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Cities in the epidemic, the epidemic in cities: Reconstruction of COVID-19 development in Polish cities

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ABSTRACT

The Covid-19 pandemic, with its epicentres in cities, came as the most severe social, economic and financial shock of the 21st century. The reconstruction of the pandemic spread in cities, the determination of factors conducive to and preventing from SARS-CoV-2 virus infections as well as searching for the ways to combat it and its effects have become the subject of many studies and analyses. The results presented in this article are part of this research. The study covered 20 large Polish cities with different functions, in the set of which: (1) the course of the infection process (by means of a rarely used trajectory method) was determined as well as its temporal variation (variance), (2) cities were classified in terms of the similarity of the epidemic process (correlation analysis), and (3) the factors conducive to infections presented in the literature (using a multivariate regression method) were verified. In this case the investigation was also carried out on the set of 66 large cities. Generally, the relative number of infections (per 10,000 inhabitants), i.e. the intensity of infections, was used as the basis for the analysis. The research has shown that the size, function and location within the country have no influence on the course and intensity of the epidemic in particular cities. Unfortunately, it was not possible to identify factors that could be responsible for infections, or at least that could determine the risk of infections (no confirmed impact on infections of population density, the level of poverty, the proportion of a post-working age population or the level of people’s health). Thus, the obtained results testify to the individual nature of the spread of the epidemic in each city and to the possible influence of other explanatory features on the infection level than those considered in this investigation, or to the level of infections as the effect of the synergetic interaction of more than just socio-economic features. The solution to this issue remains open, as it seems, not only in the case of Polish cities.

1. Introduction

As the second decade of the 21st century drew to a close, when, broadly speaking, many countries of the world, after the crisis of the 2008–2012 saw the stabilisation of socio-economic growth and entered the path of sustainable development, in 2020 in the Chinese city of Wuhan an extremely dangerous and unknown virus SARS CoV-2 appeared and, consequently, the Covid-19 pandemic. Despite the progress in medicine, epidemiology and pharmacology and the dissemination of immunisation, a new, unexpected virus spread rapidly causing irreversible consequences in the population, economy and social life.

The outbreaks of infections and their dissemination are mainly cities which concentrate people, but also centres of capital, finances, business life, science and technology as well as political authority, conducive to lively social contacts. Moreover, it is primarily in cities that sanitary and health services operate and important political decisions to combat the pandemic and mitigate its effects are taken. That is why, and also because of a high level of global and local connections, cities are perceived not only as the outbreaks of infections, but as places where the most troublesome outcomes of the pandemic occur. The pandemic, the immediate consequences of which are already known, and long-term effects are difficult to predict.

This study aims to present the development processes of the Covid-19 epidemic (pandemic) in selected cities of Poland from the onset of the epidemic to the first days of January 2021. Moreover, the similarity of the epidemic courses in the set of investigated cities has been determined and an attempt to indicate factors responsible for infections and the spread of the epidemic has been made. The study also carries out a methodological objective, which is the application of the graphical

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method of a trajectory (known in the literature as connected scatter plot) in the research on processes (the epidemic specifically). This is not very popular, but still an original and interesting graphical method for analysing development processes. By process we understand a series of successive states of affairs, which in the case of epidemic development means daily emerging (registered) infections. In the case of investigating epidemic growth, it is an innovative approach, different from commonly used ‘comparative statistics’. Therefore, it is an investigation on a continuous basis (day by day), because this is how the epidemic develops, as a process and not merely in distinguished periods. What is more, the research process embraces almost a year of epidemic growth. The method of connected scatter plot used has greater capacity to interpret the phenomenon variability over time than a traditionally applied line graph. The work falls within the scope of geographical sciences, especially urban geography, but also within geography of health. This is important because the literature on this epidemic is dominated by epidemiological and mathematical studies and spatial analyses undertaken are conducted primarily on a global (e.g., Sigler et al., 2021) and national scale (Qiu et al., 2020 – China; Zhu & Zhu, 2020 – China; Abedi et al., 2020 – USA; Wu et al., 2020 – USA, Zemtsov and Baburin, 2021 – Russia; Gribaudo et al., 2021 – Italy and Śleszyński, 2020 – Poland; Parysek & Mierzejewska, 2021 – Poland). Far fewer publications deal with individual cities (Li et al., 2020 – Wuhan; Aloi et al., 2020 – Santander; Pisano, 2020 – Paris and Milano), and even more with groups of cities (Qiu et al., 2020 – China; Xie & Zhu, 2020 – China; Magnoni, 2021 – Italy). In the latter, however, the research issue and empirical scope of the research were defined differently compared to this study.

2. The development of the Covid-19 epidemic (pandemic) as a spatial diffusion process

In the 1960s, among geographers who were interested in spatial organisation, structure and functioning of the human life environment including human beings as agents of occurring changes, a new research issue appeared—analysis of spatial processes, including primarily the research on the diffusion of innovation. Based on diffusion processes, what was tried to be built in veterinary and medical sciences were models of the spread of infectious disease epidemics (Hägerstrand, 1967; Corner, 1994). This is because it was assumed that an emerging disease of an epidemic nature was a kind of ‘innovation’, and the conducted research showed that its dissemination could be treated as expansion spatial diffusion, to a certain extent also relocation diffusion. Each of these categories of diffusion may be transmittable (epidemic) or hierarchical (cascading) in nature. There is a lot of evidence that the diffusion of the SARS CoV-2 coronavirus is transmittable expansion diffusion and also relocation diffusion in which the process of infection transmission takes place from one place to neighbouring ones (Sigler et al., 2021; Zemtsov & Baburin, 2021). The course of innovation diffusion, also an epidemic, may depend on various kinds of barriers hindering or even preventing the epidemic spread (Domanski, 1990a, 1990b; Hägerstrand, 1967; Haggett, 1965; Haggett et al., 1977; Loboda, 1983; Parysek, 1997; Pred, 1977). It should be emphasised here that the diffusion models presented in geographical literature (based on probability theory, the Markov Chain model and the Monte Carlo method) are used in currently proposed Covid-19 diffusion modeling and its consequences (e.g., Zemtsov, Baburin 2021; Krishna, 2020; Zhu & Zhu, 2020; Serra et al., 2021). Use is also made of certain long-established (1927) epidemiological models (Gribaudo et al., 2021) and regression models (Coccia, 2020). The latter, however, concern a temporal, not spatial approach to epidemic development. A separate group of models are those which analyse the epidemic results in socio-economic sphere of life and decisions taken (Aloi et al., 2020; Mel-lacher, 2020; O’Sullivan, 2020). According to current knowledge, contracting the virus is determined by direct contact from an infected individual (Thomas et al., 2020; Zemtsov & Baburin, 2021). Many different factors determine whether a person becomes infected or not. New infections can be limited or stopped only by isolation (quarantine) or vaccination. Certainly, the infected persons who do not display the symptoms of a disease may infect others and ‘act’ as reflecting barriers. As observed in the current course of the pandemic, the diffusion process can be hindered by the protection from contagion, facilitated by staying at home (avoiding contacts), using masks, maintaining so-called social distancing, washing and disinfecting hands, but also young age, good health, innate immunity and presumably other determinants. The above-mentioned factors are undoubtedly the reason for temporal and spatial differences in the course of epidemic processes, which means that each city will have its own development path of the infection, i.e., its own trajectory, which is the subject of the study. Although it has been assumed that epidemic development is a spatio-temporal process, the conducted research on the set of cities, however, could only allow for a temporal aspect reduced to the studies of the epidemic development process, and then to relevant comparisons in the set of investigated cities. The data that would allow determining the spatial distribution of infections in those cities are unavailable. This problem does not exist for research on a global, national or regional scale.

Although it has been stated above that SARS CoV-2 diffusion represents primarily the categories of expansion diffusion, this virus reached Poland by relocation. The first infected person in Poland was a resident of Lubuskie Voivodeship who returned from Germany. The illness was diagnosed on 4 March 2020, and the patient went to a hospital in Zielona Góra. Unfortunately, no model process of the reconstruction of SARS CoV-2 coronavirus epidemic development has been made so far in Poland, which results primarily from still limited resources of knowledge regarding either the virus or infection diffusion factors. A certain attempt to reconstruct the development of the epidemic (although called diffusion) was made by Śleszyński (2020). However, its temporal dimension (the first 100 days of the pandemic) and explanatory power (it was mainly the analysis of the process of change in the number of infections in Poland’s territorial units in the adopted periods) were limited. Recent months have brought a plethora of publications devoted to modeling Covid-19 diffusion processes, from theoretical mathematical approaches to the adoption of these models in empirical studies, unfortunately concerning global, domestic, regional aspects as well as those of an individual city.

It should be emphasised at this point that although pandemic development is assumed to occur through diffusion, the research results presented here were not obtained by the application of spatial diffusion models. This was due to both the lack of clear views of epidemiologists on the spatial aspects of the Covid-19 spread and no reliable data that would make it possible to conduct such a study. Moreover, it is possible to perform such research only in relation to a compact area, not to a set of dispersed cities. For these reasons, the use of the term ‘diffusion’ is metaphorical and is understood as the spread of the epidemic. Notwithstanding, according to diffusion models, the infection is assumed to occur by direct contact in a given place in a specific city (contact infection) or it comes from an individual who arrived in this city (relocation infection). Owing to that fact, the first infections were diagnosed in the investigated cities with some delay from the first, as indicated by the data in Table 2.

The difficulty in the development of a universal model of the virus dissemination and factors responsible for it stems probably from the specificity of its diffusion process in almost any place and under any conditions.

3. Cities as outbreaks of infections and the epidemic development

With the development of the Covid-19 pandemic, research was carried out not only into the nature of the SARS CoV-2 virus itself, the epidemic spread and its consequences, but also into the search for factors that are conducive to infections. The search concerned on the one hand personal factors of infection and the influence of so-called
underlying illnesses, such as tumours, hypertension, diabetes, obesity, kidney diseases, inflammation of epithelial cells, as well as psychiatric diseases, ADHD, HIV and a blood type (Nishiura et al., 2020; Siłwowska, 2020), and on the other hand, demographic, social, economic factors and others, including climatic (temperature, air humidity, wind strength, etc.) risk of infections (Abedi et al., 2020; Liu et al., 2020; Parysek & Mierzejewska, 2021; Qiu et al., 2020; Rosenfeld et al., 2020; Xie & Zhu, 2020). What is indicated at the same time is the geographic variation of factors conducive to infections (Abedi et al., 2020; Liu et al., 2020; Nicola et al., 2020; Siłwowska, 2020; Sun et al., 2020; Zhang & Schwartz, 2020). Spatial differences in the occurrence of such elements of the broadly understood Covid-19 epidemic as infection, vulnerability, interdependency, immunisation, resilience, blame and health care are also investigated (Spárke & Anguelov, 2020).

With the published research results, different sets of factors increasing the risk of contracting the SARS CoV-2 virus and incidence of Covid-19 can be prepared. The publications invoked herein indicate often mentioned risk factors, such as the following: the population number, population density, mobility, the education level, socio-demographic, ethnic and racial differences, poverty and social inequality, living standards, the healthcare level or low air quality and so on (cf. Coccia, 2020; Cole et al., 2020; Lee et al., 2020; Li et al., 2020; Liu et al., 2020; O’Sullivan, 2020; OECD, 2020; Pisano, 2020; Rosenfeld et al., 2020; UN, 2020; Wu et al., 2020). Research in Poland, carried out for the first period of the epidemic, demonstrates population density, employment in industry, old age and also a relatively low level of healthcare as statistically significant factors in the regional variation of infections (Parysek & Mierzejewska, 2021).

Should we assume that the dissemination of SARS CoV-2 virus infections is expansion and relocation diffusion, cities seem to be particularly conducive to its development. This is where the so-called social distance is the smallest and the number of contacts resulting from the organisation, structure and functioning of such a settlement unit as a city is high. In fact, it is commonly believed that social contacts, as a consequence of minimising social distancing, are the main factor behind the development of the epidemic (Fuchs, 2020). Cities are primarily such places.

### 4. Research subject and figures

The subject of the research was mostly a set of the 20 largest, big and medium-sized Polish cities, selected from the 66 cities with special status (cities with county (powiat) rights) which, however, on a European and especially global scale should be treated as medium-sized and small cities. The urban population in Poland makes up 60% of the total number of inhabitants (23,033.1 thous from 38,382.6 thous) (Statistics Poland 2019). The population number of the 20 investigated cities accounts for 15.4% of Poland’s population (5893 thous) and 25.6% of all city residents.

The choice of cities was intentional. The problem, however, was the comparison of such a set of cities for which the data on the number of daily infections could be obtained. This was required by the process analysis, conducted with the use of the trajectory method and the determination of similarity in the processes in cities (correlation). Twenty cities were selected, including four multifunctional cities with the largest number of inhabitants and 16 cities with a different population number, the functions and the geographical situation of which vary (Table 1 and Fig. 1). The number of 20 cities results also from technical considerations (graphs and information in tables take up much space). The figures were obtained from the daily records of coronavirus infections, collected and published in the Internet by a (‘non-profit’) team supervised by Michał Rogalski. These data reflect the number of infections proved by positive tests. They are, in turn, performed on medical grounds (suspected infection) and also in the populations most likely to be infected, i.e., important for combating the epidemic (hospitals, other health care institutions, sanitary services), places where the

| Table 1 |
| --- |
| **General description of the selected cities under study.** |
| **City** | **Population number** | **Location in country** | **General description** |
| Warsaw | 1,790,658 | East-central Poland | Capital of Poland; continental metropolis; multifunctional centre; political, economic and social life centre; large agglomeration centre; |
| Krakow | 779,115 | South-eastern Poland | Former capital of Poland; metropolis of subcontinental importance; macro-regional and multifunctional centre; science, cultural and tourism centre; |
| Łódź | 679,941 | Central Poland | Multifunctional centre; former, large industrial centre of industrial area, undergoing transformation; academic and film city; |
| Wrocław | 642,869 | South-western Poland | Metropolis of subcontinental importance; multifunctional macro-regional centre; industry, science and cultural centre; metropolis of national importance; |
| Szczecin | 401,907 | North-western Poland | Multifunctional centre of sea transport, as well as chemical and shipbuilding industry, services, science and culture; agglomeration centre; metropolis of national importance; |
| Katowice | 292,774 | Southern Poland (Upper Silesia) | Centre of Upper Silesia industrial agglomeration; multifunctional regional centre; economic, science and cultural centre; |
| Toruń | 201,447 | North-central Poland | Large multifunctional regional centre; industrial centre; renowned academic centre; cultural and tourism centre; |
| Rzeszów | 196,208 | South-eastern Poland | Multifunctional, dynamically growing regional centre (automotive and aviation industry); |
| Zielona Góra | 141,222 | Western Poland | Regional centre sharing function with Gorzów; industrial, service and trade centre; |
| Rybnik | 138,098 | Southern Poland (Upper Silesia) | Coal mining centre; centre of Rybnik Coal Area (ROW); |
| Wałbrzych | 111,356 | South-western Poland | Shrinking city; former centre of coal mining and textile industry; going through restructuring of economy; |
| Jastrzębie-Zdrój | 88,743 | Southern Poland (Upper Silesia) | City since 1963; former health resort; largest coal mining centre in Poland, established in 1960s (within ROW); Regional centre; former industrial centre of national significance; today multifunctional centre; centre of tourism and spa treatment; |
| Jelenia Góra | 79,061 | South-western Poland | Regional centre; multifunctional regional centre; economy; science, cultural and tourism |
| Suwałki | 69,758 | North-eastern Poland | Subregional (former regional), border centre providing services in attractive natural area; |
| Przemyśl | 60,689 | South-eastern Poland | Multifunctional centre with subordinate functions, located near the Ukraine border; head office of regional administrative units; |

(continued on next page)
large number of the employed work close to one another (e.g. in coal and metal mines) and in the communities with the concentration of the elderly (social welfare homes). People known to have had contact with the infected were also tested. Therefore, the numerical data used do not represent the entire infected population, the majority of which passes the infection asymptomatically (Sleszyński, 2020). This is so because infection screening data from the population of individual cities are not available.

The research covers the year 2020, specifically from the first day of the SARS CoV-2 virus infection in Poland, i.e., 4 March 2020 to 10 January 2021. The daily register of identified infections has been aggregated by week, obtaining the series of 45 data. The source data have been adjusted to the adopted model of research and properly aggregated or counted. The obtained results for cities have been compared to the country’s epidemiological situation.

Moreover, in some cases, the set of the investigated cities was widened to 66. In this situation, the research included all cities with special administrative status. With regard to this set of cities, what was conducted was comparative analysis of correlations between the number of infections and the set of features used consequently in regression analysis as a set of variables explaining the level of these infections.

5. Research methods

The basic method in reconstructing the Covid-19 epidemic development process in Polish cities was a trajectory method, in English literature called connected scatter plot (Hingel, 1993; Ormerod, 1993). A graphic method of time series analysis is not often used, probably because on the one hand, its advantages as a method for the analysis of processes are not discerned, and on the other hand, it is difficult to understand without going into its essence. Still, it is applied by Polish geographers (Parysek, 2002, 2004; Parysek & Mierzejewska, 2012). The term ‘trajectory’ comes from ballistics where it denotes the track of the bullet from the place it is fired to the target, i.e., where it achieves its goal. A similar situation exists in the case of the development which started in a certain moment and was analysed to a certain moment (regrettfully not until the end of it). A trajectory is a specific graph, fundamentally different from traditionally plotted linear graphs. The essence, and also the uniqueness of this method, lies in the adoption of
basically illogical assumptions. In a rectangular coordinate system, the points do not represent the size of a given phenomenon in subsequent periods, but changes (specifically events) which occurred in a certain, analysed period. In the case of this research, changes are the number of infections in a given week in relation to the number of infections in the previous week. Subsequent trajectory points describe changes which took place in consecutive weeks and the whole trajectory—the process of epidemic development understood as a sequence of events organised according to the timeline. The trajectory can adopt various forms. Reading its course is a way to interpret the process. The basic principle is to interpret the course in relation to the starting point of the coordinate system of the x and y axes, the course and shape of the trajectory and the distance between its subsequent points. Analysing the development process, a straight-line trajectory course (or close to it) indicates monotonic development (moving away from the point of intersection of the x and y axes) or economic collapse—depression, crisis, etc. (moving towards it). The shorter the distance of a given trajectory point from the beginning of the coordinate system, the lower the dynamic (pace) of changes, the longer the distance, the higher the dynamic. Greater distances between subsequent trajectory points indicate bigger changes, smaller ones show minor changes in the development process. There are often loops in the trajectory course. They demonstrate on the one hand, the return to the situation that was already present (regression in development), and on the other, the cyclicity of the process investigated. In the latter case, the loops will move away from each other and from the beginning of the coordinate system, if the development process is of cyclical nature. The overlap of several loops shows that the situation is complicated, indicates a lack of a clear development trend and a crisis. From the beginning to the end, the trajectory course is a synthetic picture of the transition from the initial to the final state of the process under study. The trajectories were plotted not on the basis of the total number of registered infections, however, but per 10,000 inhabitants. Only by calculating the number of infections in such a way was it possible to determine the intensity of the epidemic and make comparisons in the set of investigated cities.

The trajectory method applied made it possible to reconstruct the process of epidemic development and present its course in a graphic form. An important, cognitive effect of using this method is an opportunity to take a holistic view of the process, indicating the directions (development, stagnation and reversal of the epidemic) and pace of gradual changes. It also allows determining the degree of similarity of the process in subsequent phases (waves).

Use was also made of correlation analysis as a tool for determining similarity between epidemic development processes in the investigated cities and to provide classification in this respect (Lance & Williams, 1967; Parysek, 1982). Calculated for the time series of epidemic development and arranged in a matrix, correlation coefficients performed the role of similarity function. As such, they were basis for plotting a dual dendrite (a graphic image of similarity structure), the division of which into parts meant the separation of classes of cities with a similar epidemic course. It allows determining the degree of similarities and differences in the epidemic course in particular cities and formulate possible hypothesis with regard to the factors of the differences observed.

What was also used was multivariate regression analysis to determine the likely impact of socio-economic features on the level of infections in individual cities (a model with a gradual elimination of features—not insignificant explanatory variables). This analysis was preceded by determining correlation in the set of variables. Both correlation and regression analyses were characterised by a static approach. This is so because they were conducted for one period. The subject of the research was the set of 20 investigated cities. Regression analysis made it possible to measure the impact of the socio-economic factors hypothetically adopted on the level of infections together with determining the significance level. In other words, it allowed verifying the hypotheses adopted.

6. Results of the research

6.1. Development of the Covid-19 epidemic in Poland in 2020

As was already mentioned, in Poland the Covid-19 epidemic began on 4 March 2020 and it grew at a varying rate until 2–9 November, when it reached 166,547, the highest number of new infections recorded. After this period, the dynamic was gradually weakening, and the number of the infected persons in Poland at the end of 2020 was 1,296,210. At the same time, the number of those who contracted the disease grew per 10,000 inhabitants, showing a stable upward trend to the level of 337.7 persons/10,000 inhabitants at the end of the year, but with the variable growth rate.

The development of the epidemic development in Poland plotted for the infections calculated per 10,000 inhabitants of the country maps the generally described process (Fig. 2). Until October 11th, a monotonic increase in the number of infections takes place, still at a very low level, with a certain decrease in the week of September 6–13. From October 18th, there was a marked acceleration of infections, reaching its maximum on 15 November. This is a turning point, from which “the withdrawal of the process” takes place, although at a somewhat higher level than the increase that occurred. At the turn of 2021, some reversal in the downward trend is visible.

6.2. Development of the epidemic in the set of 20 Polish cities

Until 10 January 2021, the number of coronavirus infections in the 20 investigated Polish cities amounted to 240,192 (by the end of the year, i.e., after 44 weeks—229,228), which was 17.6% of all the infections in the country (Table 1). They were observed mostly in the five largest cities, i.e., in Warsaw (69,859), Łódź (32,109), Krakow (31,330), Wrocław (25,906) and in Szczecin, which is obvious considering their number of residents; whereas the lowest number was recorded in Sopot (1159). The variance in the set of the studied cities was 137.7% and was higher than the differences in the population number (130.2%).

A city in which SARS-CoV-2 appeared as early as two days after the first registration of the virus was Wrocław (two days later), and then Szczecin (three days), Krakow (five days), Łódź (seven days) and Warsaw (nine days later). It reached Suwałki the latest (35 days later), Jelenia Góra (33 days), Tarnobrzeg (33 days), Zielona Góra (31 days) and Toruń (30 days later). The process of emerging infections in the investigated cities indicates no spatial trend, but some randomness. What is observable, however, is a relatively quick manifestation of the virus in the largest cities. Thus, within five to six weeks the virus was likely to be present in all Polish cities (Table 2).

When considering the harmfulness of the virus, what is important is

Fig. 2. Trajectory of the epidemic development (infections) in Poland in 2020.

Source: own elaboration.
Typical features of the process of SARS-CoV-19 virus infections in the set of investigated cities as compared to Poland.

| Unit     | Area (km²) | Population density (pers./km²) | Delay in infections (No. of days in relation to first infection) | No. of all infections | No. of infections per 10,000 inhabitants | Infections in week with largest number of infections per 10,000 inhabitants | Total number of infections in week with largest number of infections per 10,000 inhabitants |
|----------|------------|-------------------------------|---------------------------------------------------------------|-----------------------|------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| POLSKA   | 312,705    | 123                           | 0                                                            | 1,363,219             | 355                                      | 43                                                                       | 166,547                                                                     |
| Warsaw   | 517        | 364                           | 9                                                            | 69,859                | 390                                      | 61                                                                       | 10,902                                                                     |
| Krakow   | 327        | 238                           | 5                                                            | 32,109                | 412                                      | 65                                                                       | 5065                                                                       |
| Łódź     | 293        | 232                           | 7                                                            | 31,330                | 461                                      | 58                                                                       | 3913                                                                       |
| Wrocław | 293        | 2194                          | 2                                                            | 25,906                | 403                                      | 95                                                                       | 6109                                                                       |
| Szczecin | 301        | 1335                          | 3                                                            | 19,486                | 485                                      | 48                                                                       | 1927                                                                       |
| Katowice | 165        | 1774                          | 15                                                           | 9888                  | 338                                      | 71                                                                       | 2066                                                                       |
| Toruń    | 116        | 1737                          | 30                                                           | 11,623                | 577                                      | 80                                                                       | 1616                                                                       |
| Rzeszów  | 126        | 1557                          | 8                                                            | 8129                  | 414                                      | 103                                                                      | 2014                                                                       |
| Zielona Górna | 277  | 510                           | 31                                                           | 4643                  | 329                                      | 37                                                                       | 527                                                                        |
| Rybnik   | 148        | 933                           | 8                                                            | 6071                  | 440                                      | 84                                                                       | 1161                                                                       |
| Wałbrzych | 85        | 1310                          | 12                                                           | 2862                  | 257                                      | 38                                                                       | 427                                                                        |
| Jastrzębie-Zdrój | 85  | 1044                          | 15                                                           | 3887                  | 438                                      | 56                                                                       | 501                                                                        |
| Jelenia Góra | 109  | 725                           | 33                                                           | 2255                  | 285                                      | 42                                                                       | 329                                                                        |
| Suwałki  | 66         | 1057                          | 39                                                           | 2465                  | 353                                      | 80                                                                       | 561                                                                        |
| Przemyśl  | 46         | 1319                          | 26                                                           | 2694                  | 444                                      | 87                                                                       | 529                                                                        |
| Świecień | 13         | 3812                          | 11                                                           | 1534                  | 310                                      | 62                                                                       | 305                                                                        |
| Tarnobrzeg | 85       | 550                           | 33                                                           | 1390                  | 297                                      | 44                                                                       | 208                                                                        |
| Kronos   | 44         | 1052                          | 19                                                           | 1357                  | 293                                      | 51                                                                       | 238                                                                        |
| Słononice | 202        | 202                           | 15                                                           | 1545                  | 378                                      | 40                                                                       | 163                                                                        |
| Sopot    | 17         | 2101                          | 19                                                           | 1159                  | 234                                      | 34                                                                       | 122                                                                        |

Source: own elaboration.

not so much the total number of infections, but its relation to the number of inhabitants. The most infections on the day 10 January 2021 were noted in: Toruń (577), Szczecin (485), Łódź (461), Przemyśl (444), Rybnik (440) and Jastrzębie-Zdrój (438), whereas the least: Wałbrzych (257), Jelenia Góra (285), Kronos (293) and Tarnobrzeg (297), with the average 381 for the set of cities and a small variance (20.5%), which indicates a relatively equal level of infections with regard to the number of inhabitants.

Analysed week by week in each city, the course of the epidemic demonstrated its specificity, although, in general, some similarities are likely to be identified (which will emerge from the presentation of the results of other research). This situation is illustrated well in Fig. 3, which is a synthetic image of the epidemic development from its beginning until the first days of January 2021. What can be seen is a gradual development of infections at a very low level, which is probably a result of the restrictions introduced on 16 March and tightened on 31 March, and which can be called a socio-economic 'lockdown'. With regard to the assessment of a fairly good epidemiologic situation and the onerousness of constraints placed on society and the economy, a gradual relaxation of restrictions started (4, 15 and 31 May), which caused, already during this process, a transient increase in infections, primarily in Rybnik and Jastrzębie-Zdrój. The centres of infections were hard coal mines located there. Other outbreaks could be noted in social welfare homes. A slight increase in infections was also visible in early August. As of 8 August, local differences in restrictions were introduced, defining three risk level zones: low (a green zone), medium (yellow) and high (red), which eventually clearly raised the mobility of the country's inhabitants (holiday travels) and revived economic activity, especially in broadly understood services (trade, gastronomy, tourism, recreation, cosmetic services, cultural activity, etc.). Unfortunately, the effects of the relaxation of many restrictions (with the remaining distance, masks, disinfection, hygiene) were made themselves known as early as from mid-September, resulting probably also from the fact that teaching was restored in different types of schools (working online from mid-March) as well as an autumn immunity drop. On October 24th the country’s authorities reinstated many of the constraints. However, a dynamic

Fig. 3. General trend in the intensity of the epidemic development in the investigated Polish cities in 2020 (number of infections per 10,000 inhabitants).

Source: own elaboration.
increase in infections was not stopped, the peak of which fell on the first two weeks in November. Following this period was a gradual decrease in infections until some stability from early December lasting to the first days of January (Fig. 3).

The development process of the epidemic in particular cities showed a diverse dynamic week by week. It is evidenced by a diverse variance in the time series of infections per 10,000 inhabitants between 131.5% (Jastrzębie-Zdrój) and 219.7% (Wrocław). The higher the variance, the more disturbed the epidemic course. Outside Wrocław, a significant disturbance to this process was noted in Rzeszów (206.9%), Krosno (197.3%), Suwałki (193.8%) and Katowice (190.1%), and a more stable course, apart from Jastrzębie-Zdrój, was observed also in Sopot (137.4%).

What is also evident is the general stabilisation of a relative epidemic development rate over time in particular cities, especially noticeable after 26 July. Between 8 and 28 July, the variance of infections in the set of investigated cities amounted to over 190%, and on 10 January it was 20.5% (Fig. 4).

In the light of the conducted research, the differences in the epidemic course in particular cities was visible, despite decreasing disparities in infection rates per 10,000 inhabitants in the set of investigated cities (Figs. 3 and 4).

6.3. Trajectories of the epidemic development in cities

The course and pace of the coronavirus pandemic development in selected Polish cities were analysed on the basis of the plotted trajectories, which were additionally compared to the course of infections in the entire country in order to determine any similarities and differences. This is certainly a visual similarity, referred to the trajectory course. The analysis of the plotted trajectories shows that on the whole the virus dissemination process in the investigated cities and across the country was alike, particularly in large cities, although in many of them displayed more specific features (Fig. 5a-Su). It is possible to draw some, perhaps not entirely legitimate, conclusion from this that the pandemic course in the country was shaped to a great extent by the largest cities.

On the basis of the trajectory course, some groups of cities with similar development trajectories can be distinguished. The first one comprises the cities for which the trajectories take the form of an almost closed loop similar to the one illustrating the situation in the country. This group can include Warsaw, Krakow, Łódź, Wrocław, Katowice and Toruń, which are the largest cities among the investigated ones - multifunctional, macroregional centres of various levels, situated in different parts of the country. A typical feature of the dissemination of the coronavirus there was small increases in infections in the first phase of the pandemic (over the first few weeks), then a different rate of growth of infections with its apogee in the first half of November when the dynamic of infections was the highest (large distances between the points representing infections in subsequent November weeks). In the second half of November (mainly after 15 November 2020), the situation started to stabilise, and the infection rate began to decrease, although the rate of decline was rather individualised. It was relatively fast in Warsaw, Krakow, Wrocław and Katowice, where in the last weeks of the analysed period one could observe the stabilisation in the number of infections. A slower pace was noted in the case of Łódź and Toruń. Especially in the latter, the rate of decline in coronavirus infections was rather slow. A slightly different course of infections in comparison to that described above was typical of cities from the second group, i.e., Szczecin, Zielona Góra and Wałbrzych - cities of different sizes, located near the country’s western and south-western border. Also in these cities, the infection rate was increasing, taking the highest values in the middle phase of the pandemic. This is certainly a visual similarity, referred to the trajectory course.

Especially in the latter, the rate of decline in coronavirus infections was rather pronouncedly flattened, an almost closed loop with additional small loops. In the event of Szczecin and Zielona Góra, such a loop describes the first phase of the decline in infections observed after 15 November, whereas in the case of Wałbrzych the initial phase of the epidemic. The third, most numerous group of cities with a similar trajectory of the development of coronavirus infections includes Rzeszów, Rybnik, Jelenia Góra, Suwałki, Przemysł, Świętoczłociwice, Krosno and Tarnobrzeg, which are medium and small cities of the investigated set, with different functions, situated in the country’s southern and eastern border. Trajectories for these cities take the form of a closed or almost closed loop, usually with a lot of disturbances of the infection rate in the initial and final period analysed when their epidemic situation alternately improved and deteriorated.

It is less clearly visible in Rzeszów and Suwałki, whereas more in Rybnik (numerous loops in the initial phase of the epidemic), Jelenia Góra (disturbances in the initial period analysed), Przemysł (alternating increases and decreases in infections in the middle phase of the described process, proved by the intersection of the trajectory curve) and Świętoczłociwice, Krosno and Tarnobrzeg (loops in the initial period analysed, and more or less numerous intersections of the line indicating the trajectory in the final period of the research). Quite an individual course of infections is indicated by the trajectories of the following cities: Jastrzębie-Zdrój, Świnoujście and Sopot. These are two coastal cities with tourist and recreational functions (Sopot, Świnoujście) as well as health resort and industrial ones (Jastrzębie-Zdrój). Jastrzębie-Zdrój is the only city among those analysed in which two large loops and several smaller ones are noticeable. Here, we deal with two pronounced epidemic waves and numerous disturbances in the infection process. In the case of the first loop this is related to the mining character of the city and infection detection among miners and their families in the summer season. The second distinctive loop refers to the late autumn increase in infections observed nationwide. In Świnoujście we encounter a situation in which initially the epidemic development process took place similarly to other cities—becoming more dynamic; however, starting from 8

Fig. 4. Coefficients of variation of infections in the investigated Polish cities in the subsequent weeks of 2020.
Source: own elaboration.
Fig. 5. a-u. Trajectories of the epidemic development (infections) for Polish cities in the subsequent weeks of 2020. Source: own elaboration.
November, there was an alternating pattern of growth and decline in infection dynamics (numerous loops in the final period analysed) with low intensity of infections (40/10,000 inhabitants), although quite high in the final period of the research. An individual nature of the trajectory plotted for Sopot is indicated by its many loops and intersections. The level of infections remains relatively high for this city as well. The more
complete interpretation of the development trajectory can be obtained when analysing data contained in the table and tracking their course carefully.

It is worth noting here that among the analysed cities Sopot was the one with the lowest infection rate of a maximum of 34 persons per 10,000 inhabitants in the week with the highest number of infections. Apart from Sopot, the group of cities with the lowest maximum weekly infection level, lower than the average in the country, comprised also Wałbrzych (38/10,000 inhabitants), Świnoujście (39/10,000) and Jelenia Góra (42/10,000). These are smaller cities located in northern and south-western Poland, three of them lie at the Baltic Sea. By analogy, the most infections were recorded in Rzeszów (103 persons/10,000 inhabitants), Wrocław (95/10,000) and Przemyśl (87/10,000), therefore primarily in cities situated in south-eastern Poland, close to the border with Slovakia and Ukraine, although Wrocław could be found among them as well.

Based on the trajectory, one may observe quite a close similarity between the course of the epidemic in the largest investigated cities and the development of infections in the country.

### 6.4. Similarity of epidemic development processes in the investigated cities

Similarity of the processes of epidemic development in the set of the studied cities was determined on the basis of a correlation coefficient which was treated as a similarity function. The calculated coefficients of the largest dual similarity between epidemic development processes show a high level of significance ($\alpha = 0.001$), but with a relatively small number of objects (20). The most similar courses ($r \geq 0.970$) were those of the epidemic development between: Wałbrzych and Tarnobrzeg ($r = 0.977$), and Wałbrzych and Jelenia Góra ($r = 0.972$), Katowice and Świętochłowice ($r = 0.972$), Warsaw and Łódź ($r = 0.970$). The least similar processes were those in Szczecin and Świnoujście ($r = 0.948$), and Łódź and Sopot ($r = 0.920$). There is, therefore, reason to conclude that the epidemic in the investigated cities was very similar.

A relatively faint similarity in the epidemic development did not, however, hamper the classification of the investigated cities in this respect. Classification was done using a method of elementary connections that would randomly determine both the number of classes and their composition (Lance & Williams, 1967; Parysek, 1982; Steinhausen & Langer, 1977). Six classes of similarity have been distinguished in line with the procedure of creating elementary connections (elementary clusters).

The following classification has been obtained: class I: Jelenia Góra – Wałbrzych – Tarnobrzeg, class II: Suwałki – Wrocław – Świętochłowice – Katowice – Rybnik – Jastrzębie-Zdrój, class III: Kraków – Warszawa – Łódź – Sopot, class IV: Zielona Góra – Toruń, class V: Rzeszów – Przemyśl and class VI: Szczecin – Świnoujście (Table 3). The separated classes group different cities in terms of the size, functions, geographical location and also the intensity of the epidemic. The similarity was determined only by the dynamics and course of the epidemic determined by the time variability. This is a slightly different classification from that obtained when analysing the similarity between trajectories. The classification discussed here, however, allows for the whole epidemic development represented by the statistical series of data, whereas trajectories are a synthetic picture of this process, showing additionally (on an editorially acceptable scale) the most essential changes occurring in time.

What was also determined was the degree of similarity between epidemic processes in cities and in the country. The following showed the greatest similarity in this respect: Łódź ($r = 0.890$), Warsaw ($r = 0.973$), Wałbrzych ($r = 0.972$) and Tarnobrzeg ($r = 0.970$), whereas the slightest affinity was displayed in Jastrzębie-Zdrój ($r = 0.624$), Rybnik ($r = 0.848$), Katowice ($r = 0.887$), Świnoujście ($r = 0.888$), and Rzeszów ($r = 0.888$). All the correlation coefficients of the epidemic development process in the country and in the investigated cities are significant at the high level ($\alpha = 0.001$), which also applies to a unique city which is
investigated cities raising the risk of infections can be those reducing social distance and regression model as a dependent variable (explained). Eight features similarity and dissimilarity. In this high degree of similarity, the epidemic of the economy and functions of a city do not affect the degree of sim-

As already mentioned above, in order to show the possible factors that could determine the level of risk of coronavirus infection, use was made of correlation analysis and a multivariate regression model. The subject of the performed calculations was a data matrix comprising a set of the nine considered features for 20 cities. The first of the features (y), the number of virus infections per 10,000 inhabitants, describing the intensity of infections among residents of a given city, was treated in a regression model as a dependent variable (explained). Eight features were adopted as independent (explanatory) variables which, from a theoretical point of view, should be conducive to infections or limit their possibility, and which are indicated in the literature and in official positions of epidemiological services, not only in Poland. The features raising the risk of infections can be those reducing social distance and increasing contacts as well as their intensity, i.e., (x₁) population density (per 1 km²) and (x₃) the employed in industry and construction (per 1000 inhabitants), (x₂) advanced age decreasing immunity (post-working age population per 1000), (x₄) an indicator of health condition increasing the likelihood of the disease and death (mortality per 1000 inhabitants), (x₅) the poverty level (individuals receiving a social allowance per 1000 inhabitants) and also features that can prevent infections: (x₆) a health personnel base (doctors per 10,000 inhabitants), (x₇) health care material base (beds in hospitals per 10,000 inhabitants and (x₈) material situation of inhabitants (average pay).

The correlation analysis carried out has shown that none of the computed correlation coefficients of the infection intensity indicator (y) with the features that can influence the level of infections is significant, even at the level of α = 0.1 (r₁ = 0.3598). The following correlation coefficients have been obtained: rₓ₁ = 0.079, rₓ₂ = −0.353, rₓ₃ = −0.022, rₓ₄ = 0.103, rₓ₅ = 0.210, rₓ₆ = −0.283, rₓ₇ = −0.287, rₓ₈ = −0.453. These results indicate that none of the features related to factors potentially decreasing social distance and conducive (or not) to infections (determining the risk level except for feature x₆) in the set of 20 cities shows a statistically significant relationship with the intensity of infections, which can be treated as an impact. However, these factors can interact together, causing a synergistic effect. For these reasons, a model of multivariate regression analysis was applied, with a gradual elimination of independent variables (explanatory x₃) with an insignificant impact on the value of a dependent variable (explained y).

The relatively best fit was a model of the form: y = 450.1 + 0.395 x₅ + 0.0159 × 7 + 23.234 x₉. This model indicates three variables x₁, x₅ and x₉, which explain in 40.4% (R² = 0.404%) the value of a dependent variable (the number of infections per 10,000 inhabitants). Although these variables influence the infection rate to a different degree, they determine a certain risk level. Yet, the interaction of these variables is typical. The material base of hospitals (x₃) provides on the one hand a higher level of benefits, but on the other, has a well-developed diagnostic base to detect infection. The material situation of inhabitants (x₇) has supposedly an impact on mobility and, as a result, on reducing social distance (gastronomy, entertainment, cultural and sports events, excursion, power training gyms, fitness, etc.), which is conducive to the spread of infection in a given city. The health condition of inhabitants has a specific impact (x₈). Individuals with poor health usually stay home, have limited interpersonal interactions and thus face a lower risk of getting infected. The insignificant impact of population density (x₁) results probably from its different indicator within each city. Older inhabitants (x₂), in fear of their health and limited activity, have fewer contacts and reduced possibility of infection. The insignificant impact of people working in industry, large clusters of the employed (x₃), results, on the one hand, from the various industrialisation level of the investigated cities, and on the other, from the degree of the concentration of labour in industrial plants (different numbers of employees). The poor (x₆) have no impact on the infection rate, not only because of limited mobility, but also owing to the fact that a relatively small number of residents benefit from social welfare in cities, including care homes that most often function in suburban zones, small towns or in rural areas. The number of doctors has no significant impact as well (x₈). However, some of these personnel were associated with working in Covid treatment facilities and this is to a certain extent reflected in the impact of a health care material base (x₅), while the others functioned in an online counselling system. It should be emphasised at this point that explanatory variables are not significantly correlated, which means that in regression analysis there is no variance reproduction by the considered variables.

The lack of a clear impact of the features of virus infection risk resulting from the conducted research in relation to 20 cities led to comparative studies on a sample of 66 cities. This was possible thanks to a static nature of the analysis which, in contrast to the reconstruction of epidemic spread, did not require time series of data. The investigated set was 66 cities, i.e., all Polish cities with poviat status—a subregional territorial administrative unit. What was obtained were the following
The epidemic development in individual cities was dynamically diversified week after week. At the same time, the process of infections emerging in the investigated cities does not demonstrate any spatial trend, but rather some randomness. What is observable, however, is a relatively quick manifestation of the virus in the largest cities. This confirms to a certain extent the views presented in the literature according to which what is conducive to COVID-19 dissemination is the globalization which incorporates large cities and agglomerations, with a high intensity of interpersonal contacts (Sigler et al., 2021; Zemtsov & Baburin, 2021). Such contacts are demonstrated in border and seaside areas (Sigler et al., 2021; Zemtsov & Baburin, 2021). However, the Polish coastal cities in the investigated set are different from typical ones, largely dominated by seaport activities as well as refineries and other industrial plants, material bases, warehouses, transfer stations, etc. Both Sopot and Swinoujście are cities with tourist, recreational and residential functions.

The volume of infections in individual cities was growing steadily but not monotonically, at first rather slowly, in most cases. However, from mid-November onwards, it was very dynamic, maintaining a fairly high intensity until the end of the year. It seems obvious that the number of infections is highly correlated with a city size as determined by the population number. Nevertheless, the intensity of infections is quite different, that is the relation of the number of infections to the number of inhabitants (per 10,000). Quite high differences in the incidence rate at the initial period in individual cities (determined for the set of 20 cities) evened out over time. It can be reflected in the observed changes by the influence of restrictions inhibiting infections, which limited the mobility and interpersonal contact of inhabitants (from March, August and October) and relaxations advancing infections. The obtained results showed that restrictions concerning the functioning of individuals and the economy called socio-economic lockdown brought some positive effects, although by the end of the year the number and infection rate remained at a relatively high level changing over time (cf. trajectories). This confirms the thesis that in the absence of widespread vaccination, limited mobility of people prevents the spread of COVID-19 to a great degree (Zemtsov & Baburin, 2021), especially at the initial stages of the epidemic (Chinazzi et al., 2020). Such conclusions were the basis for the epidemiological policy of both WHO and Polish sanitary services.

Spatial differences in the intensity of infections in the investigated cities relates only to a small extent to the results of the research carried out in Poland at regional level (Parysek & Mierzejewska, 2021; Śleszyński, 2020). There are significant differences between them. While some studies (Śleszyński, 2020) show that the area with the highest infection rate on Poland’s map takes the shape of a triangle, the basis of which rests on the Polish-German and Polish-Czech borders and the summit reaches the vicinity of Białystok, other research (Parysek & Mierzejewska, 2021) indicates a relatively low level of the intensity of infections in north-western and south-eastern Poland. It should be emphasised, however, that in the first studies the general number of infections over a short period was taken into account—100 days of epidemic development (Śleszyński, 2020), and in the latter, as in this research, infections per 10,000 inhabitants over an extended period. In both publications mentioned, the research was conducted at regional level, and these studies concern cities. Therefore, the period of research and research units (region vs. cities), and also the features considered (the absolute vs. relative number of infections) from both publications are incomparable (cf. Parysek & Mierzejewska, 2021; Śleszyński, 2020).

The differences in the infection rate in the set of cities have narrowed over time, which indicates a gradual convergence of the epidemic development in the studied cities. This has been accompanied by a clear levelling-off in a relative rate of epidemic development in the set of investigated cities over time. Given a maximum weekly infection level in different cities at different periods, what has been observable is a lower level of infections in smaller cities situated in the country’s northern and north-western part, including coastal regions, whereas a higher level in cities located in the southern and south-eastern part. The separated classes with the similar process of epidemic development group together cities that differ in size, function, geographical location and also the epidemic rate. However, the inter-class differences in the properties of objects included in particular classes are not large. What has been also stated is the similarity in the course of the epidemic development in cities with that in the country. This also concerns the city of Jastrzębie-Zdrój, unique in this respect (mining and health resort centre). In this mostly high degree of similarity, the least similar to that of the country has been the course of the epidemic in the Upper Silesian Industrial Region.

In both sets of 20 and 66 Polish cities, there is no statistically significant correlation between the number of infections and the risk factors considered and indicated in numerous publications. The correlation has not been confirmed also by the conducted multivariate regression analysis that determines a simultaneous impact of explanatory variables on the level of an explained variable which is the number of the infected per 10,000 inhabitants. This may lead to a generalised conclusion that each city, and presumably every other territorial unit, has its own individual epidemic development path that changes over time, which is the result of a synergetic interaction of many different factors. Thus, frequently expressed conclusions on the correlation of infection indicators with population density (Lee et al., 2020; Li et al., 2020; Oecd, 2020; Pisano, 2020; UN, 2020; Urban Density... 2020; Zemtsov & Baburin, 2021; Zhu & Zhu, 2020), or the correlation between a higher level of health care and lower mortality, or the correlation of infections and mortality with a higher proportion of people aged 60 years and older (Oecd, 2020; Urban Density... 2020; Zemtsov & Baburin, 2021) have not been confirmed. This leads to the conclusion that it is highly likely that the factors identified do not have a significant impact in the conditions of a high population density in cities (also Polish), a similar socio-cultural development level, no clear national diversity as well as material, ethnic, racial, religious differences, which is typical of Polish cities. It is worth emphasising, however, that what has been confirmed at regional level (16 regions) in Poland was statistical significance of a
positive impact on the level of infections of such factors conducive to interpersonal contacts as population density and occupational activity, especially in large institutions, and advanced age, as well as reducing the impact of a relatively well-developed material base of health service in this respect. What has not been confirmed, on the other hand, was the influence of social welfare homes. Material status, defined by the number of owned cars, however, increased the risk of infection to a certain degree (Parysek & Mierzejewska, 2021).

The uniqueness of the research conducted, owing to its subject (a set of cities), material scope (studies on the process that was developing for almost a year, its pace and differences in time and the investigated set of cities, similarity in the courses and an attempt to identify differentiating factors), the temporal scope (almost a year) as well as the method applied, is a major obstacle to relate the obtained results to literature. It is also difficult to compare works on epidemiology, virology and modeling spatio-temporal diffusions (mathematics, statistics, big data, computer science) with a paper that falls within the scope of geographical studies. A publication that would study a set of cities, the research of which would deal with the development of the epidemic in a similar approach indicating differentiating factors, has not been found.

8. Conclusion

All studies into determining the course and intensity of the epidemic, which are not detailed and fragmented epidemiological studies are, unfortunately, only approximate. This results from the lack of reliable figures, different, regarding the subject matter and in terms of time and space, which will probably be never obtained. The basic data that can be acquired in Poland for the country’s territorial units in the full time series (in subsequent days) is the number of infections specified on the basis of positive test results. The number of tests, however, is severely limited in relation to the population number. This is so because there are no screening tests which would cover the entire country’s population. However, such tests could not be considered representative, especially in research on epidemic development processes. A positive or negative result on the day of testing does not necessarily mean the same situation in a few days’ time. What is more, individuals with positive test results do not have to show symptoms, be ill, be hospitalised, and recover or die. There are also people unaware of being infected with the virus, who unwittingly participate in the diffusion of infections, and those who have probably built up so-called herd immunity about which it is hard to predict how long it will last. All this makes the investigated situations only closer to the reality we live in, but as statisticians say, any research is better than no research. It does not mean, however, that the research into the development of the SARS-CoV-2 epidemic should not be carried out, especially such that may have a practical impact.

After preparing short-term and crisis response to the shock caused by the coronavirus pandemic, urban authorities need to start developing long-term strategies (OECD, 2020). For this very purpose, what is useful is the knowledge of the spread of the virus, the factors conducive to infections and ways of mitigating the pandemic effects provided to some extent by the research conducted. This knowledge can serve, therefore, to prepare urban authorities better to create the best possible conditions for preventing the spread of the epidemic and mitigating its effects, which means a safer life of inhabitants and functioning of the economy, and the most effective strategies of development in the situation of the epidemic, lockdowns and after its normalisation. Undoubtedly, cities of the future should be made better prepared to respond to epidemics promptly, but the way this preparedness is to be built remains open (Piisano, 2020; Wahba et al., 2020; UNWTO, 2020; Allam & Jones, 2020; Allam, 2020a, 2020b; Aloi et al., 2020; OECD, 2020). The field of the research still seems to be very large.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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