STAGES OF SPATIAL DISPERSION OF THE COVID-19 EPIDEMIC IN POLAND IN THE FIRST SIX MONTHS (4 MARCH-20 SEPTEMBER, 2020)

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Abstract

The article is a continuation of research published by the author elsewhere (Śleszyński, 2020). The elaboration presents the regularity of spatial distribution of infections during the first six months after the detection of SARS-CoV-2 coronovirus in Poland under strong lockdown conditions. The main aim is to try to determine the basic temporal-spatial patterns and to answer the questions: to what extent the phenomenon was ordered and to what extent it was chaotic, whether there are any particular features of spread, whether the infection is concentrated or dispersed and whether the spreading factors in Poland are similar to those observed in other countries. Daily data by county (poviat)* were collected by Rogalski's team (2020). The data were aggregated to weekly periods (7 days) and then the regularity of spatial distribution was searched for using the cartogram method, time series shifts, rope correlation between the intensity of infections in different periods, Herfindahl-Hirschman concentration index (HHI) and cluster analysis. A spatial typology of infection development in the population was also performed. Among other things, it was shown that during the first period (about 100 days after the first case), the infections became more and more spatially concentrated and then dispersed. Differences were also shown in relation to the spread of the infection compared to observations from other countries, i.e. no relation to population density and level of urbanization.

Key words

pandemic • COVID-19 • SARS-CoV-2 • medical geography • geoepidemiology • spatial diffusion • lockdown • Poland

Introduction

Pandemic COVID-19, initiated in China in 2019. (Zhao & Chen, 2020), which spread around the world in spring 2020. (WHO, 2020), for obvious reasons, caused great interest in science. Some of the studies are

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* In the article, 'county' and 'poviat' (or 'poviats' and 'counties') are used interchangably (Editor's note).

related to problems that fall within the scope of medical geography and geoepidemiology. This is due to the fact that the spread of any infectious disease in the human population has its very important conditions related to the subject of geography studies (Cliff & Haggett, 1989; Wilson, 2010; Meade, 2014).

The special feature of any infectious disease is its spread, or so-called local transmission. In medical geography, the most prominent feature of medical geography (Sattenspiel & Lloyd, 2009) is its spatially continuous spread (diffusion) and discontinuous (dispersion), e.g. jump dispersion. The former is accidental (random) and the latter systematic, most often associated with the slow transmission of infections from the epicenter to the centrifugal. This is therefore a more exhaustive distinction than is usual in socioeconomic geography.

Since the SARS-CoV-2 coronavirus is transmitted between people by droplets, the development of the epidemic is closely related to social contact models. These, in the geoepidemiological context, depend on four main groups of conditions:

- the natural environment, i.e. especially climate (also in the stricter sense meteorological and topoclimatic conditions), orography and hydrography, determining the natural factors of 'supply' of viruses, but also human mobility (Skydsgaard, 2010; Amin, 2020; Ficetola & Rubolini, 2020);
- spatial development, i.e. settlement structure, population density, urban forms, communication network (Darch et al., 2018; Carozzi, 2020; Hamidi et al., 2020);
- particularly complex socioeconomic factors, especially on the psychosocial side, i.e. lifestyles, cultural-civilizational, religious factors, etc., mobility models and so-called social distance (understood as limiting contacts and physical distance between people), level of social development, hygiene and epidemiological awareness (Ngwa et al., 2017; Badr et al., 2020; Tammes, 2020; Traoréand & Konané, 2020; Vokó & Pitter, 2020);
- the level of development of state and local government services, etc., including

in particular medical and epidemiological services and the so-called blockades and exit strategies (Levin et al., 2007; Moore & Hawarden, 2020; Thompson et al., 2020).

In each of these conditions one can find successive cause-effect relationships, in which, from the point of view of geography, the physical space and relations between the elements present in it are crucial.

Although research on the spread of infectious diseases has a very long tradition (Panum, 1846), knowledge of the determinants and diffusion factors is still unsatisfactory. The well-known textbook on this subject (Sattenspiel & Lloyd, 2009), while emphasizing the key role of social contacts, marginally treats, among other things, the issue of communication channels, i.e., all contemporary knowledge of transport geography. Meanwhile, the role of communication nodes as places where the virus spreads seems to be crucial. This applies both on a global scale, especially airports, and on a local scale, such as urban and regional transport nodes.

Research problem and research objectives

The global scale of the epidemic, unprecedented since the 1918-1919 influenza and 1980s HIV epidemics, has resulted in an increased interest in the medical services, including unseen details of infection registration. As the literature review, presented further on, shows, owing to the development of information technologies, it is possible with great time and space accuracy, although the statistical solutions used are very different in different countries. For a number of countries and geographical areas, however, this gives the best opportunity in the history of medical geography to analyze the spatial spread of infections. Thus, there is an excellent chance to deduce the spatial and temporal diffusion patterns with unprecedented precision.

The essence of the research problem here is still a high degree of ignorance about the conditions and mechanisms of virus spread. So far, no clear answer to the main

causes of the epidemic has been found. The question of social distance is not an answer here, as this assumption is too general. The point is that there is no clear indication of which specific features related to mobility and in which countries are most important. A correct conclusion is hindered by the fact that most studies are based on comparisons of the spatial development of the number of infections with indicators from before the pandemic, and yet mobility in times of the epidemic has been severely restricted in the vast majority, which has resulted in strong changes, e.g. in the structure of commuting to work and daily ranges of urban systems. Thus, the first step in researching the geography of the coronavirus should first be to establish the basic regularities of diffusion and spatial dispersion and, in order to establish cause-effect relationships, to search for indicators and variables that well reflect the actual mobility and social distance in times of pandemic and sanitary restrictions.

Against this background, the basic aim of the article is to attempt to determine the basic temporal-spatial diffusion regularities of coronavirus SARS-CoV-2 in Poland in the first six months, i.e. between 4 March and 20 September 2020. As it is already known, this period was characterized by a relatively low development of infections, which most probably resulted from a strong lockdown introduced in the initial period of the epidemic. Under these conditions, the aim is especially to show the basic territorial and wider geographical regularities associated with the registered incidence of COVID-19. This is to answer the following specific questions:

1. Is the diffusion ordered or chaotic, i.e., according to the classic proposal of R.L. Morrill (1968) hierarchical or contact (wave)?
2. Is it possible to indicate any particular features of the increase in the intensity of coronavirus infections in the regional structure of Poland?
3. Is the infection concentrated or dispersed?
4. Are the factors of coronavirus spread in Poland similar to those observed in other countries, or are they different?

The above questions are key to understanding the nature of spatial diffusion of the coronavirus. The answer to the first three questions informs about such spreading characteristics, which can be codified in the form of a model. The answers to the questions are also of great pragmatic value because they help to 'manage' the epidemic more effectively, i.e. to direct the medical and orderly forces, etc., where the problem is greatest.

Taking into account the current state of knowledge (December 2020), it is known that since the second half of September in Poland (and in many European countries even earlier) there has been an intensive increase in the number of infections, called (and predicted earlier) as the so-called 'second wave' of the epidemic. This study is therefore a kind of geographical summary of the first period of the outbreak in Poland.

Research review

Since it has been more than a year since the SARS-CoV-2 coronavirus outbreak, a great deal of spatial diffusion work has already been published. Their exact number is difficult to determine. According to estimates, in 2020, 4% of all scientific publications worldwide were related to the epidemic (Else, 2020). According to the 'Dimensions' database (https://reports.dimensions.ai/covid-19/), the number of papers in March 2021 exceeded 350,000. Virtually every country in the world is involved in research (197 countries, according to the 'Dimensions' database). However, most of the studies come from a few countries (USA – 61,800, UK – 25,200, China – 25,100, Italy – 14,900), where the epidemic first developed. From Poland there were 2300 publications. This compares with 9900 in Germany, about 800 in Czechia, about 300 in Slovakia, 2700 in Sweden and 2500 in Russia. It is worth noting the number of papers from individual centers (universities, institutes). The largest number of papers came from Harvard University (3960), followed by the University of Oxford (2392) and the University of Toronto (2183). In sixth place

was Huazhong University of Science and Technology in Wuhan (1953). Some of these papers even received several thousand citations each in one year.

About half of the papers (168,700) are in the "Medical and health services" group. An important position is held by "Studies in human society" (19,800). Relatively few works are classified as "Earth sciences" (1400). A number of papers use spatial analysis methods and GIS tools (eg. Franch-Prado et al., 2020). Interestingly (and is 'a sure sign of the times'), the vast majority of these applications are prepared by non-geographers.

The rate of growth of research on the SARS-CoV-2 coronavirus and the COVID-19 pandemic is thus paralleled (Callaway et al., 2020). There is an increasing need for literature reviews (e.g., Sharifi & Khavarian--Garmsir, 2020 on the impact of pandemics on urban life and lessons for urban planning, design, and management). As early as July 2020, there were claims that there had been a 'massification' of pandemic research and that this threatened to marginalize other types of research and the term 'covidization of science' was coined (Pai 2020).

Understandably that the first 'spatial' and 'geographical' studies came from China (Du et al., 2020, Liu et al., 2020). When the disease has spread practically all over the world, there is already a certain amount of research concerning other countries, especially large ones and those where medical geography is at a high level (Ascani et al., 2020; Jia et al., 2020; Danon et al., 2020; Mollalo et al., 2020; Şahin, 2020). There are also works based on very detailed spatial data in cities (Cordes & Castro, 2020). There is a growing number of works from peripheral parts of the world as well, such as Algeria (Rahmani et al., 2020) or Java Island (Fitriani & Yaja, 2020). These studies basically emphasize what is known about the spread of viruses in human populations, including more or less strong relationship with population density and mobility levels.

The COVID-19 outbreak first developed in major cities: Wuhan, Milan, Madrid, and New York. Therefore, it has been hypothesized that the development of infections is influenced by the settlement rank associated with global functions, especially air transport hubs (Khanh et al. 2020, Pequeno et al. 2020). An association with population density (Sun et al. 2020, Tammes 2020), air temperature (Bashir et al., 2020; Méndez-Arriaga 2020), and humidity (Wu et al. 2020) has also been observed. Many of these insights into viral disease transmission were long known and well documented (e.g., as a result of air travel contacts; Mangili & Gendreau, 2005). However, as the epidemic progressed, subsequent studies were less conclusive (Hamidi et al., 2020) and pointed to the greater importance of household characteristics, family structure, etc. This was especially true in Sweden, which is known to have been unaffected by lockdown for many months (Florida & Mellander, 2020).

In comparison to Western Europe in particular, the USA and China, not many studies have been published for Poland and Central European countries. The 'Dimensions' database indicates 132 works (March 12, 2021), mostly medical. The first synthetic attempt to investigate the phenomenon nationwide by counties (poviats) and establish basic regularities was published in the *Czasopismo Geograficzne* (Śleszyński, 2020). On a regional scale it was, for example, a study by Krzysztofik et al. (2020), which deals with the phenomenon of a strong increase in infections in the Śląskie voivodship.

As early as June 2020, a special issue of the 'Prace Komisji Geografii Komunikacji PTG' (*Transport Geography Papers of Polish Geographical Society*) on the impact of the COVID-19 pandemic on various aspects of mobility will be published: passenger rail transport in Poland and Italy (Taczanowski, 2020; Taczanowski & Kołoś, 2020), air traffic in Poland (Pijet-Migoń, 2020), bus transport in rural areas of the Low Beskids and Bieszczady Mts. (Ciechański, 2020), tourist trips (Wiskulski, 2020), passenger transport in the Dolnośląskie voivodship (Smolarski, 2020), and the novel for Poland application of Google LCC telemetry data in measuring lockdown

movements (Tarkowski et al., 2020). In addition, various other articles are successively published, e.g. on the hospitality (Napierała et al., 2020), urban policy (Śleszyński et al., 2020), spatial accessibility (Rosik et al., 2021), and monographs, e.g. on spatial policy (Nowak, 2021).

There are few papers trying to explain cause-effect relationships of coronavirus spread (Jarynowski et al., 2020). In this study, the virus diffusion was studied using a correlation method depending on various variables, e.g. population density, permanent residence and remuneration in the economy, and even political support. The results clearly indicate the role of mobility in the spread of the virus in Poland, which is quite obvious in the light of the previous knowledge of medical geography and geoepidemiology in general, as mentioned.

Data sources and test methods

In Poland, the most detailed data available on the spread of coronovirus are collected by a social effort of an Internet group led by Rogalski (2020) team. The data is collected by a team of about 5 people on the basis of data mainly from the websites of voivodship and poviats sanitary and epidemiological stations. This is information on the increase in the number of registered (detected) infections day after day aggregated to 360 poviat units (poviats, and in a several cases groups of two poviats).

It should be stressed that the word 'registered' used is of key importance and requires methodological commentary. Well, the detectability of each disease depends on its correct diagnosis in the population. In the case of COVID-19 it depends primarily on the tests performed. These tests, in turn, are performed in those populations where there is a higher probability of finding an infection. Due to drip-transmission of coronavirus, the tests in Poland were performed mainly in places that were more likely to be affected, i.e. health and social care institutions (e.g. hospitals, nursing homes) and in those

communities (families, workplaces and other population concentrations) where the infection was already diagnosed. According to the statements of Raciborski et al. (2020), from March 4 to April 30, 2020, when the first 338 thousand RT-PCR tests were performed and the first 12.9 thousand cases of the disease were found, 33% were related to people under quarantine, 26% were related to the health care system (hospital or clinic), and 13% occurred in nursing homes. The problem of data collection and comparability is not specific to Poland, and problems of this type are reported in different parts of the world (Roser et al., 2020).

In the analyses, basic geographical methods were used to analyze variables in time and space. They concerned in particular the evaluation of dynamics and degree of concentration. In order to answer the first and third question (i.e., whether diffusion is orderly/chaotic and whether this infectivity is concentrated/dispersed), the analysis of time series and analysis of linear correlation of co-occurrence of infections in poviats in 29 weekly intervals (March 4-10, March 11-17, etc.) was used. In the case of the second question, cartographic analysis was used, showing the intensity of recorded infections in poviats per 10 thousand population.

Apart from the analyses on the units of the poviats, the analysis also used a division into their types, related to the degree of urbanization. In this, aggregation to functional areas of cities was assumed, as this type of area, based on daily functional-spatial relationships (commuting to work, education, personal services, trade, etc.), seems to be the most appropriate reference field for research on the spread of infectious diseases, even with limited mobility. Due to the aggregation of infection data by county, it was not possible to take advantage of the existing delimitations of urban functional areas where the reference field was the commune. The boundaries of urban functional areas were tried to match the delimitation made for 18 voivodeship capitals (Śleszyński, 2013) or the surrounding rural counties

were added to the cities. The boundaries of the functional areas were tried to match the functional areas. In this way, a database containing 80 functional areas was created, consisting of 166 poviats (the largest functional area – Katowice – contained 19 poviats). Due to the availability of data it was divided into six types:

1a – core areas (urban centers) of over 250 thousand inhabitants (30 poviats, 23% of the country's population),

1b – core areas below 250 thousand inhabitants (28 poviats, 7% of the country's population),

2 – mixed areas (rural counties with a larger city or strongly urbanized) (39 poviats, 14% of the country population),

3 – rural counties which are external zones of types 1a and 1b, mainly external 'ring' counties (68 poviats, 21% of the country population),

4 – other more densely populated counties (over 70 people per 1 km^2) (101 poviats, 20% of the country population),

5 – other less populated counties (less than 70 people per 1 km^2) (105 poviats, 15% of the country population).

For the purposes of typology, which was carried out using the classic Ward's cluster analysis method (it is most useful for the geographical clustering of discrete data, and such is the case with the development of the coronavirus epidemic in Poland), a set of seven variables was prepared:

V1 – cumulative number of infections per 10,000 inhabitants (22 September 2020),

V2 – cumulative number of infections per 1 km^2 (22 September 2020),

V3 – week of detection of the first infection,

V4 – number of weeks with new infections per 10,000 inhabitants above 3.0,

V5 – number of weeks with new infections per 10,000 inhabitants below 0.75,

V6 – number of weeks in which the number of new infections was higher than in the previous one,

V7 – Standard deviation of the intensity of new infections for 29 observation weeks (4 March–22 September 2020).

Their choice was associated with the desire to capture the most important features of decomposition, related to the variation of space-time. In this way, the first two variables take into account the state at the end of the first stage of infection in Poland, including the variable V2 takes this into account in relation to the degree of urbanization. The variable V3 is one of the most commonly used indicators in geoepidemiology. Thresholds in variables V4 and V5 have been set so as to refer to regulations in Poland, including counties in the so-called yellow and red zones, in which increased protection measures were applied during the epidemic (including stricter regulations concerning social distance). Variable V6 tries to capture the direction of changes, and variable V7 is the basic measure of crop variability. All in all, such selection of variables to the typology is subjective, but intuitively it seems to reflect all the most important parameters of spatial-time variability as well.

The correlation matrix is shown in Table 1. In only one case was the Pearson linear correlation coefficient higher than: 0.5 (V1-V4 = +0.93) and the highest mean of the variable's correlation with the other variables occurred for V1 and V4 (0.15). This indicates a good choice of indicators overall.

Cluster analysis was performed using k-means method (sample of 364 county units, standardized variables V1-V7, square of Euclidean distance, maximization of cluster distance, conversions to 100 iterations) in Statistica ver. 13.1.

Basic data, such as population and county area, were collected from the Local Data Bank of the Statistical Office of Poland as of 1 January 2020. The changes since then due to natural traffic and migration in relation to the later period of the epidemic are not significant, as they generally do not exceed 1%. Actual population movements, related to unregistered internal and international migration, as well as those caused by the epidemic (as a result of remote work, many people could move from cities to the countryside, e.g. to their 'second homes'; unfortunately,

Table 1. Correlation matrix between variables used to typify counties

	V1	V2	V3	V4	V5	V6	V7
V1	1.00						
V2	0.58	1.00					
V3	-0.09	-0.11	1.00				
V4	0.93	0.48	-0.03	1.00			
V5	-0.80	-0.50	0.19	-0.70	1.00		
V6	0.06	0.07	-0.21	0.05	-0.17	1.00	
V7	0.20	-0.03	-0.14	0.16	-0.19	0.13	1.00

the scale is not known) can have a much more serious impact.

Results

Position after more than six months of the epidemic (March 4-September 20, 2020)

The first case of coronavirus was diagnosed in Poland on March 4, 2020, but there are, as in other countries, assumptions about its earlier occurrence (Jarynowski et al., 2020). After 200 days, i.e. September 20, 2020, the epidemic 'spilled' across the country, but high and low intensity regions can be clearly identified (Fig. 1). There were very large differences in this respect. On the map, the first of the separated classes has a range of < 4 cases per 10 thousand population, the last (seventh) – within 128-204. This is thirty times more, and there are also counties (e.g. Drawsko, Olecko), where less than 10 cases were detected by 20 September.

Generally, the increased area of occurrence is the south of Poland. The highest concentration of infections concerns especially southern Wielkopolska, southern Mazovia, Silesia (Upper and Opole Silesia), Zagłębie Dąbrowskie and Małopolska (without Bieszczady Mts. and Beskid Niski Mts.). The only larger and more compact area in the north is Pobrzeże Bałtyckie (Baltic Coast from Gryfice to Gdańsk), as well as northern Podlasie. The less infected areas (human populations living in these areas) are poviats located especially in the northern Poland in the lakeside.

The picture presented on the map does not correspond to the historical conditions known from literature (e.g. borders of the partitions) and contemporary (metropolitan-periphery). There is also a conclusion that there is no stronger spread of the virus in many densely populated agglomerations and larger cities (Szczecin, Rzeszów, many medium cities). The influence of rivers as barriers is also visible – for example, the Vistula River in many sections.

Diffusion and spatial dispersion in time

The following maps show the development of the number of infections in relation to the population by month (Fig. 2). The data for March and April were aggregated due to relatively small values in the initial period of the pandemic, and all values were recalculated in relation to the full 30 days to maintain full comparability. The relatively high degree of overlap of subsequent new infections is noticeable. This leads to the conclusion that the infectivity is related to physical proximity, understood as the probability of virus transmission due to social contacts (work, short distance transport, use of services, etc.).

The first map shows the development of recorded infections in the first few weeks (between March 4 and April 30). From the psychological point of view, the beginning of the epidemic was a very difficult time for society. The Poles and their families were suddenly severely restricted, and the media was dominated by an extremely catastrophic message, especially related to comparisons

20th September 2020

Poland = 79.2 thous.
infections detected
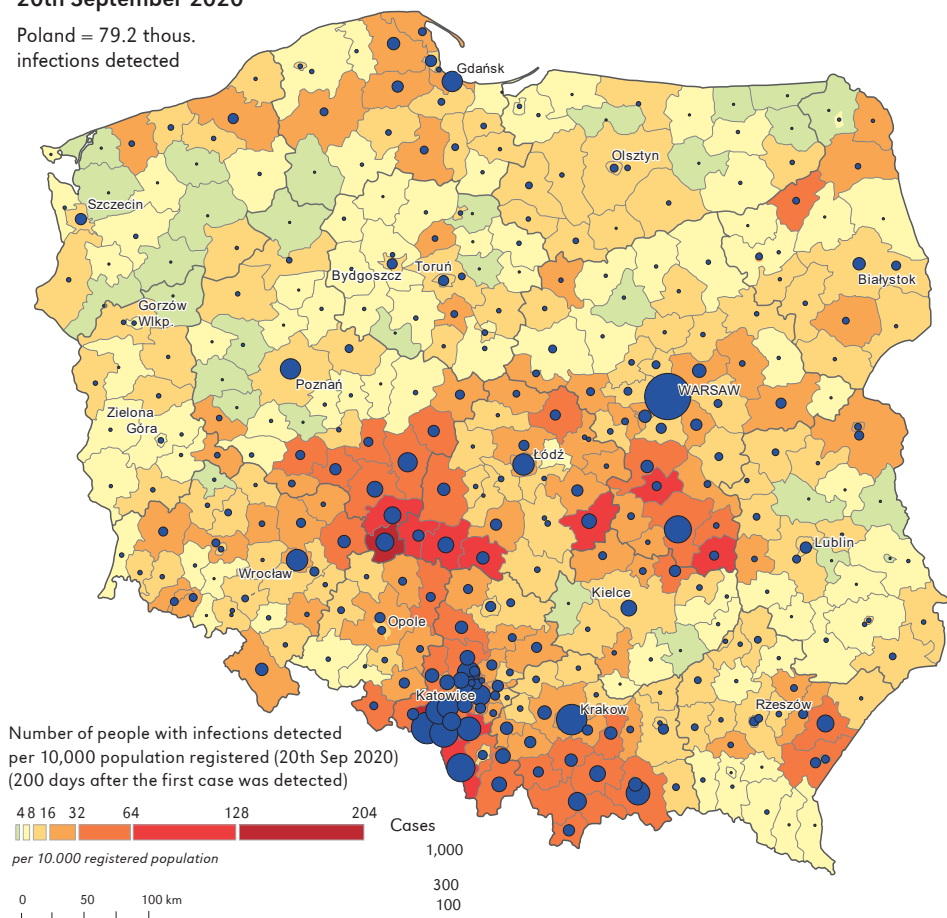
Figure 1. The intensity of detected SARS-CoV-2 coronavirus infections in relation to the population on 20 September 2020
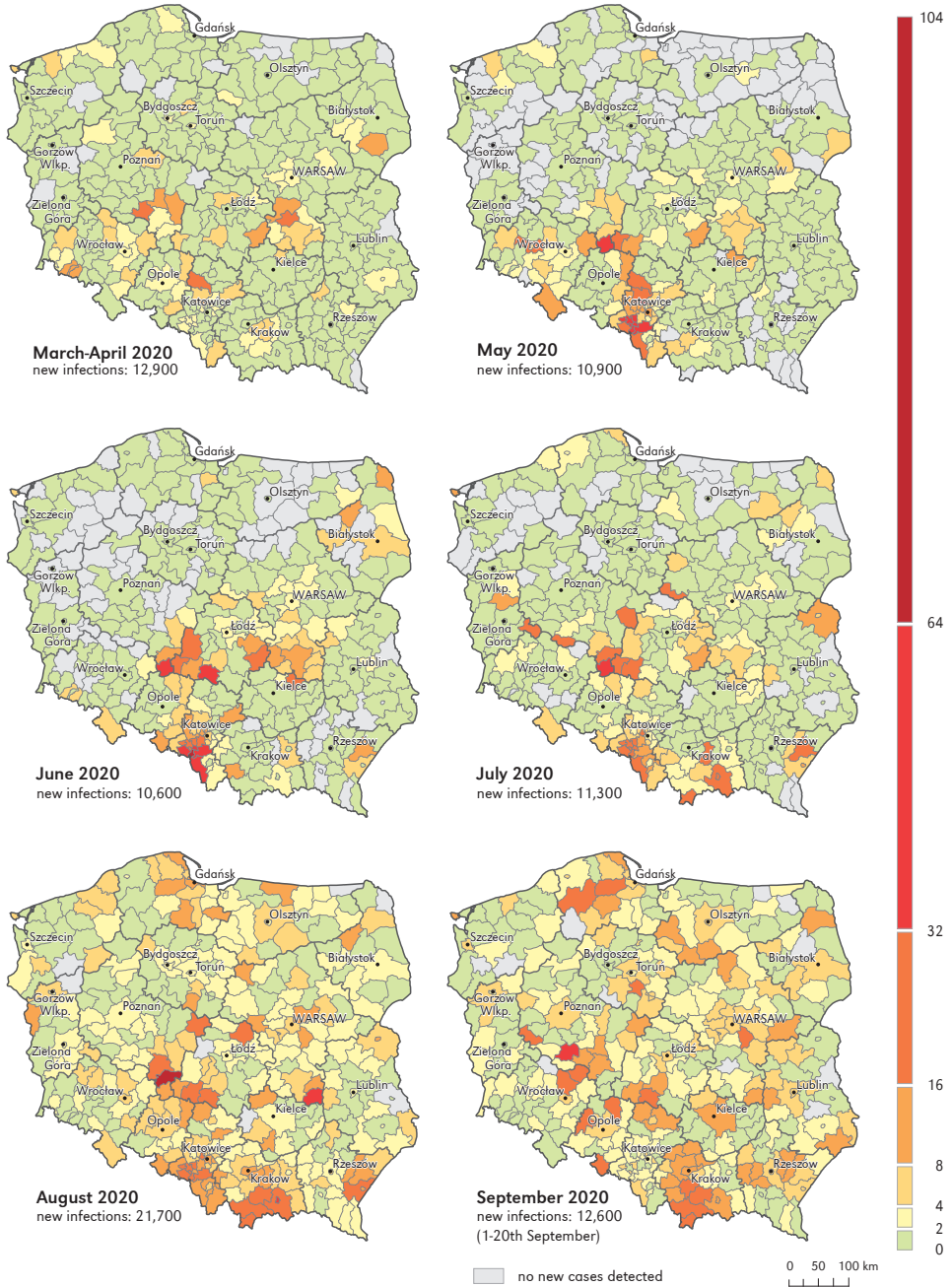
Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

with other most affected countries, such as Italy and Spain. At the beginning of April several intense local infections appeared: south of Warsaw (Radom region, Białobrzegi, Grójec), between Wrocław and Kalisz, east of Krakow, in the vicinity of Kołobrzeg and Bielsk Podlaski. This is where the Polish 'zero patients' were located. If one traces the media reports, a significant part of the cases found there were related to hospitals and social care homes (Duszyński et al., 2020).

The next map covers May and it is a period of slightly increased infection, although still

in quite a small group of several dozen poviats, where this problem was previously diagnosed, and in units adjacent to them. In other words, these first local poles, observed in several places in the country, clearly 'spilled' into their surroundings. This happened quite evenly in the south-western part of the country (Dolnośląskie, Opolskie, Śląskie, southern part of Wielkopolskie, Mazowieckie and Podlaskie Voivodships). To the north of Gryfice county the growth took place in the neighboring Kołobrzeg (and then further east in Koszalin), but not e.g. in Kamień poviat.

Figure 2. Expansion of SARS-CoV-2 coronavirus spread by months (new cases detected)

Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

What is most interesting, however, is that as of April 7, 1/4 of the cases of coronavirus persisted in 17 poviats most severely affected by the plague.

The increases in infection could be related to tests in these units, which is due to the 'normal' probability of infection, quarantine, etc. However, it would be much more interesting to conclude that there is no strong development of the epidemic in other poviats, especially in the north of the country. Undoubtedly, the reason for this was a strong tightening of social contacts and a decrease in movements between distant regions. There were no 'typical' channels of transportation, such as especially railroad and long-distance car transportation, no business and conference trips, etc.

The observed downward trend on the map with data from May was consolidated in June with a few exceptions. Already in the tenth week of the epidemic (May 6-12) we can see an increase in infections in the western part of the Śląskie Voivodship, which persisted especially in the 11-14th week (May 13 – June 8). It resulted from mass tests of miners in the mines of the Rybnik agglomeration. In general, June was a period of increased testing in the Silesian voivodship and thus a clear increase in the number of detected infections. However, it is not very clear on the map due to the size of the population, concentrated in the Rybnik agglomeration and the Katowice conurbation in a small area.

Moreover, during the 11th and 12th week (May 13th-26th) there are several more local infection centers. The Kępno poviat turned out to be a special case here, where high intensity of infections occurred during the whole vacation period.

In July, and then even more so in August and early September (as a result of delayed transmission of infections in the human body), diffusion of confirmed cases could be expected due to holiday trips. Indeed, in such poviats as Lębork, Nowy Sącz and Tatra Mts., the sum of confirmed infections in the two holiday months was over 90% of the infections since March 10. What is most interesting,

however, is the fact that not all tourist regions have been equally infected. The map does not indicate a stronger intensity of infections in the region of Western Pomerania, Eastern Beskids Mts., Pojezierza (Masurian, Pomeranian) and Roztocze.

What has changed in the geography of the coronavirus? While still in July the new infections occurred almost exclusively on 'islands', in August, and then very clearly in the first two weeks of September, we are dealing with a weak but noticeable spill of infections on a large part of the country. Although the phenomenon is still focal, the difference between the most and least infected regions is not as great as in the spring months. In May there were 14 poviats with an index of more than 16 new infections per 10 thousand population and 313 below 4, while in August it was 69 and 236 poviats respectively.

In general, a high correlation was observed between the infections found in the counties (Tab. 2). High fitting coefficients (R) have been observed since June (all above +0.7) and in some pairs of months exceed 0.5 (June-May, July-August). This shows that the diffusion was of an orderly character already after 2-3 months, i.e. new infections were statistically more frequent in places with infected population. It is also worth noting that the September-August correlation is already quite low (+0.231), and September does not correlate with the remaining previous months.

The above conclusions are reinforced by an analysis of the correlation between infections at weekly intervals (Fig. 3). Importantly, this relationship has become stronger over time. In June 2020, there are quite high correlations for one- and two-week intervals. Thus, a conclusion can be drawn about the convergence of infections in poviats. Since July these indicators are clearly lower, indicating a change in the trend. This shows high fluctuations of the weekly interval, indicating the formation of new poles of infections.

These results mean that in the last analyzed period new outbreaks were less and

Table 2. Correlation matrix between the intensity of new SARS-CoV-2 infections recorded in counties by month

Month	Number of new case recorded (thous.)	March	April	May	June	July	August	September
March (4-31 Mar)	2.1	x	0.331	0.056	-0.002	-0.013	-0.047	-0.022
April	10.9	0.331	x	0.261	0.098	0.056	0.000	-0.044
May	10.7	0.056	0.261	x	0.746	0.598	0.304	-0.089
June	11.7	-0.002	0.098	0.746	x	0.595	0.355	0.011
July	11.6	-0.013	0.056	0.598	0.595	x	0.555	0.038
August	21.6	-0.047	0.000	0.304	0.355	0.555	x	0.231
September (1-20 Sep)	12.7	-0.022	-0.044	-0.089	0.011	0.038	0.231	x

Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).
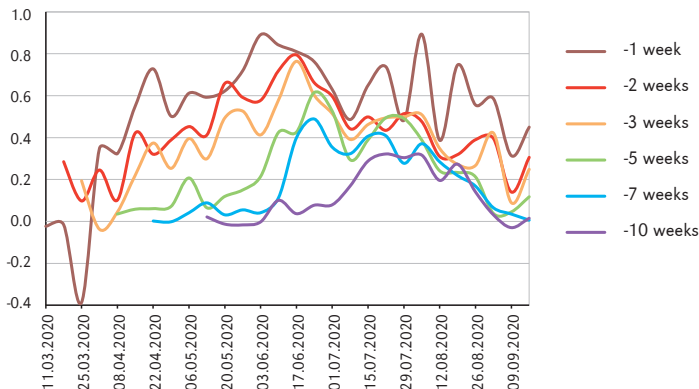
Figure 3. Correlation analysis between the severity of detected SARS-CoV-2 coronovirus infections at a given time in counties and the situation one, two, three, five, seven and ten weeks earlier
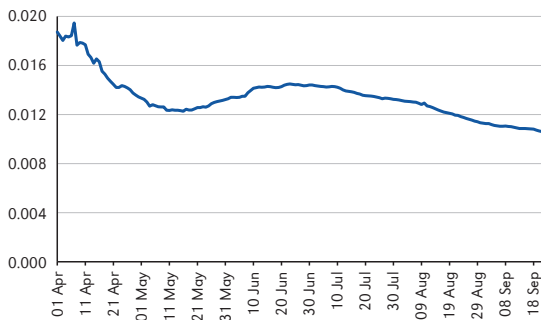
Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

less related to existing clusters of infections. In the light of the latest knowledge, this documents the end of the first stage of the epidemic in Poland, characterized by a relatively low spread of the virus due to diffusion and dispersion.

Spatial concentration of infections

In the next stage, statistics on the allocation of infections were compiled. For this purpose, the Herfindahl-Hirschman Index (HHI) was used, showing 'geographical flattening' in communes and poviats, i.e. the prevalence of the epidemic in terms of the number of infections in relation to the population. Until mid-May the value of the index decreased quite systematically (on the first day when the infected person came from 1 county, the index was 1, after 10 days it was only 0.08 for 26 counties). Then, more or less until the end of June, the index grew, which meant an increase in infections in a smaller area of the country. From that time until September 20, the HHI index decreased again, indicating the spread of new infections

Figure 4. Herfindahl-Hirschman Index (HHI) showing the concentration of detected SARS-CoV-2 coronavirus infections in subsequent intervals (day after day)
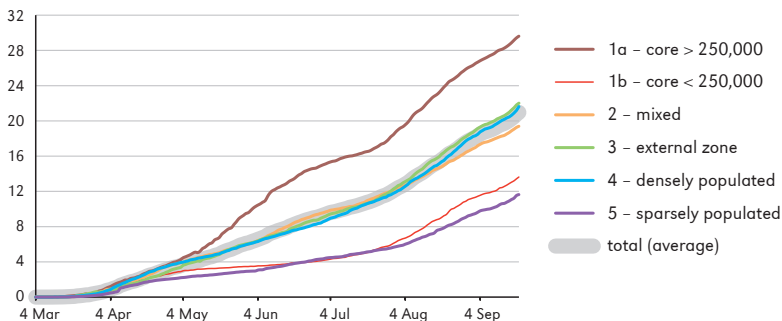
Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

in a more evenly distributed way. Despite these fluctuations, they are still concentrated.

Infection increases by county type

The development of the number of infections in different types of poviats is presented in Fig. 5. Until about May 10, the growth of infections was quite even in all types of poviats. After that period there was a quite fast growth of confirmed cases of infections in the largest cities and agglomerations (over 250 thousand inhabitants). As far as cores of less than 250 thousand inhabitants are concerned, the increases compared to other types of poviats were relatively small, very similar to the poviats with the lowest

population density, which in itself is difficult to explain, as it differs from the observation of the spread of infectious diseases in other countries. The remaining three types (mixed poviats, outer zones of urban poviats and more densely populated poviats) were characterized by quite a similar increase, especially in the case of type 3 and 4. Such results are not unambiguous and suggest that the increase of infections in Poland was not directly proportional to the degree of urbanization, which for Silesian voivodeship, on the basis of the data according to the communes, was already proven by Krzysztofik et al. (2020). Nevertheless, if we sum up types 1-4 and 5-6, it turns out that in functional areas of cities on August 15, the incidence rate

Figure 5. Detected coronavirus infections in Poland in the period 4 March – 15 August 2020 by types of counties

Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

in 10 thousand people was 16.7 and in the remaining areas – 11.7. Thus, in functional areas of cities, the cumulative incidence was over 40% higher.

As more detailed data indicate, such a picture was influenced by a higher incidence rate in the southern part of the country (Fig. 3). Particularly high increases occurred in the agglomerations of Śląskie and Małopolskie voivodships.

Typology of spread

The results of the typology, according to the assumptions described in the methodological subchapter, are presented on the map (Fig. 6). There were 5 classes distinguished. There is a clear spatial concentration of county units in individual classes, which suggests a conclusion of a diffusive non-hierarchical rather than dispersive character of the virus spreading. The first three classes (1-3) are

concentrated especially in the southern part of the country and concern the poviats with the highest dynamics of virus development. At the same time, class 1 includes especially regions with stronger virus occurrence especially in the initial period (Radom region, Southern Poland). On the other hand, classes 4 and 5 concern regions with generally weaker course of the epidemic.

Discussion and conclusions

The presented analysis is an attempt to systematize knowledge on the spread of SARS-CoV-2 coronavirus infections in Poland in the light of available empirical data during the first phase of the epidemic (first six months). As already mentioned, there are reservations about this, resulting from detection in relation to the actual state of affairs. It should be emphasized that the analyses concern the first six months of the spread
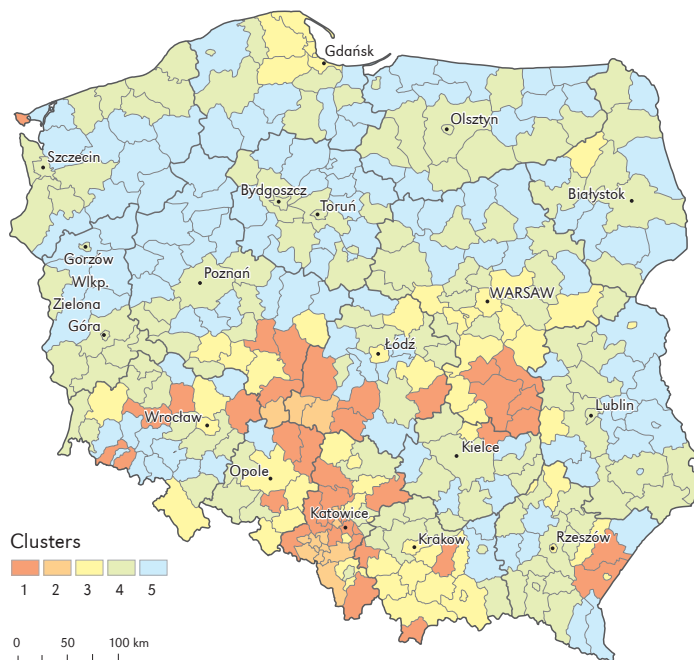
Figure 6. The cluster analysis, made for seven temporal variables, showing the evolution of epidemic in Poland (k-means method, square of Euclidean distance, maximization of cluster distance)

Source: based on data collected by Rogalski (2020) and Rogalski et al. (2020).

of the virus, i.e. the so-called first, relatively undetectable wave of the epidemic. During that time 79 thousand infections were detected, i.e. only about 7% of what was recorded in the time shorter by half, i.e. the next three months (21 September – 21 December 2020). The actual impact of the epidemic will be known as detailed death data become available in the statistics.

The most important conclusion is the quite strong concentration of infections found. In the first six months of the epidemic there were no mass infections or they were asymptomatic. The growth statistics were 'driven' by a relatively small number of poviats and thus a relatively small population. On the one hand, this is a positive conclusion, because it shows the purposefulness and effectiveness of early reduction of social contacts by the authorities, which is not obvious in different countries that introduced it (Askitas et al., 2020). These studies show that the most effective were the cancellation of public events, the introduction of restrictions on private meetings and school closures, and secondly, restrictions in workplaces and generally increasing the time spent at home, but this had different effects in different countries, such as Spain (Aloi et al., 2020), Italy (Bonaccorsi, 2020) or France (Pullano et al., 2020).

So why did the strategy in Poland turn out to be effective during the so-called first wave? It seems that it may condition a relatively high social heterogeneity. Studies from other countries show that a stronger spread is observed in economically weaker environments (poorer) and among ethnic minorities, as evidenced especially by the USA (Cheng et al., 2020; Pan et al., 2020). These minorities are less compliant with top-down state orders, seeing them as another form of 'oppression' (Basett et al., 2020). In Poland, adherence to the rules in the first few months was relatively common and a certain social tension only occurred in the summer months.

The second positive conclusion could be that if we assume the health resilience of Poles (the key argument here is the observed number of deaths compared to previous years and other countries – in relation to the real number of infections, rather than the stated number), then in about 10 weeks (the first half of May) we were dealing with the extinction of the plague in most of the country. However, this conclusion can be broken down by the counter-argument that the populations of these less infected poviats have not yet 'survived' their 'high wave' of the disease, because the issue of the disease is, as the US studies show, only 'a matter of time' (Khose et al., 2020), especially in urban-rural relations (Paul et al., 2020). In order to confirm or exclude this, it was necessary at that time to carry out antibody screening in selected poviats of this type (and not where there is a lot of infection, a lot of tests are done and the detection rate is also high). As indicated by the data from the so-called second wave of the epidemic (after September 20), unfortunately the second scenario a spatially 'egalitarian' increase in infections, turned out to be more likely.

As for the answer to the question of chaotic or orderly (contact or hierarchical) nature of diffusion, the spread in the first phase was quite mosaic. In subsequent periods an order can be found in the sense that subsequent infections co-occurred more often in areas with already infected populations. Similarities can be found here to a kind of spatial 'chaos' in the first weeks in those countries where the course of the epidemic was much faster, such as the USA (Moore et al., 2020). This would indicate that in Poland the first six months were not the 'first wave', but the initial, long-distributed stage of the epidemic.

In any case, the analyses quite clearly show that in the first period of development of the SARS-CoV-2 epidemic in Poland, as in other countries, there were no stronger links with population density and urbanization level (Paul, 2020). This confirms the effect ambiguity observed in the Swedish study (Florida & Mellander, 2020), cited to demonstrate the uniqueness of the coronavirus spread relative to other known viruses. However, the situation of Poland and Sweden during the first pandemic period is fundamentally

different (no lockdown in Sweden). Interestingly, in many large cities the level of infection was the same as in peripheral regions with low population density. This may be due to the effect of a strong disappearance of social contacts after the introduction of restrictions in March and April and the development of the epidemic in the space where it was already more infected. In general, research indicates that lockdown, or non-pharmaceutical interventions more broadly, are highly effective (Flaxman et al., 2020).

All in all, therefore, the analyses presented clearly indicate that in the Polish model of the spread of the SARS-CoV-2 epidemic, the virus's geography, understood in two ways, is particularly important and interesting: as a description of the spatial differentiation of the phenomenon and as a way to interpret and explain it. The latter is the most interesting, but requires, as mentioned, more detailed analyses, as well as even more detailed data on infections, the demographic structure of patients, or mortality (mortality).

The epidemic should also provide a stimulus for the development of medical geography in Poland, a much-needed interdisciplinary, or perhaps transdisciplinary, field of research practiced by a very small group of specialists. This is the reason why spatial analyses are underutilized in the fight against epidemics, while abroad they help to plan lockdowns and local mobility restrictions more effectively (precisely in the territorial sense). Another direction of research that could give new vitality to Polish geography could be behavioral geography.

The presented material may also provide many other conclusions, but in order to formulate them reliably, more comprehensive analyses are needed, related to techniques such as Geographic Information Systems, spatial autocorrelation and others. This article suggests some of the conditions of virus diffusion and outlines the directions of potential research work related to medical geography and geoepidemiology in Poland. As already known, Poland did not resist the 'high wave' of infections (autumn 2020, spring 2021) and therefore the period studied includes the spread under conditions of effective lockdown. Research from this period may therefore serve to better identify and understand effective ways to contain the epidemic.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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