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Granularity matters – measles first- and second-dose vaccination coverage in Poland, 2014–2018

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Abstract

Introduction and Objective. Vaccination coverage of ≥95% is essential to interrupt measles transmission. Accurate measurement of vaccine uptake is critical for identifying vulnerable populations and guiding public health interventions. The aim of the study is to: present differences in the sufficient measles vaccination (MCV) coverage in Poland, measured at different granularity level, and to identify clusters with sufficient/insufficient MCV coverage.

Materials and Method. Data on MCV coverage was extracted from annual reports collected by sanitary-epidemiological stations in Poland between 2014–2018. Spatial analysis using Local Moran's I was performed to identify neighbouring poviats with similar MCV rates and outlier areas with markedly dissimilar values.

Results. MCV coverage in Poland exhibited substantial spatial and temporal variability. The first dose of measles vaccination (MCV1) coverage ranged from 89% – 99% at the voivodeship level and from 80% to 100% at the poviat level, while the second dose measles vaccination (MCV2) coverage ranged from 84% – 99% and from 32.3% – 100%, respectively. Spatial disparities were particularly pronounced in several voivodeships, with Mazowieckie consistently demonstrating both the highest positive and negative deviations between poviat-level and voivodeship-level coverage. Statistically significant local spatial autocorrelation was observed in an increasing number of poviats for MCV1, rising from 14 in 2014 to 47 in 2018. For MCV2, the number of poviats with significant clustering fluctuated, peaking at 27 in 2015.

Conclusions. The use of fine-grained poviat-level data revealed disparities in MCV coverage and localized gaps that would be obscured at the voivodeship level, underscoring the importance of high-resolution spatial analysis for guiding targeted vaccination efforts and improving public health equity.

Key words

vaccination coverage, MMR vaccine, childhood immunization, measles, vaccine uptake.

INTRODUCTION

Achieving high vaccination coverage remains one of the most effective strategies for mitigating both the spread and impact of infectious diseases [1–3]. As a commonly available method of preventing infectious diseases, vaccinations contribute to shaping not only individual but also collective prevention [4–6]. A decline in vaccination coverage along with an increased number of vaccine-preventable disease cases have been observed in recent years [7, 8]. According to estimates of the World Health Organization (WHO), 23 million children did not receive the complete age-appropriate vaccination course in 2020 due to the COVID-19 pandemic, and associated disruptions. Global estimates of coverage with the first dose of measles-containing vaccine (MCV1) dropped from 86% in 2019 to 81% in 2021 [8].

Due to the highly contagious nature of the measles virus, a very high level of herd immunity is required, with vaccination coverage of at least 95% needed to interrupt transmission [9]. As of July 2025, surveillance data from the WHO reported 239,816 suspected measles cases and 108,074 confirmed cases across all WHO regions. The Eastern Mediterranean Region accounted for the largest proportion (35%), followed by the African (21%) and the European Region (21%) [10]. From 1 July 2024 – 30 June 2025, 30 EU/EEA Member States reported a total of 14,401 cases of measles and 8 deaths. 84.3% of cases with a known age and vaccination status were unvaccinated [11]. Reliable calculation of the vaccination uptake is vital in assessing the success of the vaccination program, identifying susceptible populations for further interventions, and informing future health policy decisions [12, 13]. Following significant outbreaks that underscored gaps in vaccine coverage, in recent years, several European countries (e.g. Italy, France and Germany) have introduced mandatory measles vaccination, while in Poland, measles vaccination has been a compulsory component of the national immunization program since 1975 [14 – 16].

The childhood immunization data reporting in Poland (described below) does not allow for easy identification of smaller territorial areas (such as poviats) to target actions of public health authorities in the case of lower than expected

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vaccination coverage on their territory. The analysis of data at the poviat level will allow to identify areas with insufficient vaccination coverage to achieve herd immunity and direct targeted public health activities aimed at increasing the vaccination uptake. This study aimed to: 1) present the differences in the sufficient MCV1 and MCV2 coverage measured at different granularity levels (voivodeship vs. poviat), and 2) identify clusters with sufficient/insufficient MCV1 and MCV2 coverage.

MATERIALS AND METHOD

Childhood immunization data reporting in Poland. Data on childhood routine vaccines administered in Poland in the studied period was recorded by the entities conducting medical activity providing outpatient and stationary health services participating in preventive vaccinations, which were obliged to send the individual data in a paper form to the poviat sanitary-epidemiological stations (PSSE) once a year (since 2024 the data is sent quarterly in an electronic form) [17,18]. PSSE sent the aggregated data using MZ-54 form to respective voivodeship sanitary-epidemiological stations (WSSE). There are 318 PSSE and 16 WSSE in Poland [19]. Aggregated data from WSSE is sent to the Chief Sanitary Inspectorate and the National Institute of Public Health National Institute of Hygiene-National Research Institute [20]. Each year, both institutions publish a document entitled *Vaccination in Poland*, in which the voivodeship is the smallest territorial unit assessed [21].

Data collection. Measles vaccination coverage data used in the study was collected with granularity at the poviat level. Data was collected from 2014–2018 when the second dose of the MCV vaccine was administered to children at age 10. This analysis does not cover the period following the 2019 revision of the immunization schedule, which moved MCV2 administration to age 6 [22]. Due to the aggregated nature of the data received from sanitary-epidemiological stations, it was not possible to identify individual patients who received the vaccination. The vaccination coverage rate for each calendar year was calculated as the proportion of the vaccinated children in a birth cohort targeted for immunization. The numerator represented the number of children who received the specific vaccine during the observed calendar year. The measles-containing vaccines (MCV1 in the 3rd year of life, MCV2 in the 11th year of life) were chosen as indicators. The threshold was defined at 95% to divide territory units into those with sufficient (≥95%) and insufficient (<95%) measles vaccination coverage. Data from the voivodeship level was compared with the data from the poviat level.

Data integration and analysis. Microsoft Excel and SAS programme version 9.4 were used for data integration and analysis. Descriptive statistics was used to present the MCV1 and MCV2 coverage at the voivodeship and at the poviat levels. Spatial analysis using Local Moran's I was performed to identify neighbouring poviats with similar MCV (MCV1 and MCV2) rates and outlier areas with markedly dissimilar values. The level of significance was set at .05. Poviats with sufficient MCV vaccination coverage surrounded by poviats with similarly high values were in category called 'high-high' (HH). Poviats with insufficient MCV vaccination coverage surrounded by poviats with similar values were included in the 'low-low' (LL) category. An outlier 'high-low' (HL) area described a poviat with sufficient MCV vaccination coverage surrounded by poviats with insufficient MCV vaccination coverage. An outlier 'low-high' (LH) area described a poviat with insufficient MCV vaccination coverage surrounded by poviats with sufficient MCV vaccination coverage. The proximity of poviats was determined using the shared boundary criterion.

RESULTS

Between 2014–2018, MCV1 coverage ranged from 89% – 99% on the voivodeship level, and from 80% – 100% on the poviat level (Tab. 1), while MCV2 coverage in the same period ranged from 84% – 99% on the voivodeship level, and from 32.3% – 100% on the poviat level (Tab. 2). Figures 1 and 2 depict differences in the areas of Poland with sufficient (≥95%) and insufficient MCV1 (Fig. 1) and MCV2 (Fig. 2) vaccination coverage measured at the poviat and at the voivodeship levels. The voivodeships exhibiting the greatest variation in MCV1 coverage across constituent poviats were as follows: Mazowieckie, Łódzkie, and Małopolskie in 2014; Mazowieckie, Łódzkie, and Pomorskie in 2015; Łódzkie, Pomorskie, and Mazowieckie in 2016; Mazowieckie, Małopolskie, and Podlaskie in 2017; and Lubelskie, Mazowieckie, and Łódzkie in 2018. The voivodeships demonstrating the highest levels of disparity in MCV2 coverage across poviats in their area were as follows: Warmińsko-Mazurskie, Mazowieckie, and Lubuskie in 2014; Podkarpackie, Mazowieckie, and Pomorskie in 2015; Mazowieckie, Podkarpackie, and Łódzkie in 2016; Podkarpackie, Mazowieckie, and Małopolskie in 2017; and Mazowieckie, Małopolskie, and Podkarpackie in 2018.

The greatest positive deviation between the poviat with the highest MCV1 coverage and the corresponding voivodeship-level coverage was observed in the Mazowieckie voivodeship in 2014, 2016, 2017, and 2018, and in the Małopolskie Voivodeship in 2015. Conversely, the largest negative deviation between the poviat with the lowest MCV1 and the voivodeship-level coverage was recorded in Mazowieckie in 2014, in Łódzkie during the period 2015–2017, and in Lubelskie in 2018. The greatest positive deviation between MCV2 coverage in the poviat with the highest coverage and the corresponding voivodeship-level coverage was consistently observed in Mazowieckie Voivodeship across all years analyzed. In contrast, the largest negative deviation between the poviat with the lowest MCV2 coverage and the voivodeship-level coverage was recorded in Warmińsko-Mazurskie in 2014, in Podkarpackie in 2015 and 2017, and in Mazowieckie in 2016 and 2018.

For MCV1, statistically significant local spatial autocorrelation (based on Local Moran's I) was observed for 14 poviats in 2014 year, 26 in 2015, 27 in 2016, 44 in 2017 and 47 in 2018. The proportion of poviats forming spatial clusters with similar MCV1 coverage increased over time, accounting for 4.1% in 2014, 7.5% in 2015, 7.2% in 2016, 11.9% in 2017, and 13.4% in 2018. Additionally, a subset of poviats exhibited statistically significant negative local spatial autocorrelation, indicating spatial outliers: 1 poviat in 2014, 2 in 2015, 4 in 2016, 6 in 2017, and 4 in 2018 (Tab. 3).

Table 1. MCV1 vaccination coverage at the voivodeship and the poviat level 2014–2018

	MCV1									
	2014		2015		2016		2017		2018	
Voivodeship	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.
DOLN[a]	97.7	93.6 - 99.8	96.5	93.9 - 100	96.1	93.4 - 99.6	95.1	91.5 - 100	92.9	88.3 - 99.3
KUJA[b]	99	98.3 - 100	98.7	97.6 - 99.7	98.3	96.7 - 99.7	97.5	95.2 - 100	96.6	94 - 99.7
ŁÓDŹ[c]	96.8	91.6 - 100	95.1	90 - 99.7	94.6	81 - 99.7	93.9	86 - 100	92.0	83.6 - 98.7
LUBU[d]	98.8	97.2 - 99.8	97	94.7 - 99.5	96.6	94.3 - 99.1	95.8	93 - 99.2	94.4	90.3 - 97.8
LUBE[e]	97	93.3 - 100	96.4	93.5 - 99.5	95.3	90.7 - 99.7	93.1	86.7 - 97.9	91.3	80.1 - 97.1
MAŁO[f]	96.2	91.6 - 100	94.9	93.8 - 99.9	93.9	88.4 - 98.7	92.7	86.7 - 98.9	92.2	86 - 99.6
MAZO[g]	94.5	83 - 99.9	93.0	88.5 - 100	91.6	88.3 - 99.7	89.6	83.9 - 99.5	89.7	82.9 - 99.7
OPOL[h]	98.1	97.1 - 100	97.3	94.9 - 100	97.1	95.6 - 99.7	96.4	94.4 - 98.9	95.6	93.3 - 98.7
PODK[i]	97.7	93.9 - 99.7	97.2	94.3 - 99.7	96.3	89.1 - 100	94.5	88.8 - 99.1	93.5	88.9 - 99.5
PODL[j]	96.4	94.4 - 99.5	95.5	92.7 - 98.5	93.6	90.3 - 98.5	91.9	85.8 - 97.9	89.0	83.4 - 98
POMO[k]	96.6	93.9 - 99.4	96.4	92.3 - 99.9	94.9	82.8 - 99.3	94.4	90.3 - 99.4	93.5	88.7 - 99.1
ŚLĄSK[l]	96.6	95.2 - 98.9	96.0	93.7 - 98.8	95.4	92.3 - 98.3	93.8	89.9 - 97	92.4	88.8 - 96.4
ŚWIĘ[m]	98.4	94.9 - 99.8	98.1	94.3 - 99.8	99	97.9 - 100	97.1	95 - 99.5	96.2	94 - 99.1
WARM[n]	95.7	99.1 - 100	99	98 - 100	98.7	97.3 - 100	98.3	95.9 - 100	98.2	96.3 - 99.8
WIEL[o]	97.9	95.7 - 100	97.4	95 - 99.7	96.5	92.9 - 100	95.9	92.6 - 99.1	94.5	90.9 - 99
ZACH[p]	98.2	98.16 - 100	98	95.1 - 100	97.5	92.7 - 100	97.1	94.7 - 99.8	95.4	91.9 - 99.5

MCV1 (measles-containing vaccine, 1st dose) vaccination coverage at the voivodeship level [%]; § range (min.-max.) of MCV1 vaccination coverage at the poviat level [%]; [a] Dolnośląskie; [b] Kujawsko-Pomorskie; [c] Łódzkie; [d] Lubuskie; [e] Lubelskie; [f] Małopolskie; [g] Mazowieckie [h] Opolskie; [i] Podkarpackie; [j] Podlaskie; [k] Pomorskie; [l] Śląskie; [m] Świętokrzyskie; [n] Warmińsko-Mazurskie; [o] Wielkopolskie; [p] Zachodniopomorskie

Table 2. MCV2 vaccination coverage at the voivodeship and the poviat level 2014–2018

	MCV2									
	2014		2015		2016		2017		2018	
Voivodeship	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.	Voi#	Pov§ min. – max.
DOLN[a]	95.4	89.8 - 99.8	94.3	85.9 - 99.8	93.5	83.5 - 100	94.1	89.0 - 100	92.3	85.5 - 99.4
KUJA[b]	99.3	98.8 - 100	99.1	98.4 - 100	99.0	97.9 - 100	98.7	97.7 - 99.8	98.2	95.9 - 100
ŁÓDŹ[c]	94.4	85.1 - 99.3	93.4	82.0 - 99.4	92.8	79.6 - 99.5	92.7	83.6 - 99.5	92.9	84.1 - 99.7
LUBU[d]	97.2	82.7 - 99.6	96.9	92.8 - 100	96.8	90.1 - 99.4	95.3	88.0 - 99.1	95.7	91.4 - 99.2
LUBE[e]	97.3	94.0 - 100	96.5	89.2 - 100	96.0	86.9 - 100	95.8	89.6 - 99.8	94.3	88.4 - 99.8
MAŁO[f]	95.1	88.0 - 99.8	94.4	87.6 - 98.8	92.8	82.8 - 98.8	92.3	82.1 - 98.4	91.5	80.8 - 98.4
MAZO[g]	86.4	72.4 - 99.7	85.9	72.6 - 99.5	83.7	67.3 - 99.5	85.4	72.4 - 100	84.7	65.2 - 100
OPOL[h]	95.9	91.0 - 99.5	96.6	91.4 - 99.1	96.7	91.2 - 99.5	95.7	93.9 - 99.2	95.2	93.2 - 99
PODK[i]	92.0	82.4 - 99.1	90.1	71.2 - 99.5	89.7	75.8 - 98.8	85.1	32.3 - 98.7	89.2	82.3 - 98.8
PODL[j]	96.5	94.2 - 99.8	96.6	94.3 - 99.4	95.4	89.8 - 99.7	93.6	86.5 - 99.7	93.4	89.2 - 99.1
POMO[k]	94.0	93.4 - 99.3	93.3	81.5 - 99.8	92.0	80.7 - 99.2	92.8	84.6 - 99.6	91.5	84.4 - 99.1
ŚLĄS[l]	95.1	83.7 - 98.7	95.1	84.5 - 98.9	94.6	84.3 - 99.6	93.8	82.6 - 98.6	92.9	85.5 - 97.4
ŚWIĘ[m]	97.4	94.7 - 100	96.6	93.1 - 99.6	96.2	88.9 - 99.7	96.5	92.8 - 99.9	96.0	92.5 - 99.4
WARM[n]	97.4	46.3 - 100	99.4	98.8 - 100	99.3	98.7 - 100	99.1	97.9 - 100	98.8	97.1 - 100
WIEL[o]	98.0	95.9 - 100	97.4	95.1 - 100	96.3	92.4 - 99.8	95.4	88.3 - 99.5	95.2	91.1 - 99.5
ZACH[p]	96.7	91.3 - 100	96.3	90.0 - 100	95.4	89.4 - 99.8	95.4	87.6 - 99.6	95.1	88.1 - 99.8

MCV2 (measles-containing vaccine, 2nd dose) vaccination coverage at the voivodeship level [%]; § range (min.-max.) of MCV2 vaccination coverage at the poviat level [%]; [a] Dolnośląskie; [b] Kujawsko-Pomorskie; [c] Łódzkie; [d] Lubuskie; [e] Lubelskie; [f] Małopolskie; [g] Mazowieckie; [h] Opolskie; [i] Podkarpackie; [j] Podlaskie; [k] Pomorskie; [l] Śląskie; [m] Świętokrzyskie; [n] Warmińsko-Mazurskie; [o] Wielkopolskie; [p] Zachodniopomorskie

For MCV2, statistically significant local spatial autocorrelation was observed for 23 poviats in 2014, 27 in 2015, 22 in 2016, 16 in 2017 and 25 in 2018. The percentage of poviats forming spatial clusters with similar MCV2 coverage was 5.9% in 2014, 7.8% in 2015, 6.6% in 2016, 4.7% in 2017, and 7.2% in 2018. Statistically significant negative local spatial autocorrelation was identified for 4 poviats in 2014, 2 in 2015, 1 in 2016, 1 in 2017, and 2 in 2018 (Tab. 4).

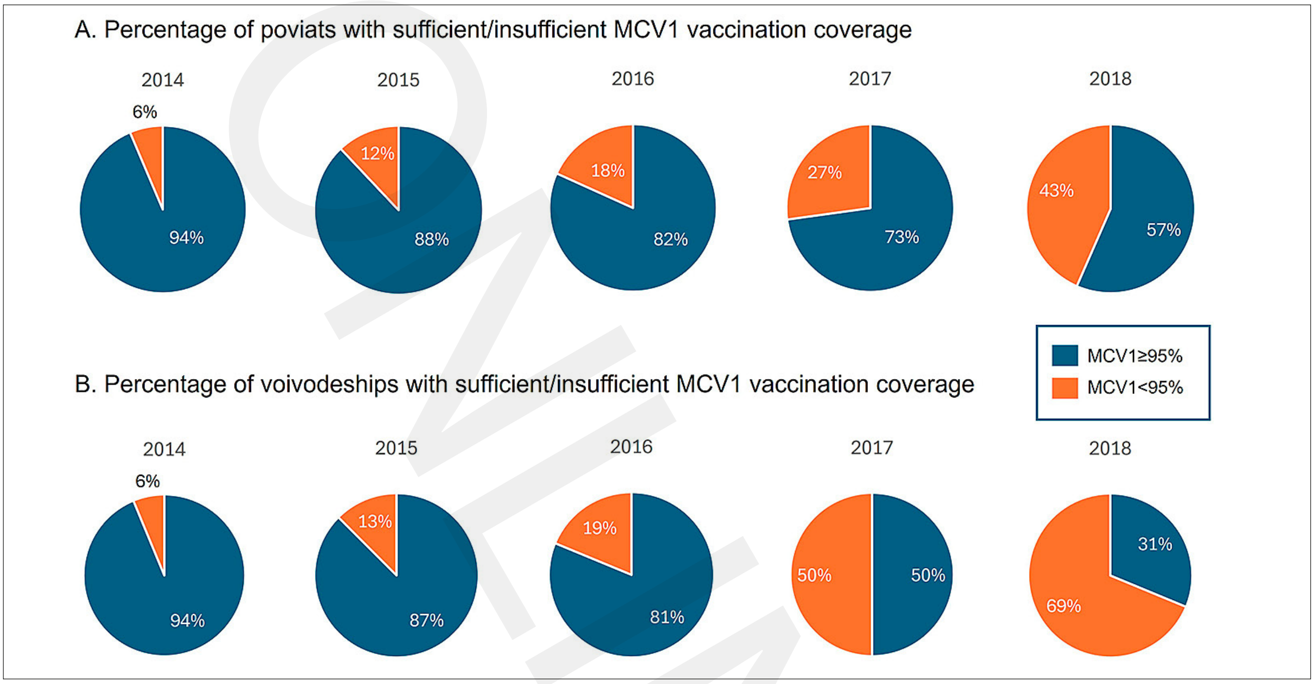

Figure 1. Areas of Poland with sufficient (≥95%) and insufficient (<95%) MCV1 vaccination coverage, poviat and voivodeship perspective (2014-2018)

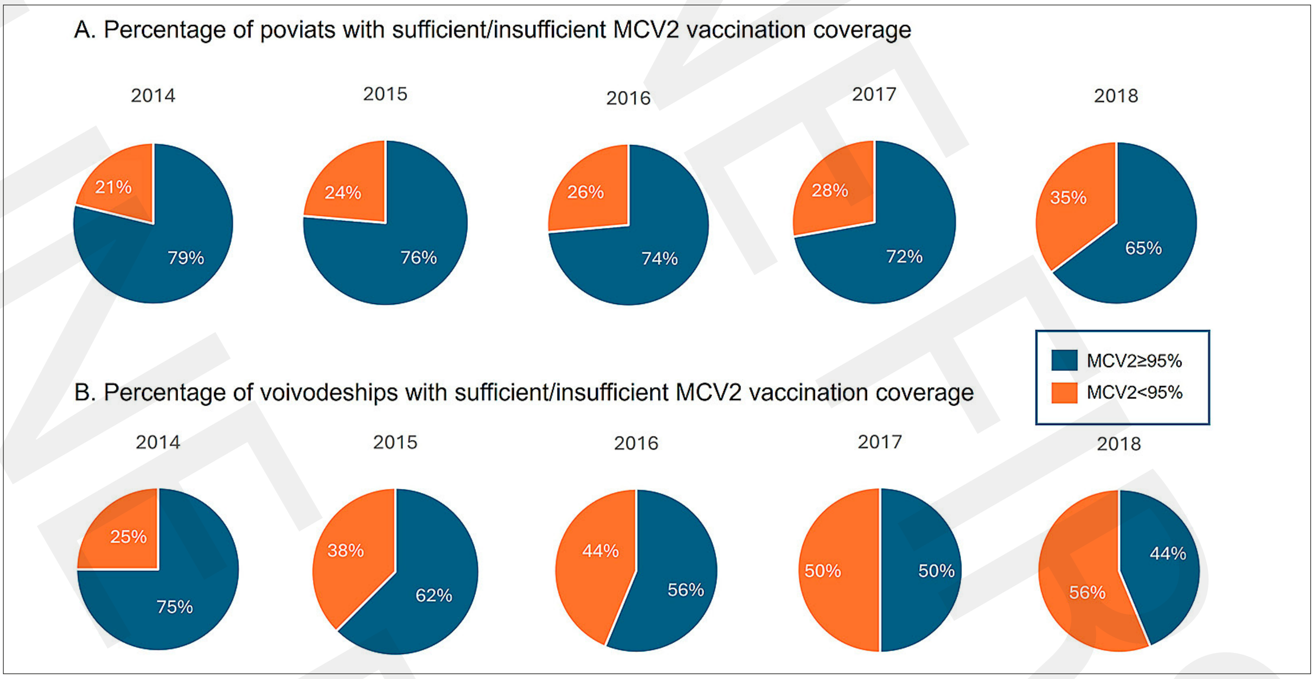

Figure 2. Areas of Poland with sufficient (≥95%) and insufficient (<95%) MCV2 vaccination coverage, poviat and voivodeship perspective (2014-2018)

DISCUSSION

The European Immunization Agenda 2030, a strategic framework developed by the WHO Regional Office for Europe, seeks to reduce disparities in immunization coverage through the local-level interventions, based on a comprehensive monitoring systems at regional, national, and subnational levels. One of the strategic priorities is to enhance subnational capacity to interpret and analyze immunization surveillance data in order to identify critical gaps and populations at elevated risk of VPD outbreaks [23]. Previous studies have shown that the under-immunization and vaccine refusal cluster geographically [24 – 28]. Masters et al. found that, when non-vaccination was locally clustered, reporting aggregated data at the state- or county-level could result in substantial underestimates of outbreak risk. The authors suggested collecting vaccination data of higher granularity to prevent a return to endemic measles transmission in the USA

[28]. Leveraging digital technologies and data triangulation is needed to improve immunization monitoring and VPD surveillance and strengthen the quality of the reported data [23].

Main findings and analysis of results. The comparison of MCV1 and MCV2 vaccination coverage across voivodeship and poviat levels between 2014 – 2018 reveals important insights into the spatial dynamics of immunization in Poland. At the voivodeship level, 5 regions: Kujawsko-Pomorskie, Opolskie, Świętokrzyskie, Warmińsko-Mazurskie and Zachodniopomorskie, consistently achieved sufficient coverage for both MCV doses. Lubuskie and Wielkopolskie voivodeships also demonstrated stable and generally sufficient coverage, though in 2018 both fell marginally (less than 1%) below the 95% threshold. However, when examining the data at the poviat level, substantial internal disparities become evident. While MCV1 coverage remained relatively stable, with minimum values generally above 80%, MCV2 coverage exhibited significantly greater variability. In some poviats, coverage for the second dose dropped below 70%. The divergence between MCV1 and MCV2 coverage at the poviat level suggests challenges in ensuring both doses completion. This pattern may reflect insufficient reporting systems, logistical barriers to follow-up, or localized vaccine hesitancy. The Mazowieckie voivodeship consistently exhibited the greatest internal variability in both MCV1 and MCV2 coverage, appearing repeatedly among the regions with the largest differences between poviats. This may reflect the socio-economic and demographic heterogeneity within the voivodeship, which encompasses both the metropolitan area of the capital of Poland and more rural districts. Similar patterns are observed in eastern and southeastern regions, including Lubelskie and Podkarpackie, where broader coverage ranges and lower minimums highlight barriers to full immunization.

Both MCV1 and MCV2 show recurring LL clusters in central and eastern Poland, especially in the poviats of Łódź, Pabianice, Zgierz, Pruszków, Warsaw and Warsaw West. These areas consistently exhibit insufficient coverage surrounded by similarly underperforming neighbours.

Studies performed in OECD and European countries show that urban settings are associated with higher vaccination coverage [29–31]. Surprisingly, urban and peri-urban areas, such as Kraków, Warsaw and Łódź, frequently appear in LL clusters for both MCV doses, suggesting systemic issues in vaccine uptake even in well-resourced regions. LL clusters identified in Mazowieckie, Łódzkie, and Małopolskie voivodeships warrant focused investigation by sanitary inspection authorities to elucidate the underlying determinants of persistently insufficient MCV coverage.

Furthermore, HL and LH outliers offer valuable case studies to understand what drives success or failure in specific contexts. These areas could inform best practices or reveal structural weaknesses. Communication strategies and operational practices employed by PSSE in HL outlier areas (e.g. Piaseczno, Sanok, Grójec), where high coverage was achieved despite being surrounded by LL areas, should be systematically evaluated and considered for adaptation in LL and LH areas to enhance immunization uptake.

In conclusion, while vaccination coverage reported at the national and regional level presents general immunization performance, local-level analysis reveals significant disparities that must be addressed to achieve comprehensive and equitable vaccine coverage. Granular surveillance is therefore indispensable for guiding effective public health strategies and ensuring that no population is left behind in the pursuit of measles elimination. These observations underscore the critical importance of data granularity in vaccination reporting.

Limitations of the study. While the study had several strengths, including using data from the territory of the entire country on the lowest available granularity, some limitations must be acknowledged when evaluating these findings. Firstly, vaccination coverage data was provided by sanitary-epidemiological stations in multiple formats, including handwritten documents, scanned images, and digital files. To enable standardized analysis, one of the authors manually digitized the data, ensuring consistency and interoperability across all formats. Secondly, the data was provided in a pre-aggregated format, which precluded analysis of vaccine uptake at the individual level. Thirdly, the analysis did not cover the period following the 2019 revision of the immunization schedule, which moved MCV2 administration to age 6.

Future research. Lack of the access to the individual level vaccination data should not be viewed as a barrier to conducting more granular research. It is imperative to maximize the utility of existing data sources and to develop more robust data collection and analytical frameworks capable of accurately monitoring and improving vaccine coverage at both the voivodeship and poviat levels. The use of cluster analysis proves effective in identifying priority regions. Future surveillance should integrate spatial methods to dynamically monitor and respond to emerging immunization patterns. Urban centres should not be assumed to have high coverage, data shows they may be hotspots of insufficient immunization. Future studies should also investigate barriers to completing the vaccination schedule, from the perspective of both the health system and the parent.

CONCLUSIONS

This study underscores the value of granular, spatial analysis in revealing disparities in measles vaccination coverage across Poland. While voivodeship-level data presents general immunization, poviat-level findings expose significant gaps – particularly in MCV2 uptake, with some areas falling below 70%. Notably, urban centres like Warsaw, Łódź, and Kraków frequently appear in low-coverage clusters, challenging assumptions about urban vaccine performance. Analysis of higher-granularity data with early identification of vulnerable areas enables local public health and medical professionals to design and implement more precise interventions aimed at enhancing vaccine uptake within their communities, supporting a shift from reactive to pro-active public health strategies. Recognizing and addressing spatial disparities in vaccine coverage is essential for achieving equitable immunization.

Table 3. Neighbouring poviats with similar MCV1 coverage rates (HH, LL) and outlier areas with dissimilar MCV coverage rates (LH, HL) with significant Local Moran's I values ($p<0.05$), 2014–2018

2014				2015				2016				2017				2018			
Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]
Kraków	LL	91.6	3.46	Łódż	LL	92.3	3.24	Łódż	LL	91.7	2.87	Łódż	LL	89	1.46	Środa Śląska	LL	88.6	0.91
Pruszków	LL	83	16.52	Pabianice	LL	90.3	3.48	Pabianice	LL	81	1.73	Luków	LL	86.7	2.42	Łódż	LL	88.2	1.92
Warsaw West	LL	89.1	14.11	Zgierz	LL	90	3.18	Luków	LL	90.7	1.11	Wieliczka	LL	93.4	1.20	Pabianice	LL	83.6	1.93
Wołomin	LL	92.6	2.47	Łuków	LL	93.5	1.35	Wieliczka	LL	93.8	1.88	Kraków	LL	86.7	3.00	Zgierz	LL	87.2	1.52
Warsaw	LL	92.9	7.48	Wieliczka	LL	94	2.03	Kraków	LL	88.4	4.25	Garwolin	LL	94.3	0.87	Łuków	LL	80.1	3.24
Łomza	LL	94.7	0.79	Kraków	LL	89.2	6.03	Mińsk Mazowiecki	LL	94.5	1.53	Łosice	LL	90.9	2.20	Ryki	LL	89.9	1.35
Gdynia	LL	94.2	1.92	Otwock	LL	89.4	1.63	Otwock	LL	88.8	1.05	Mińsk Mazowiecki	LL	94.5	1.18	Garwolin	LL	91.8	1.18
Sopot	LL	93.9	3.78	Pruszków	LL	89.3	5.46	Pruszków	LL	89.3	4.31	Ostrów Mazowiecka	LL	91.6	0.91	Łosice	LL	87.8	3.09
Rybnik	HH	95.3	1.18	Siedlce	LL	93.3	1.13	Siedlce	LL	93	1.06	Otwock	LL	83.9	2.26	Mińsk Mazowiecki	LL	93	0.83
Ruda Śląska	HH	95	1.36	Warsaw West	LL	91.3	5.39	Warsaw West	LL	88.3	5.16	Pruszków	LL	90	3.55	Ostrów Mazowiecka	LL	89.1	1.20
Giżycko	HH	100	0.88	Wołomin	LL	93	2.10	Wołomin	LL	89.9	2.28	Siedlce	LL	86.8	2.66	Pruszków	LL	86	2.35
Sochaczew	HH	95.2	0.79	Warsaw	LL	92.4	5.20	Warsaw	LL	90.8	4.49	Warsaw West	LL	88.2	3.72	Siedlce	LL	82.9	4.20
Gdańsk	HH	95	1.35	Gdańsk	LL	93.8	1.32	Białystok	LL	90.8	1.03	Wołomin	LL	86.1	3.78	Sochaczew	LL	91.2	0.86
Piaseczno	HL	99.9	-3.28	Gdynia	LL	92.3	2.12	Bielsk Podlaski	LL	91.3	1.03	Warsaw	LL	84.4	7.31	Warsaw Zachodnia	LL	85.8	3.34
				Sopot	LL	93.3	4.24	Lomza	LL	90.3	1.11	Białystok	LL	89.1	0.94	Wołomin	LL	85	2.23
				Rybnik	LL	94	1.15	Gdańsk	LL	92.3	1.03	Łomża	LL	85.8	2.07	Warsaw	LL	88.4	2.41
				Ruda Śląska	HH	95.4	0.90	Gdynia	LL	92.2	1.00	Gdańsk	LL	91.1	0.93	Białystok	LL	85.2	1.52
				Bartoszyce	HH	99.5	0.97	Sopot	LL	94.6	1.53	Gdynia	LL	90.3	1.31	Łomża	LL	83.4	2.55
				Braniewo	HH	100	1.26	Jaworzno	LL	92.3	0.95	Sopot	LL	91.2	2.84	Siemiatycze	LL	91.4	1.00
				Kętrzyn	HH	100	0.88	Kielce	HH	99.4	0.64	Lubliniec	LL	92.4	0.74	Sopot	LL	90	1.92
				Lidzbark Warmiński	HH	100	0.99	Działdowo	HH	99.2	0.83	Rybnik	LL	92.1	0.87	Rybnik	LL	88.8	0.98
				Sochaczew	HH	95.8	0.80	Brodnica	HH	99.5	0.81	Jaworzno	LL	89.9	1.34	Wodzisław Śląski	LL	89.2	0.99
				Garwolin	HH	96.1	0.87	Zgierz	HH	95.4	0.80	Bartoszyce	HH	99	1.05	Bartoszyce	HH	98.8	1.25
				Mińsk Mazowiecki	HH	95.1	2.11	Poznań	HL	92.9	-0.65	Braniewo	HH	99.7	1.38	Braniewo	HH	99.4	1.36
				Źielona Góra	HL	94.7	-0.80	Piaseczno	HL	99.7	-2.13	Działdowo	HH	99.8	1.22	Działdowo	HH	99.8	1.21
				Piaseczno	HL	100	-3.13	Tarnobrzeg	LH	91.9	-1.52	Elbląg	HH	98.8	0.95	Elbląg	HH	98	0.86
								Kwidzyń	LH	82.8	-2.08	Iława	HH	99.4	0.92	Giżycko	HH	99.6	1.15
												Kętrzyn	HH	99.8	0.97	Iława	HH	98.4	0.81
												Lidzbark Warmiński	HH	100	1.18	Kętrzyn	HH	99.8	1.29
												Nowe Miasto Lubawskie	HH	99.3	0.97	Lidzbark Warmiński	HH	99	1.17
												Ostroda	HH	98.7	0.85	Nidzica	HH	98.6	0.99
												Piła	HH	99.1	1.02	Nowe Miasto Lubawskie	HH	99.4	1.14

2014				2015				2016				2017				2018			
Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV1[c]	LM[d]
												Złotów	HH	98.9	0.94	Ostroda	HH	98.6	0.98
												Walcz	HH	99.1	0.82	Piła	HH	99	1.08
												Gołub Dobrzyn	HH	99	0.83	Drawsko Pomorskie	HH	98.8	0.97
												Nakło-nad- Notecia	HH	99.1	0.84	Swidwin	HH	99.5	1.17
												Rypin	HH	100	1.18	Wałcz	HH	98.9	0.85
												Sepolno Krajeńskie	HH	99.4	0.82	Gołub Dobrzyn	HH	99.7	1.02
												Zgierz	HL	99.2	-1.03	Nakło-nad- Notecia	HH	98.4	0.89
												Źielona Góra	HL	93	-0.73	Rypin	HH	99.5	1.02
												Nowy Dwór Mazowiecki	LH	98.1	-1.02	Sepolno Krajenskie	HH	99.5	1.07
												Piaseczno	HL	99.5	-2.86	Tuchola	HH	99.6	0.87
												Węgrów	HL	97.8	-1.12	Człuchów	HH	99.1	0.89
												Tarnobrzeg	LH	88.8	-1.40	Piaseczno	HL	99.7	-1.72
																Radom	LH	85.7	-1.77
																Tarnobrzeg	LH	89.9	-0.93
																Wysokie Mazowieckie	HL	98	-1.18

[a] reporting area covered by the Poviat Sanitary-Epidemiological Station; [b] cluster or outlier type: HH – high-high. poviats with sufficient MCV1 coverage. surrounded by poviats with sufficient vaccination coverage; LL – low-low. poviats with insufficient MCV1 coverage. surrounded by poviats with insufficient vaccination coverage; HL – high-low. poviats with sufficient MCV1 coverage. surrounded by poviats with insufficient vaccination coverage; LH – low-high. poviats with insufficient MCV1 coverage. surrounded by poviats with sufficient vaccination coverage; [c] MCV1 (measles-containing vaccine. 1st dose) vaccination coverage at the poviat level [%]; [d] Local Moran's I ($p<0.05$)

Table 4. Neighbouring poviats with similar MCV2 coverage rates (HH, LL) and outlier areas with dissimilar MCV2 coverage rates (LH, HL) with significant Local Moran's I values (p<0.05), 2014–2018

2014				2015				2016				2017				2018			
Poviat[a]	Cluster/ Outlier Type[b]	MCV2[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV2[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV2[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV2[c]	LM[d]	Poviat[a]	Cluster/ Outlier Type[b]	MCV2[c]	LM[d]
Łódź	LL	90.4	0.82	Łódź	LL	88.8	1.76	Łódź	LL	87.5	1.80	Łódź	LL	87	0.97	Łódź	LL	87.9	1.19
Zgierz	LL	85.1	0.76	Pabianice	LL	91.9	0.75	Pabianice	LL	87	1.12	Kraków	LL	82.1	1.96	Zgierz	LL	87.6	0.91
Nowy Dwór Mazowiecki	LL	89.8	1.32	Zgierz	LL	82	1.67	Zgierz	LL	79.6	1.57	Piaseczno	LL	86.8	2.56	Kraków	LL	80.8	3.12
Otwock	LL	91.1	1.10	Kraków	LL	87.6	1.61	Kraków	LL	82.8	2.41	Pruszków	LL	76.7	8.41	Garwolin	LL	92	0.73
Piaseczno	LL	89.1	3.18	Garwolin	LL	89.7	0.93	Otwock	LL	89.4	1.90	Warsaw West	LL	84.1	4.59	Otwock	LL	66.7	5.74
Pruszków	LL	83.5	8.02	Nowy Dwór Mazowiecki	LL	92.8	1.36	Piaseczno	LL	79.8	7.27		LL	80.1	2.45	Piaseczno	LL	88.5	4.63
Warsaw West	LL	84.4	6.15	Otwock	LL	90.5	2.05	Pruszków	LL	80	11.73	Warsaw	LL	72.4	6.37	Pruszków	LL	76	11.46
Wołomin	LL	86.3	2.30	Piaseczno	LL	87.4	5.24	Sochaczew	LL	88.6	1.19	Brzozów	LL	89.8	3.17	Sochaczew	LL	86.4	1.69
Warsaw	LL	72.4	8.10	Pruszków	LL	80.3	14.83	Warsaw West	LL	82.8	6.63	Dębica	LL	88.7	0.89	Warsaw West	LL	80.9	7.95
Brzozów	LL	89.9	1.48	Sochaczew	LL	89.4	1.41	Wołomin	LL	82.9	2.91	Krosno	LL	32.3	3.47	Wołomin	LL	81.7	2.69
Dębica	LL	89.5	0.78	Warsaw West	LL	77.6	12.71	Warsaw	LL	73.1	10.46	Mielec	LL	82	1.54	Warsaw	LL	73.2	12.61
Przemyśl	LL	82.4	1.85	Wołomin	LL	85.8	2.76	Brzozów	LL	92.3	0.95	Przemyśl	LL	83.4	1.07	Brzozów	LL	87.4	1.84
Przeworsk	LL	88.6	1.22	Warsaw	LL	72.6	12.68	Dębica	LL	83.5	2.56	Ropczyce	LL	87.9	1.78	Dębica	LL	90.1	1.02
Rzeszów	LL	89.8	1.14	Brzozów	LL	91.6	1.81	Łancut	LL	86.1	1.20	Rzeszów	LL	84.4	1.39	Łańcut	LL	85.2	1.83
Strzyzów	LL	90.7	0.822	Dębica	LL	87.6	1.58	Mielec	LL	75.8	2.95	Strzyzów	LL	89.4	2.90	Mielec	LL	82.3	1.51
Pruszcz Gdański	LL	83.4	0.988	Jaroslaw	LL	91.5	2.23	Przemyśl	LL	85.1	0.96	Sanok	HL	98.7	-2.01	Przemyśl	LL	85.6	1.13
Tczew	LL	87.9	0.862	Mielec	LL	80.1	2.31	Rzeszów	LL	85.9	1.58					Ropczyce	LL	88.8	1.77
Lubliniec	LL	83.7	1.26	Przemyśl	LL	71.2	3.80	Strzyzów	LL	85.1	2.21					Rzeszów	LL	83.4	2.05
Myszków	LL	84.5	1.766	Rzeszów	LL	87.2	2.07	Tarnobrzeg	LL	80	1.96					Strzyzów	LL	89	1.45
Bartoszyce	LH	46.3	-6.745	Tarnobrzeg	LL	82.3	1.25	Tczew	LL	81.5	1.19					Gdańsk	LL	84.4	2.02
Braniewo	HL	99.4	-1.774	Pruszcz Gdański	LL	89.6	0.82	Gdańsk	LL	88.4	0.89					Gdynia	LL	86.6	1.56
Kętrzyn	HL	100	-1.147	Tczew	LL	81.5	1.26	Grójec	HL	98.6	-0.65					Sopot	LL	86.7	3.38
Lidzbark Warmiński	HL	100	-1.144		LL	90	0.98									Giżycko	LL	99.5	0.73
				Sopot	LL	89.7	1.93									Skierniewice	HL	98.9	-0.91
				Lubliniec	LL	84.5	0.88									Grójec	HL	97.7	-0.68
				Wrocław	LH	85.9	-0.72												
				Sanok	HL	99.5	-1.40												

[a] reporting area covered by the Poviat Sanitary-Epidemiological Station. [b] cluster or outlier type: HH – high-high. poviats with sufficient MCV2 coverage. surrounded by poviats with sufficient vaccination coverage; LL – low-low. poviats with insufficient MCV2 coverage. surrounded by poviats with insufficient vaccination coverage; HL – high-low. poviats with sufficient MCV2 coverage. surrounded by poviats with insufficient vaccination coverage; LH – low-high. poviats with insufficient MCV2 coverage. surrounded by poviats with sufficient vaccination coverage. [c] MCV2 (measles-containing vaccine. 2[nd] dose) vaccination coverage at the poviat level [%]. [d] Local Moran's I (p<0.05)

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