Pilla, F., Basu, B., Basu, A. S., & Molter, A. (2020). Examining the association between socio-demographic composition and COVID-19 fatalities in the European region using spatial regression approach. *Sustainable Cities and Society*, *62*. https://doi.org/10.1016/j.scs.2020.102418

Santos, V. S., Siqueira, T. S., Cubas Atienzar, A. I., da Rocha Santos, M. A. R., Vieira, S. C. F., et al. (2022). Spatial clusters, social determinants of health and risk of COVID-19 mortality in Brazilian children and adolescents: A nationwide population-based ecological study. *The Lancet Regional Health - Americas*, *13*, 100311. https://doi.org/10.1016/j.lana.2022.100311

Sobczak, M., & Pawliczak, R. (2022). COVID-19 mortality rate determinants in selected Eastern European countries. *BMC Public Health*, *22*, 2088. https://doi.org/10.1186/s12889-022-14567-x

Sleszinsky, P. (2021). Stages of spatial dispersion of the COVID-19 epidemic in Poland in the first six months (4 March-20 September, 2020). *Geographia Polonica*, *94*(3), 305-324. https://doi.org/10.7163/GPol.0207

Stach, A. (2021). Temporal variation of spatial autocorrelation of COVID-19 cases identified in Poland during the year from the beginning of the pandemic. *Geographia Polonica*, *94*(3), 355-380. https://doi.org/10.7163/GPol.0209

Stier, A. J., Berman, M. G., & Bettencourt, L. M. A. (2021). COVID-19 attack rate increases with city size. *npj Urban Sustainability*, *1*(31). https://doi.org/10.1038/s42949-021-00030-0

Sun, Y., Hu, X., & Xie, J. (2021). Spatial inequalities of COVID-19 mortality rate in relation to socioeconomic and environmental factors across England. *Science of the Total Environment*, *758*. https://doi.org/10.1016/j.scitotenv.2020.143595

Szysz, M. & Torój, A. (2023). Socio-Economic and Demographic Factors Associated with COVID-19 Mortality in European Regions: Spatial Econometric Analysis. *Econometrics*, *11*(2), 17. https://doi.org/10.3390/econometrics11020017

Tang, I. W., Vieira, V. M., & Shearer, E. (2022). Effect of socioeconomic factors during the early COVID-19 pandemic: a spatial analysis. *BMC Public Health*, *22*(1), 1-9. https://doi.org/10.1186/s12889-022-13618-7

Tchicaya, A., Lorentz, N., Leduc, K., & de Lanchy, G. (2021). COVID-19 mortality with regard to healthcare services availability, health risks, and socio-spatial factors at department level in France: A spatial cross-sectional analysis. *PLoS ONE*, *16*(9). https://doi.org/10.1371/journal.pone.0256857

Tóth, C. G. (2022). Narrowing the gap in regional and age-specific excess mortality during the COVID-19 in Hungary. *Eastern Journal of European Studies*, *13*(1), 185-207. https://doi.org/10.47743/ejes-2022-0109

Urban, R. C., & Nakada, L. Y. K. (2021). GIS-based spatial modelling of COVID-19 death incidence in São Paulo, Brazil. *Environment and Urbanization*, *33*(1), 229-238. https://doi.org/10.1177/0956247820963962

Urbanovics, A., Sasvári, P., & Teleki, B. (2021). Evaluation of the COVID-19 regulations in the Visegrad group. Transforming Government: People, *Process and Policy*, *15*(4), 645-657. https://doi.org/10.1108/TG-08-2020-0228

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), 401-418.

Uzzoli, A., Kovács, S. Zs., Fábián, A., Páger, B., & Szabó, T. (2021). Spatial Analysis of the COVID-19 Pandemic in Hungary - Changing Epidemic Waves in Time and Space. *Region - Journal of ERSA*, *8*(2). https://doi.org/10.18335/region.v8i2.343

Vokó, Z., Kiss, Z., Surján, G., Surján, O., Barcza, Z., Pályi, B., Formanek-Balku, E., Molnár, G., Herczeg, R., Gyenesei, A., Miseta, A., Kollar, L., Wittmann, I., Müller, C., & Kasler, M. (2021). Nationwide effectiveness of five SARS-CoV-2 vaccines in Hungary - The HUN-VE study. *Clinical Microbiology and Infection*, *28*(3), 398-404. https://doi.org/10.1016/j.cmi.2021.11.011

Vokó, Z., Kiss, Z., Surján, G., Surján, O., Barcza, Z., Wittmann, I., Molnár, G. A., Nagy, D., Müller, V., Bogos, K., Nagy, P., Kenessey, I., Wéber, A., Polivka, L., Palosi, M., Szlavik, J., Rokszin, G., Müller, C., Szekanecz, Z., & Kasler, M. (2022).

Effectiveness and Waning of Protection with Different SARS-CoV-2 Primary and Booster Vaccines During the Delta Pandemic Wave in 2021 in Hungary (HUN-VE 3 Study). *Frontiers in Immunology*, *13*. https://doi.org/10.3389/fimmu.2022.919408

Wali, B., & Frank, L. D. (2021). Neighborhood-level COVID-19 hospitalizations and mortality relationships with built environment, active and sedentary travel. *Health and Place*, *71*, 102659. https://doi.org/10.1016/j.healthplace.2021.102659

World Health Organization Regional Office for Europe (2000). Highlights on health in Hungary. Copenhagen: WHO Regional Office for Europe. https://iris.who.int/handle/10665/108672

Wrigley-Field, E., Garcia, S., Leider, J. P., & Van Riper., D. (2021). COVID-19 Mortality at the Neighborhood Level: Racial and Ethnic Inequalities Deepened in Minnesota in 2020. *Health Affairs*, *40*(10), https://doi.org/10.1377/hlthaff.2021.00365

Yu, H., Lao, X., Gu, H., Zhao, Z., & He, H. (2022). Understanding the Geography of COVID-19 Case Fatality Rates in China: A Spatial Autoregressive Probit-Log Linear Hurdle Analysis. *Frontiers in Public Health*, *10*, 751768. https://doi.org/10.3389/fpubh.2022.751768