Articles

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Social Geography of COVID-19 Vaccinations and Inequalities in Access to Medical Services in Poland

There is a need for a spatial analysis of COVID-19 vaccinations in Poland in order to assess the solutions taken to combat this epidemiological threat. Differences in vaccination rates highlight problems of inequality in access to health care. The analysis presented here aims to show inequalities in estimated vaccination rates and their predictors. The disparities were analysed at the NUTS-4 district level. The study uses spatial exploratory and statistical techniques in applying a model of the determinants of vaccination rates at the district level. The main dependent variable is the percentage level of full-scheme vaccination in a given district, and the independent variables were social, political, demographic, economic and epidemiological predictors. The results suggest a strong influence of systemic (organisational) barriers on vaccination rates. The proposed model using only a few key socio-epidemiological variables explains >75% of the variation in vaccination rates between districts (in particular, political preferences – specifically the choice of the party currently in power – explains as much as 30%). As a result of the analyses conducted, districts at risk of exclusion were selected, i.e., mainly rural and small-town districts of the eastern areas of Poland and districts potentially at risk, dispersed in clusters throughout Poland. Given that, peripheral regions with high support for the ruling party, fare less well in the vaccination campaign, the selected municipalities and districts should be strengthened in terms of personnel, information and medicine, with the aim of levelling out inequalities in access to health.

Keywords: vaccination, COVID-19, social geography, health inequalities, access to health care

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Introduction

Compared to other EU and OECD countries, Poland is characterised by large disparities in access to medical services (Cianciara 2015; Libura 2020). Social inequalities in access to health are diverse and encompass many socio-economic characteristics. The causes of inequalities may be of supply-related nature (number of physicians, distance from a clinic or a hospital, availability of procedures) or may be demand-related (health need/awareness, fear of becoming ill, willingness or unwillingness to be vaccinated, trust in professionals, etc.). The social factors of health inequalities are an important element in determining priorities in public health. From this perspective, health challenges (such as the COVID-19 pandemic) need to be associated with an analysis of the social factors that determine public safety. A sociological point of view brings not only theoretical contributions to the health sciences, but also the analysis and evaluation of solutions applied, for example, in the area of safety management.

In 2019, 4.2% of the Polish population reported unmet needs for medical examinations due to cost, distance or waiting time (the EU average was 1.7%). There were differences between groups with different incomes: 5.7% of the poorest people (from the lowest income quintile) reported unmet needs compared to 3.3% of the richest (OECD 2021). The basis of access inequalities hindering the satisfaction of healthcare needs is primarily the number of physicians per population, and systemic barriers, such as queues to specialists or the cost of alternative (private) services. The issue of existing disparities in the availability of medical services, including vaccinations, is a very important aspect of public health, but also a challenge for social researchers. In this study, we would like to draw the attention of social researchers to the spatial aspect of inequalities in access to vaccinations.

The social geography of inequalities in access to medical services is a rare topic addressed in the field of sociology. The basis for ensuring equal access to health should be the allocation of infrastructure and human resources made on a rational basis and based on analyses such as maps of health needs. In Poland, however, maps of health needs have a low cognitive value (they are mainly based on existing data) and are not used as a basis for decision-making. The organisation and allocation of services is political rather than expert-based in Poland. Additionally, the pandemic has highlighted and exacerbated some of the problems of the health care system in our country. Therefore, we decided to look at the social geography of vaccinations in the light of socio-economic variables to explain the impact of these factors on vaccination rates for COVID-19.

The social geography of vaccinations

Social inequalities in access to health services can be described as a problem at the intersection of sociology (including at least some of its sub-disciplines, such as sociology of medicine, sociology of social inequalities, urban sociology), health geography (formerly medical geography), and public health (Hill 2020). The approach presented in this article corresponds to Learmonth's concept of analysing the socio-spatial aspects of disease and health (Learmonth 1979). The tasks of the social geography of inequalities include, among others: analysing the spatial organisation of health system resources; assessing the optimisation of the spatial organisation of the system; and characterising the population benefiting from health care services (Rosenberg 1998).

The pandemic has created a new system of vaccination challenges. New factors, including access to medical knowledge and exposure to an environment unfavourable to vaccination, were superimposed on the old divisions resulting in lack of access to medical services (Yeast et al. 2015). The pandemic showed that many of the determinants of good health remained underestimated in public safety decisions, including the organisation of health resources, and arranging medical systems in spatial, financial and staffing contexts. These factors could include, for example, trust in medical personnel or vaccination culture.

The desire to contain the COVID-19 pandemic and reduce its impact has necessitated continuous monitoring of vaccination rates and spatial and social disparities. Analyses of the social barriers to vaccination rates have been undertaken in many countries from both the demand and the supply aspects. Attempts have been made to describe the relationship between COVID-19 vaccination rates and access to health care in spatial terms, such as analysing the distance from the vaccination point (Bump 2021). Among other things, interactive maps were created that could be used as a tool to support government-led vaccine distribution. It has been recognised that the percentage of people who had to be vaccinated away from their place of residence can be a satisfactory measure indicating inequalities in access to vaccinations between different regions (Barry et al. 2021), and that inadequate allocation of vaccination has led to additional inequalities in COVID-19 mortality (Chen 2022). Rankings visualising the level of risk of non-vaccination at the local level enable optimisation of population vaccination strategies (Bump 2021) and highlight the need for viable public health interventions to ensure equitable distribution of healthcare resources across populations.

Vaccines are the best way to prevent the effects of the COVID-19 pandemic. However, not all citizens are willing to be vaccinated. In many countries, discussions and dilemmas about vaccines, their safety and efficacy go beyond the orbit

of scientific and medical knowledge, becoming an area particularly vulnerable to rumour and misinformation (Islam et al. 2021). The actions of anti-vaccine organisations (Kołłątaj et al. 2020) and negative public emotions around vaccines are geographically and socially diverse (Jarynowski, Skawina 2021).

In Poland, by 15.06.2021 (which corresponds to the timeframe adopted in the following analysis), 41% of Poles had received the first dose of the vaccine and 26% had been fully vaccinated. According to CBOS (Centre for Public Opinion Research), 26% of adult citizens declared that they had opted out of vaccination (CBOS 2021). Reasons for not vaccinating include lack of time (21%), undergoing COVID-19 (18%), postponing to a later date (17%), fear of Vaccine Adverse Events – VAE (16%) and poor health (10%). Approximately 10% of the unvaccinated declared difficulties in signing up for vaccination and 3% of those surveyed by CBOS reported that the inability to vaccinate was due to the lack of a vaccination centre near their place of residence (Omyła-Rudzka 2021). Demand-related reasons dominate among the distinguished motives for not receiving the vaccine, while supply barriers are indicated much less frequently. While the social unrest and controversy surrounding the COVID-19 vaccines have been a subject of numerous studies, supply barriers have rarely been analysed. In Poland, the supply-related aspect of this issue is practically not described. Therefore, in this study, we propose an approach to estimate what impact access barriers have had on vaccination rates, among others. The temporal scope of the analysis is limited to June 2021, when the access formula changed and vaccination could be received much more easily, in pharmacies and other places. It also seems that the first few months of the vaccination programme best describe the regional supply vulnerabilities of the system (e.g., its capacity), and thus could be a good indicator of vulnerability for other epidemiological threats in the future.

The public health interest dictates (Włodarczyk 2020) that failures in the planned National Vaccination Programme should be tracked, with particular attention paid to inequalities in access to vaccines (lack of vaccines or vaccination points), prioritisation of groups at risk of severe COVID-19 infection and its consequences, and reluctance to vaccinate. Social inequalities in the context of supply barriers are rarely addressed with regards to this issue. Barriers related to social controversy over the safety and efficacy of COVID-19 vaccines are much more frequently discussed.

Factors limiting access to specific health services can be explained by impediments classified into 5 domains: reachability, spatial accessibility, organisational accessibility, cost accessibility and acceptability (Kaczmarek et al. 2007). Thus, vaccination rates are influenced by the number of staff (primary health care providers, staff approving eligibility for vaccination, vaccination centres), and communication difficulties or specific views (Islam et al. 2021). In the analysis presented here, we pay particular attention to the role of supply (vaccination points and their staff) and

its spatial distribution. The qualitative research identified a list of factors hindering access to health services (among others, in long-term care): limited supply (few providers), inadequate transport services, telecommunication barriers, financial unviability of some important services, and challenges in recruiting and retaining long-term care workers. Giving up some services or forms of care and replacing it with another choice (e.g., family care, opting out of vaccination) can be considered both as a cultural preference ("we will not put my parents in a nursing home" or "vaccination can be dangerous for me and my children") or a reaction to the poor quality of public services (Siconolfi et al. 2019), for example lack of trust in medical knowlegde. With regard to vaccination, the role of the family in the decision to vaccinate (so-called lay referral system) cannot be overlooked, which is partly a result of the communitarianism of making medical decisions in general, but also a response to the information chaos about vaccinations. Difficulties regarding signing up for vaccination and lack of accessibility constituted another variable impacting the establishment of anti-vaccination attitudes. However, it is worth noting that the barriers to accessing a physician, i.e., the inability to contact one or to commute to a GP's office, are *de facto* the inability to create a satisfactory patient-doctor relationship, which results in lower levels of trust in medical services. Trust in the relationship with a medical professional is a key ingredient for effective and quality care and a cornerstone in the fight against vaccination reluctance or disregard for medical advice. Relatively easy access and frequent contact with the physician can, in turn, be important in building an environment of responsibility for health at both the individual and local community level (as in the case of outbreaks or prevention of unnecessary consequences of infections).

In many countries, vaccination rates are higher in highly urbanised areas than in rural areas (Murthy et al. 2021). Variation in vaccination rates also depends on socioeconomic status, household composition and the proportion of people with disabilities, the health status of the population and the level of education. Interestingly, in the USA, vaccination rates are lower in regions with a higher proportion of mobile households (Barry et al. 2021). This shows that spatial barriers to vaccination are complex and overlap with other health inequalities (e.g., lack of access to physicians also means poorer access to medical knowledge). Limited access to doctors and distance from, for example, a vaccination point, lack of opportunity or high travel costs are factors that discourage vaccination and may, firstly, overlap with other social inequalities (low income) and secondly, increase the effect of other anti-vaccination arguments. Also in Poland, getting to the vaccination point, especially for at-risk groups such as seniors, was a matter of mobilising the personal resources of individuals, such as family or neighbours, who organised safe transport. This was mainly the case in the first period after the introduction of the vaccines (seniors were able to be vaccinated first, right after the

representatives of the medical staff). For seniors, only 100 outpatient vaccination centres were launched nationwide.

Research also indicates that by supporting priority groups (seniors, professional groups), the discriminatory mechanism of geographical accessibility can be overcome (Jarynowski, Stochmal, Maciejewski 2020). However, this involves adequate planning of the access pathway (vaccination points) (Diesel 2020). In Poland, decisions on the vaccination access pathway were chaotic, and the vaccination information policy was also problematic.

Available analyses of determinants of vaccination rate (e.g., of adolescents in the US) showed, among other things, that 67% of differences in vaccination rates between urban and rural areas could be attributed to differences in characteristics at the district level (Tsai 2021). The most important variables referred to characteristics measuring access to primary health care, but also parental education and income level, race and quality of care (including influenza vaccination as a factor). The results indicate that the most important predictors of high vaccination rates include the number of primary care physicians (positive correlation) and car ownership (negative correlation). Socio-political factors such as education level and political views, including, for example, voting preferences and local political circles supporting the so-called anti-vaxxers, may also be important (Hornsey et al. 2020).

However, it is not only the nature of the region that influences vaccination rates. Many observers believe that promotional activities undertaken in the local media, implementing solutions based on local needs, working with local organisations and opinion leaders or working directly with groups of undecided citizens can successfully improve access to COVID-19 vaccines and remove barriers to access (Murthy et al. 2021). The ability to work with local partners who understand the nature of the community and the mechanisms that govern it can be key to the success of tackling health threats such as epidemics (Douthit et al. 2015: 611–620).

On the issue of access to vaccination, another point is worth addressing. Until April 2021, patients could only be vaccinated at special vaccination centres, but over time the number of sites and locations expanded to include clinics, pharmacies and shopping centres. The first patients were able to receive the vaccine without being deemed eligible by a physician at the beginning of July 2021 (eligibility for vaccination assessed by professionals other than physicians did not affect the baseline presented in the article). However, not all patients could be deemed eligible for vaccination by a pharmacist: in case of doubt in the assessment of a patient's health status (e.g., an elderly person, a person with chronic diseases, a person with a disability, a person at risk of vaccine adverse events), the pharmacist could refuse the vaccination and refer the patient to a physician. When it comes to the availability of vaccinations, there were therefore problems in terms of staff qualifications (fast-track training for pharmacists) as well as the level of trust in pharmacists, who

up to now have not been involved in deciding if patient can be safely vaccinated (which in Poland is usually done by a physician) and the administration of vaccines (the "traditional" task of a nurse). The low popularity of pharmacies as vaccination sites can be evidenced by information from October 2021 posted on the website of the Supreme Pharmaceutical Chamber, stating that only 110,000 patients were vaccinated at 900 Pharmacy Vaccination Centres between April and October of that year (NIA 2021). The supply-side "trick" with pharmacies has run into the problem of the level of trust in the various health professions (in the early stages of vaccination), which could be considered as a limitation of access to medical procedures. Although in many situations the pharmacist is an important medical support and source of reliable information for patients, at the local level pharmacies as a vaccination provider have encountered a barrier of public trust.

Study purpose

While most analyses on the social determinants of vaccination rates focus on awareness aspects, related to the demand component (willingness or unwillingness to be vaccinated, doubts about vaccine safety, etc.) the present analysis aims to show the inequality of estimated vaccination rates in relation to the supply aspect. We sought to explain differences in vaccination rates using simple statistical methods (Jarynowski et al. 2014). In this article, the authors focus on assessing the impact of a constellation of selected factors on vaccination rates. The (supply-side) approach used is an attempt to complement the growing pool of research reports analysing the demand-side thread of pro- and anti-vaccination decisions among Polish citizens. The aim was to propose to complement and raise the validity of spatial factors, which may be of great importance in Poland in the context of meeting health needs. Limitations of the study include the limited time of analysis, the data are not exhaustive and not all variables were taken into account by the authors.

The data obtained can be used to classify at-risk areas and to propose cohesion policies at the district level. The implementation of comprehensive surveillance of vaccination rates should support timely, appropriate and effective action in the prevention and control of COVID-19 (Wojtyniak, Goryński 2020). The ability to optimally deploy resources in time and space is fundamental to efficient regional management at operational (district or municipality) and tactical (vaccination point) level, and it is to this aim that this analysis contributes. The intermediate objective is to propose further measures to optimise redistribution as a form of influence on the supply of health services in society, that is to say – in simple terms – what forms of support the most "lagging" (least vaccinated areas) can receive in a broader, not only vaccine-related, health perspective.

Material and Methods

Data and definition of variables. Some variables were selected for analysis, aggregated and available as of June 2021. The primary dataset of completed vaccinations in municipalities (MOH, Municipality Vaccinations 2021) required clarifying due to mis-recording of region identifiers by government programmers, but through collaboration with community activists/analysts (Jarynowski 2021) we were able to map the data. We took 380 districts as the unit of analysis. For this purpose, we calculated the average vaccination rate for each district (percentage of the population vaccinated with the full regimen) as of 15.06.2021 (*vacc* – the names of the variables defined here used further in the article are in italics and in brackets). Thus, vaccination rate is our dependent variable. The dataset was supplemented with available data on the uptake of at least one dose of vaccine and the size of the vaccinated population in different age categories. Analysing the material presented in the maps by some data analysts (Seweryn 2021; Kowalski 2021; Tarnowski 2021; Pilczyk 2021), we tried to describe the determinants of vaccination rates with district-level accuracy.

The independent variables were taken from the COVID-19 spread model (CSO 2021; Jarynowski et al. 2020; NEC 2019). These were:

- income (*Income*) normalised economy income data from 2019 (100 – average for Poland);
- forest density (*Forest_density*) – percentage of forest in 2018;
- population density (*density*) – in people/km2 in 2019;
- population size (*population_size*) – the number of people living in a given district in 2018;
- total industry revenue (*industry_revenue*) in 2018 in million PLN;
- occupational structure (*empl_agriculture*) – number of people working in the agricultural sector in 2014;
- number of people of post-productive age (*post-productive_age)* in 2019;
- betweenness mobility (*betweenness_mob*) – weighted betweenness centrality, calculated from the number of people registered at the tax office covering municipality A and working in municipality B (the place of registration of the employer's activity). A key measure in social network analysis (Jarynowski et al. 2014), namely the estimated total number of people entering and leaving a district;
- results from the National Electoral Commission – support for the Law and Justice (PiS) party (*PiS_support*) in the European Parliament elections. Due to the lack of poll research with district accuracy, electoral preferences are a very good indicator of social attitudes in local communities.

The following were added to the model:

- variables determining virus burden in the immediate geographical environment (Rogalski 2021):
- *(size_COVID*) summed numbers of COVID-19 infections (from 04.03.2020 to 15.06.2021) and (*covid_death*) deaths from COVID-19 (24.11.2020 to 15.06.2021). It should be emphasised that details of deaths for each district from the first wave are not publicly available;
- excess mortality (*excess_mortality*) calculated as the number of deaths in 2020 divided by the average deaths in the five-year period (2015–2019);
- the number of consultations given in primary care in 2020 (*HealthcareAcc*) as an indicator of demand-driven accessibility to primary care. An indicator for 2019 (*HealthAcc_old*) was tested to exclude the effect of the pandemic, but the correlation between the two indicators is practically equal to 1, so no significant regional changes in access to medical advice were observed;
- the number of physicians working in health care per 10000 inhabitants (*HealthAcc_phys*) as an indicator of supply-side accessibility to health care;
- religious service attendance rate (*relig*) indicating the level of religiosity, with data specific to the provincial level (Cichomski et al. 2009).

It should be stressed that the selection of variables is analytical and not synthetic and consisted of selections based on preliminary correlation analyses. Some variables are only approximate. Thus, corporate profitability is a proxy for margin levels, which translates into the structure of production and positions in the supply chain (social contract). Forest density instead indirectly indicates the organisational structure in the district. It is noteworthy that some epidemiological variables such as the number of tests without additional information (such as how many tests are performed due to symptoms, outbreaks, legal requirements or screening) create more problems in terms of interpretation than they add value in explaining the relationship. The correlation between vaccination rates and their socioeconomic predictors (Walkowiak et al. 2022) at the population level is not well researched in contrast to the individual level by survey method. Therefore, the article is exploratory and hypothesis-generating.

Statistical analyses. Spatial exploratory and statistical techniques were used in the study (Kowalski et al. 2021; Bochenek et al. 2021). Pearson's coefficient was determined to obtain information on the relationship between variables in the form of correlation. Linear regression allows the impact of individual variables on the analysed quantity (vaccination rate) to be examined. The interpretation of this influence is based on the intrinsic parameters of the model (hence, we counted the percentage of the explained variability and proposed different models taking into account the Akaike criterion). In addition, the spatial clustering of DBSCAN (DeRidder et al. 2020) allows the automatic detection of clusters of districts.

Clustering of areas with similar vaccination rates is a well-known phenomenon used in epidemiological practice (Utazi et al. 2019). Exploring the distributions of vaccination rates allowed a heuristic setting of threshold values for classes of regions with different needs. Analyses were performed in the R environment and scripts and source data were deposited in a repository.

Optimisation issue. In addition, in view of the above analyses, we propose to divide the districts using the vaccination rate function into:

a) districts doing very well whose experience should serve as an example;
b) districts performing moderately that do not require additional investment;
c) below-average districts in need of local support (e.g., in individual municipalities);
d) vulnerable districts that require systematic assistance.

Results

Data exploration. The distribution of COVID-19 vaccinations in Poland in 2021 (as of 15.06.2021) varied widely [Fig. 1]. When analysing the level of vaccination coverage, it is easy to notice differences reflecting the division into urban and rural districts and the relationship with political preferences [Fig. 1, 2], which has already been noted in the analytical and medical community (Janota 2020). The clear variation in vaccination coverage between districts (average: 22.8% and standard deviation: 4.5) makes it possible to distinguish clusters and islands of highly vaccinated and poorly vaccinated regions (see subsection on the optimisation issue for a detailed interpretation).

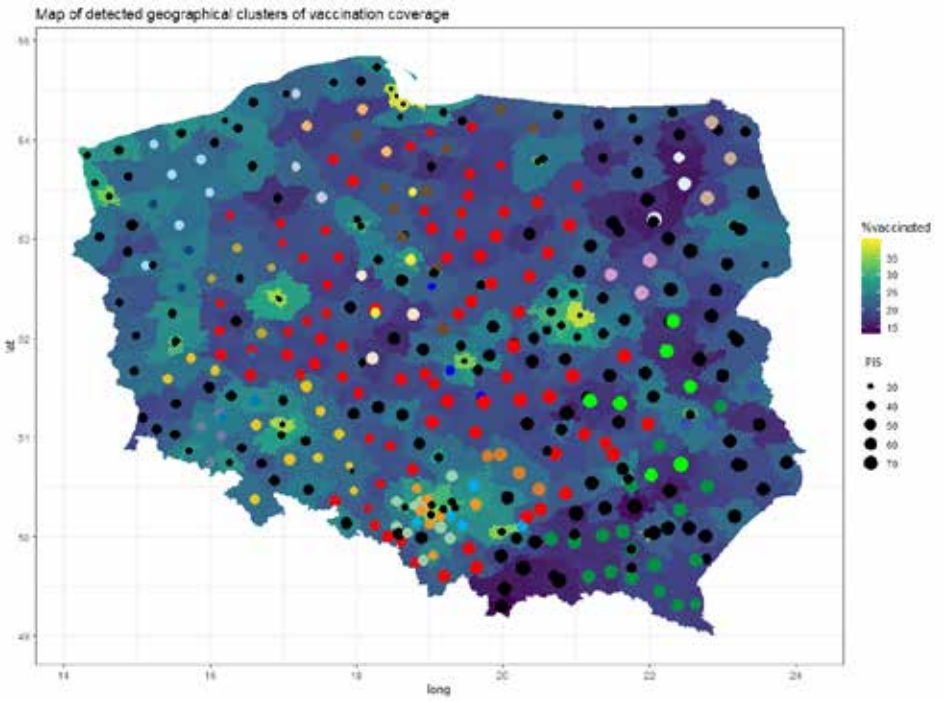

Figure 1. Percentage of residents vaccinated vs. support for Law and Justice (PiS) party at the district level in Poland. Method: Dbscan – spatial clustering at district level with an additional dimension – normalised percentage of vaccination coverage (map colour, see legend). The size of the circle points corresponds to the percentage of support for the Law and Justice party in the 2019 elections and the same colour of the circle is used to indicate the districts located in the same cluster (according to the level of vaccination coverage and geographical coordinates). Parameterisation eps=0.8, minimum number of districts in the cluster=3

Source: own study.

In the hierarchical arrangement [Fig. 2] of the correlations (dendrograms), a cluster of strongly positively correlated variables related to mobility, old age of the population, industrialisation, demand access to health care, number of COVID-19 cases, and COVID-19 deaths can be observed (upper left corner, Fig. 2). Another cluster consists of variables related to health service supply access, population size, population density, income and our most important variable, vaccination coverage (middle bands, Fig. 2). This may be an important rationale for the conclusion that access to vaccination based on the existing health service delivery network is an important criterion for vaccination coverage. The last cluster (bottom right corner, Fig. 2) refers to variables slightly negatively correlated with the first two clusters and is related to religiosity, excess deaths in 2020, support for Law and Justice, and environmental variables like forest density or agricultural employment.

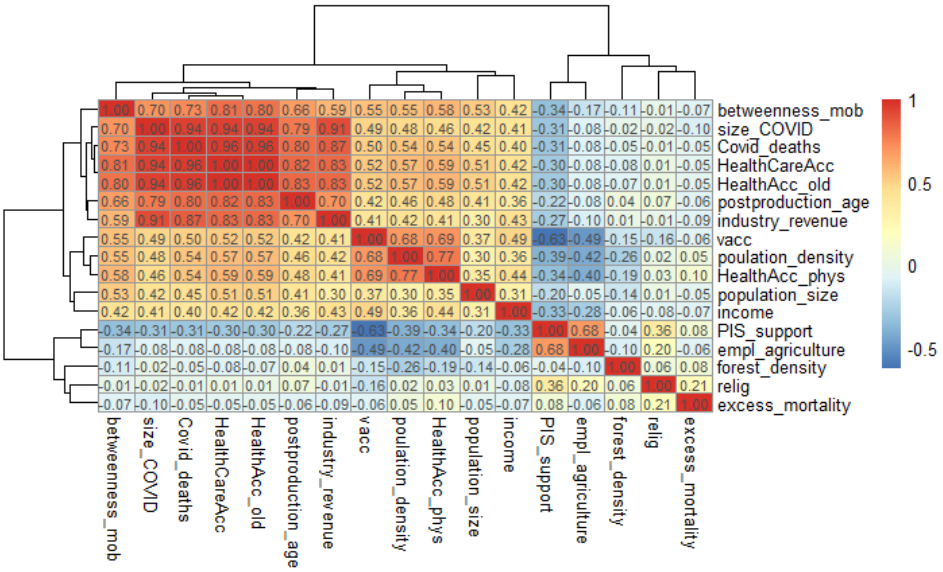

Figure 2. Pearson's correlation coefficient between the variables considered in the hierarchical analysis at the district level, where the most important variable (dependent) is vaccination rate (*vacc*) in relation to other variables such as those defining accessibility to health services: availability of physicians (*HealthAcc_phys*), access to health care facilities as measured by the number of medical consultations per capita in 2020 (*HealthCareAcc*) and in 2019 (*HealthAcc_old*) and other variables

Source: own study.

Levels of the demand access to health services in the pandemic year (2020) and the preceding year (2019) correlate at close to 1, meaning that spatial differences in health service use have not changed despite a completely different distribution of consultation types. This may be largely related to the execution of contracted services by the National Health Service (NFZ). The strong correlation between demand access to health services and the number of COVID-19 cases (0.94) and related deaths (0.96) as well as simultaneous negative correlation of these variables with excess deaths constitute an interesting observation. This can be explained in several ways. However, a conclusion arises that virtually nothing is known about the geographical distribution of SARS-CoV-2 infections, because we can predict the number of infections and deaths due to COVID-19 by looking mainly at the supply-side access to health care (Jarynowski, Belik 2022). This makes the negative correlation with excess deaths all the more indicative of a silent epidemic in areas with poorer access to health services.

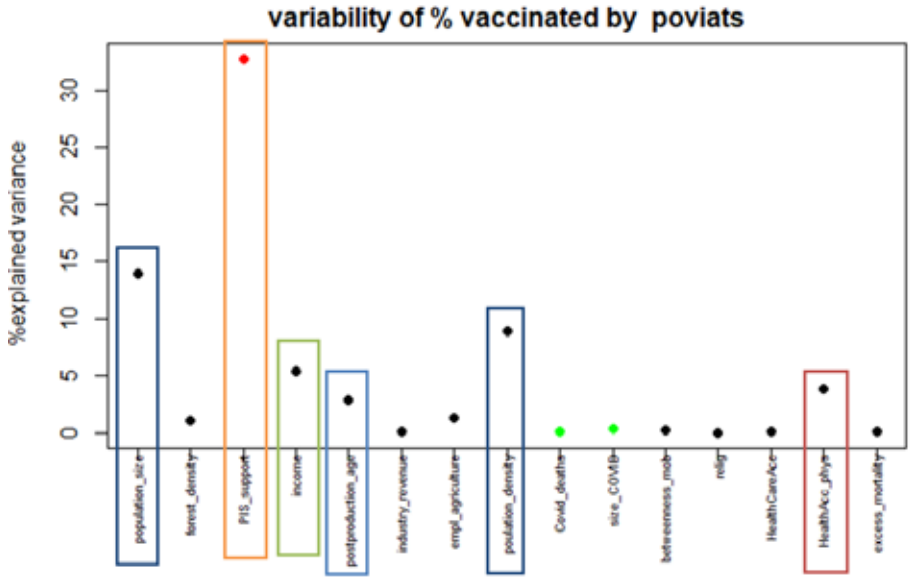

Figure 3. Linear multivariable regression predictive model of % vaccination coverage (the full model gives 75% of explained variance) on all tested non-co-linear variables (which are not a linear combination of other variables) at the district level. The % explained variance for each variable on the x-axis is shown on the y-axis. Coloured dots indicate epidemiological (green) and socio-political (red) and other (black) variables. Colour-coded boxes underline the significant predictors: demographic in blue for the urban dimension (dark) and age structure (light), economic in green, access to health care in red, political preferences in orange

Source: own study.

Predictive model of vaccination rates. Regression analysis of the full linear models [Fig. 3] indicates a small (borderline statistically significant) role of virus burden and religiosity. Excess deaths are not significant. Support for the Law and Justice party is a particularly significant predictor of vaccination dynamics (33%), which is indirectly related to the social structure of the electorate or the potential for resource management by local authorities. Population size (14%) and density (9%) also have a very strong influence on vaccination distribution, as most often vaccination points are located in densely populated areas (Elmachtoub, Grigas 2021). Income (6%) has a relatively high power to explain variation as well as the size of the post-working age population (2%). Supply-side access to health care (number of physicians) is also important (3%).

Table 1. Multivariate linear regression (variable selection according to Akaike's criterion) for two types of models (with and without interactions between variables). Dependent variable: the percentage of vaccination coverage in districts is significantly related to support for PiS: directly (model without interactions) and indirectly (model with interactions – taking into account intermediate variables, such as income, among others)

Model without interactions				**Model with interactions**		
Predictor	*cf.*	*CI (confidence interval)*	*p-value*	*cf.*	*CI (confidence interval)*	*p-value*
(Intercept)	22.0643	19.2966 – 24.8320	<0.001	-1.1243	-10.7156 – 8.4669	0.818
population_size	4.6227	-0.1247 – 9.3702	0.056	3.4938	-1.0001 – 7.9878	0.127
PIS_support	-0.1311	-0.1547 – -0.1075	<0.001	0.3378	0.1516 – 0.5239	<0.001
Income	0.0636	0.0365 – 0.0907	<0.001	0.3517	0.2369 – 0.4666	<0.001
industry_revenue	-0.0001	-0.0002 – 0.0000	0.109	-0.0001	-0.0002 – -0.0000	0.008
poulation_density	0.0028	0.0023 – 0.0033	<0.001	0.0026	0.0021 – 0.0031	<0.001
size_COVID	0.0001	-0.0000 – 0.0001	0.100	0.0001	0.0000 – 0.0001	0.026
betweenness_mob	0.0002	-0.0000 – 0.0004	0.108			
forest_density*post-production_age				-1.7585	-3.8080 – 0.2910	0.092
PIS_support * income				-0.0057	-0.0079 – -0.0035	<0.001
Observations	380			380		
R2	0.669			0.689		

Source: own study.

It should be emphasised that inequalities in access to vaccinations are most likely the effect of cumulative barriers, as in the case of the highlighted non-linear interaction of income with support for PIS or the interaction of forest density and size of the senior population (which, for example, may reflect elderly people living in hard-to-reach areas [Table 1]). The strongest explanatory variable for the percentage of vaccination remains, in both variants (models with and without interactions), support for Law and Justice. For every percentage point of support for the Law and Justice party, there is a 0.13% lower vaccination rate (after accounting for the impact of confounders such as population size and income on the correlation's deflation).

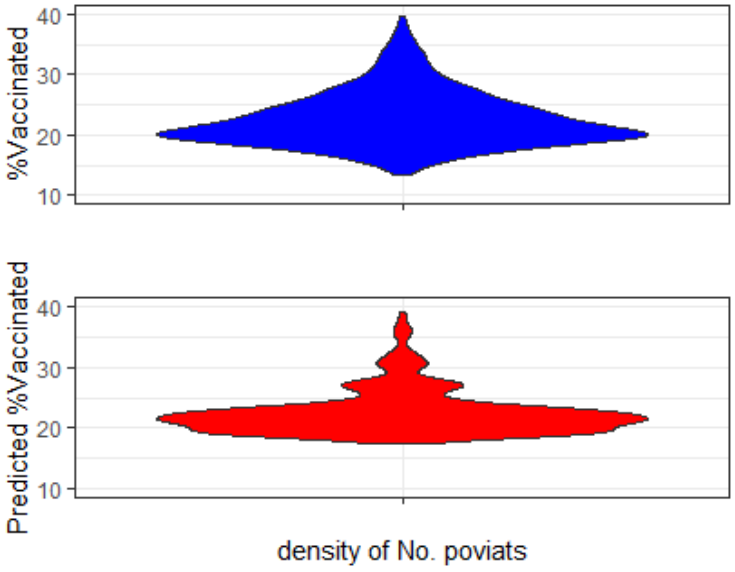

Figure 4. Histograms (violin plots) of the density of the district numbers for individual values of actual and model-predicted vaccination coverage without interactions [Table 1, left]

Source: own study.

The mode of vaccination rate is 20% and the median is 21.6% [Fig. 4]. Poviat districts (the most highly vaccinated ones located in the tail [Fig. 3]) shift the centre of gravity of the nationwide vaccination rate upwards due to their large populations.

Proposed classification of districts – an optimisation issue. We proposed to divide the districts into groups, using the average of the actual vaccination rate percentage and the predictive magnitude [Fig. 4, Table 1, left] with thresholds:

a) average vaccination rate >25%;
b) 20%< average vaccination rate <25%;
c) 18%< average vaccination rate <20%;
d) average vaccination rate <18%.

Including the resultant of the predictive model and the observed vaccination level distribution is a standard optimisation approach, as it reduces the significance of the error of poor selection of predictor variables and reduces randomness. It should be emphasised that the above distribution is ad hoc and other proposals may prove better in identifying issues.

Category D primarily includes clusters determined by the dbscan method [Fig. 1], and in particular:

- the southern borderlands of the Małopolskie and Podkarpackie voivodships, with particular emphasis on Podhale, and the Eastern Beskids;
- borderland of the Świętokrzyskie and Podkarpackie voivodships;
- borderland of the Mazowieckie and Podlaskie voivodships;
- borderland of the Mazowieckie and Lubelskie voivodeships.

Category C clusters can additionally be observed [Fig. 1]:

- in large areas outside the urban agglomerations of the broadly-considered eastern wall;
- on the border of the Łódzkie and Wielkopolskie regions;
- borderland of the Świętokrzyskie and Mazowieckie voivodships;
- southern Wielkopolska;
- south-west of the Pomorskie voivodeship;
- locally in other areas of the country.

Discussion

Our analysis is an attempt to add to our knowledge of the spatial relationships of vaccination rates in Poland in the light of the available empirical data (Włodarczyk 2020). The most important finding in the area of the social geography of vaccination coverage is the strong concentration of areas at risk for the fourth wave of the pandemic with a strong correlation with the level of (low) accessibility to health services in these areas. The results indicate that systemic (organisational) barriers may be an important factor in vaccination rates, indirectly influencing pro- or anti-vaccination attitudes, which are the focus of attention of the media, researchers and vaccination organisers. The still large unvaccinated population as of summer 2021 is not likely to be anti-vaccination, but rather made up of undecided or excluded citizens (Trojanowska et al. 2021; Bałandynowicz-Panfil 2021), especially in the C and D regions. The vaccination programme in peripheral areas accelerated (especially in at-risk groups there was a convergence to the Polish average [Walkowiak et al. 2022]) only at the beginning of 2022, i.e., when vaccination effectiveness against the Omicron variant was already declining (Jarynowski 2023). However, it is worth emphasising that the

barriers to vaccination against COVID-19 reveal not only the low level of preparedness of the health system for the epidemic threat and its fragile resources on a big scale, but also the limited resourcefulness of the authorities and the timing of decisions.

The variation in vaccination rates at the local level is therefore, in our view, partly the result of supply and not just demand for vaccination. It is possible that barriers are constituted not only by the distance from the place of residence to the vaccination point, or the number of medical staff, but also the lack of cooperation with local opinion leaders (e.g., parish priests) and the lack of a medical culture favourable to vaccination. It is worth noting that the change from a denialist attitude to a decision to vaccinate can occur smoothly, as indicated by simulation results supported by Polish media data (Sobkowicz and Sobkowicz 2021), and therefore accessibility factors will be key to achieving the goals of the National Vaccination Programme.

It is worth noting that vaccination rates do not correlate with strictly measurable demand-driven access to health care (nor do they come out as significant in the model [Fig. 3, Table 1]). This may be partly due to agglomeration of data to the district level or to socio-economic demand for health services (Czekirda, Jarosz 2020). Other methods of approximating the availability of health services should be considered in the future. For example, the participation of private health services in vaccination campaigns may be a great relief for public services (in this context, it is worth recalling the lack of relationship between demand availability for NHS services and vaccination rates described in this analysis), especially as the strong correlation of demand availability with covid statistics may indicate that the public health service has borne the brunt of most of the impact of the pandemic. However, on the supply side of health services (staff size), there is a strong correlation (0.69) with vaccination rates and a significant variance explanation (5%). This is a further argument for the important role of the way in which vaccination campaigns are organised (supply) in explaining in-depth the spatial variation in vaccination rates, taking into account determinants other than citizens' willingness/acceptance of vaccination (demand) (Duszyński et al. 2021). It is conceivable that the main reason for the variation in vaccination rates may lie in the hands of local authorities and resource-limited health services, although the influence of demographic, socio-economic and ideological factors cannot be ignored. It is worth emphasising that resource allocation is a modifiable factor, much more so than successfully persuading opponents of vaccination, so it is worth exploiting opportunities to intervene.

Limitations. The article adopts simplified definitions of access to health care (Golinowska et al. 2011). Other measures should be considered in the future, such as the average travel time to the emergency medical team, the time to reach the nearest hospital/ambulatory care unit by public transport, etc. It is worth noting that religiosity (measured by surveys) does not have a statistically significant effect

on vaccination rates [Fig. 3]. Perhaps using other indicators, e.g., the dominicantes index (Nowakowska 2011), would allow this relationship to be assessed, although it seems that it would still play a secondary role. The list of predictors could also be extended to include, for example, travel time by public transport/own transport to the nearest vaccination point, average household income and Gini coefficient, local election turnout, average education, unemployment rate, migration rates, etc.

The above study on the regional variation in COVID-19 vaccination rates suggests that conducting summer promotion and accessibility campaigns will significantly increase vaccination rates in areas lagging behind in vaccination coverage (Szymczyk 2016). It seems, therefore, that the main responsibility for the preparation of the campaign should lie with the regional government delegations, regional media and local governments (Jarynowski, Skawina 2021), which tend to be much more trusted than their central counterparts. On the other hand, substantive and financial support from the central administration is essential. Thus, significant resources and responsibilities should be directed to the poorest-performing districts (or municipalities) to prepare regional programmes aimed at increasing vaccination availability and to develop communication strategies.

Due to demographic, social and epidemiological variations in vaccination acceptance, as well as organisational capacities in the region, summer campaigns (before the potential autumn/winter wave in 2021/2022) should be redesigned at regional level (Halik, Kuszewski 2007). Unfortunately, by summer 2021, no nationwide seroprevalence studies with a spatial structure beyond individual regions such as the Silesian agglomeration (Zejda et al. 2021) had been published, so a precise determination of the herd immunity threshold (Jarynowski, Grabowski 2015) in the regions (further hampered by different vaccine protection levels for different SARS-CoV-2 variants) is not possible.

Summary

Variance explanation. A large part of the spatial variance in vaccination rates is accounted for by modifiable factors such as social attitudes and the resourcefulness of local organisers (33%), limited access to health care (3%) and hard-to-reach populations with special needs (2%) [Figure 3]. Less well-organised institutional and less accessible health care in less privileged regions may result in a large number of their populations not being reached with effective information and assistance in the vaccination process. The results suggest that an important variable explaining spatial variation in population vaccination rates is the way in which vaccination campaigns are organised (supply) and not just the willingness/acceptance to vaccinate (Rzymski et al. 2021a). Therefore, in addition to the continuation of

educational programmes consisting of reliable information (Rzymski et al. 2021b) or marketing programmes (such as information campaigns and incentives, e.g., raffles), actions to facilitate accessibility to vaccination centres should also be strengthened in some locations.

Recommendations for districts at risk of exclusion. Districts in group A can be expected to continue to meet their targets. For districts C and D, investments should be made in rural peripheral areas (e.g., through better pricing of outreach and mobile teams, especially in villages already excluded). Mobile vaccination points should appear at points of concentration of the local population, e.g., under rural parish churches or during outdoor events such as harvest festivals. For D regions, there is a need for systematic actions combining communication campaigns with the use of different types of influence agents, e.g., religious organisations (such as the Catholic Church), NGOs (such as Rural Housewives' Circles) or officials (such as village leaders). Social welfare centres (GOPS and MOPS) should be supported so that they can assist families caring for dependents in the vaccination process, e.g., in forwarding requests for consent to the district courts if the patient is unable to give consent. Vaccinations can be offered by making phone calls to potential patients. It seems that the use of this form of intervention outside of D areas may even be counterproductive, as anti-vaccination movements particularly active in Poznań, Trójmiasto and Silesia will legally torpedo such actions (Jarynowski, Skawina 2021). Due to staff shortages particularly evident in D districts, long-term programmes aiming to fight the health access exclusion should be prioritised (Lachowski, Florek 2007). It is worth emphasising that this is a long-neglected section of the operation of the national social and health system (Drożdżak 2015). Additional incentives should be provided to support non-physicians medical practitioners (or those in training) who undertake work in rural D regions (Genowska et al. 2017; Charzyńska-Gula 2013). Another interesting solution would be to have summer internships or field trips of medical and health students with a focus on public health in areas C and D, aimed at health education (including promotion of COVID-19 vaccinations) among the local population. It may be worth relocating some staff experienced in population vaccination from regions A to D. Demand factors should take into account the socio-demographic profile of the region and be based on correct communication regarding vaccination with groups most at risk of infection or disease effects, e.g., seniors (Jarynowski, Skawina 2021; Bałabdynowicz-Panfil 2021; Skawina et al. 2016; Mastalerz-Migas et al. 2021), with a particular focus on rural populations (Seń et al. 2019). In summary, efforts to increase vaccination rates should be more often local, both in terms of demand and supply availability.

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