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Short communication

Geospatially clustered low COVID-19 vaccine rates among adolescents in socially vulnerable US counties

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ABSTRACT

COVID-19 vaccinations are widely available across the United States (U.S.), yet little is known about the spatial clustering of COVID-19 vaccinations. This study aimed to test for geospatial clustering of COVID-19 vaccine rates among adolescents aged 12–17 across the U.S. counties and to compare these clustering patterns by sociodemographic characteristics.

County-level data on COVID-19 vaccinations and sociodemographic characteristics were obtained from the COVID-19 Community Profile Report up to April 14, 2022. A total of 3,108 counties were included in the analysis. Global Moran's *I* statistic and Anselin Local Moran's analysis were used, and clustering patterns were compared to sociodemographic variables using t-tests. Counties with low COVID-19 vaccinated clusters were more likely, when compared to unclustered counties, to have higher numbers of individuals in poverty and uninsured individuals, and higher values of Social Vulnerability Index (SVI) and COVID-19 Community Vulnerability Index (CCVI). While high COVID-19 vaccinated clusters, compared to neighboring counties, had lower numbers of Black population, individuals in poverty, and uninsured individuals, and lower values of SVI and CCVI, but a higher number of Hispanic population. This study emphasizes the importance of addressing systemic barriers, such as poverty and lack of health insurance, which were found to be associated with low COVID-19 vaccination coverage.

1. Introduction

COVID-19 was declared a pandemic on March 11, 2020, by the World Health Organization (WHO). (Cucinotta and Vanelli, 2020) Vaccine rollout began in December of 2020 for those ages 16 and older and quickly expanded to other age groups, with the COVID-19 vaccine being approved for adolescents aged 12–15 beginning May 2021. (Wallace et al., 2021) The COVID-19 vaccine is safe and highly effective in adults as well as in adolescents, with one study showing that two doses of the Pfizer-BioNTech vaccine were up to 93 % effective against adolescent hospitalizations. (Olson et al., 2021).

Despite the effectiveness of the vaccine, as of May 10, 2023, only 62 % of adolescents aged 12–17 in the United States (U.S.) were fully vaccinated against COVID-19 compared to 67 % of adults ages 18–24, 72 % of adults ages 25–49, 84 % of adults ages 50–64, and 94 % of adults ages 65 and up. (Centers for Disease Control and Prevention. COVID Data Tracker. Accessed September 29, 2023) Fully vaccinated is defined as completing the second dose of the mRNA COVID-19 vaccine, completing the second dose of the Pfizer-BioNTech or Moderna COVID-19 vaccine, or completing the single dose of the Jansen/Johnson & Johnson COVID-19 vaccine. (Centers for Disease Control and Prevention. COVID Data Tracker. Accessed September 29, 2023) Additionally, vaccination coverage varies geographically. (Brown et al., 2021) For instance, on the county level, data from May 2021 found that healthcare

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facilities in counties where the majority of residents were Black and were least likely to serve as COVID-19 vaccination sites. (Hernandez et al., 2022) Similarly, data from the CDC indicated that in January 2022 COVID-19 vaccination coverage in rural areas (59 %) was lower than in urban counties (75 %), disparities in vaccine coverage almost doubled since April 2021 where vaccination coverage in rural counties (39 %) was only slightly behind coverage in urban counties (46 %). (Saelee et al., 2022)

However, there is limited research on the spatial clustering of COVID-19 vaccination coverage, specifically in adolescent populations. Concentrated unvaccinated individuals in communities could allow the virus to spread, thus resulting in increased COVID-19 cases and fueling its variants. (Alvarez-Zuzek et al., 2022) Therefore, it is critical to understand what factors may be linked to community level vaccination rates to decrease such disparities. The purpose of this study was to identify geospatial clustering of high and low vaccine rates among adolescents across U.S. counties and to compare these clustering patterns by sociodemographic characteristics.

2. Methods

2.1. Data

Data on the COVID-19 vaccine status and sociodemographic characteristics of adolescents aged 12–17 up to April 14, 2022, were downloaded from the COVID-19 Community Profile Report, (U.S. Department of Health Human Services. COVID-19 Community Profile Report. Accessed December 22, 2022) a publicly available and deidentified dataset. A total of 3,108 U.S counties was included in the analyses excluding Alaska, Hawaii, and U.S. territories as contiguous mapping was required for spatial analysis. By April 14, 2022, the total number of fully vaccinated adolescents aged 12–17 across contiguous U.S. counties was 14,042,806. The present study used publicly open deidentified datasets, and was thus exempt from ethnical compliance (we obtained our IRB exemption [IRB001974] from the National Institutes of Health).

2.2. GIS process

U.S. county cartographic boundary shapefiles were downloaded from the U.S. Census Bureau from 2018. This file was uploaded into ArcGIS 10.5. and the COVID-19 vaccination proportions were mapped using choropleth maps across the contingent U.S. (Andrews et al., 2021; Shishkov et al., 2023).

2.3. Analyses

Standardized crude COVID-19 vaccine rates were calculated by dividing the number of fully vaccinated adolescents by the total adolescent population aged 10–19 years of the county and multiplying by 100,000 people. (Centers for Disease Control and Prevention. CDC WONDER. Accessed September 15, 2023) The purpose of this step was to standardize the number of COVID-19 cases across the U.S. The subsequent analyses were performed in two-fold processes. The first was using a Global Moran's I statistic (ranging from -1 to $+1$) to determine if COVID-19 vaccination rate proportions were spatially autocorrelated at the county level. (Andrews et al., 2021; Shishkov et al., 2023) A positive Moran's I statistic indicates clustering of COVID-19 vaccination proportions within a geographic area (counties) while a negative Moran's I statistic indicates that the vaccination proportion was dispersed, not clustered, across a particular geographic area (i.e., a county). The second step was using Anselin Local Moran's analysis to determine counties with high or low COVID-19 vaccination proportions statistically different from counties surrounding them. (Anselin, 1995) The geospatial distribution of vaccination clusters was classified as: hot spots (counties with high vaccination status), cold spots (counties with low vaccination status), outliers (for example: counties with high vaccination rates surrounded by counties with low vaccination rates), and unclustered counties (counties that were neither a hot spot, cold spot, or an outlier). The results allow for comparison against sociodemographic characteristics (e.g., poverty rates [standardized by 100,000 people], Social Vulnerability Index [SVI], and COVID-19 Community Vulnerability Index [CCVI]) at the county level. Including SVI and CCVI in the analysis allows for a more complete overview of the impact of socially vulnerable communities and vaccine uptake. SVI uses US census data to rank 16 social factors (including poverty, crowded housing, etc.) to determine the social vulnerability of each county in the United States. CCVI combines data from the SVI with COVID-19 factors such as healthcare system strength to determine communities that might be at a greater risk of COVID-19 cases and deaths. Sociodemographic county-level data was obtained from the CDC COVID-19 Community Profile Report. (U.S. Department of Health Human Services. COVID-19 Community Profile Report. Accessed December 22, 2022) T-tests were performed to test for statistical differences in sociodemographic characteristics of high or low clustered counties compared to unclustered counties.

3. Results

The overall administration of COVID-19 vaccinations ranged from 0.00 to 240,036.60 per 100,000 people across U.S. counties. The highest COVID-19 vaccination rates occurred on the west coast (e.g., California) and New England states (Connecticut, Maine, and Massachusetts) while the lowest rates occur in the Midwest (Missouri, and Nebraska) and parts of the South (Alabama, Louisiana, and Tennessee) (Fig. 1, Panel A). The Moran's I value was 0.40 for the contiguous U.S counties indicating that spatial clustering occurred across U.S counties. Subsequently, the z-score was 69.86 indicating that there is a less than 1 % chance that this clustering pattern occurred as the result of random chance.

The Anselin Local Moran's analysis, depicted in Fig. 1, Panel B, shows high COVID-19 vaccination clusters aggregating among large metropolitan counties, specifically on the east coast (e.g., Connecticut, Massachusetts, New York) and west coast (California), and low COVID-19 vaccination clusters agglomerating more in rural counties located in the Midwest (Missouri, parts of Indiana and Ohio) and the South (Alabama, Georgia, and Tennessee).

Statistically significant differences were found in the geospatial distribution of high and low vaccination clusters when compared by sociodemographic characteristics (Table 1). High COVID-19 vaccinated clusters were more likely than unclustered counties to have lower numbers of Black population (5,123.9/100,000 people), individuals in poverty (19,173.9/100,000 people), uninsured individuals (7,310.1/100,000 people), and lower values of SVI (0.41) and CCVI (0.43), but a higher number of Hispanic population (18,123.6/100,000 people). Low COVID-19 vaccinated clusters were more likely than unclustered counties to have higher numbers of individuals in poverty (25,727.0/100,000 people), and uninsured individuals (11,109.9/100,000 people), and higher values of SVI (0.57), and CCVI (0.57), but a lower number of Black population (7,885.8/100,000 people). Counties with high outlier clusters, counties with high vaccination rates surrounded by counties with low vaccination rates, were more likely than unclustered counties to have higher numbers of Black population, Hispanic population, uninsured individuals, and a higher value of CCVI. Low outlier clusters, counties with low vaccination rates surrounded by counties with high vaccination rates, were more likely than unclustered counties to have lower numbers of Black population, individuals in poverty, and lower values of SVI, and CCVI.

4. Discussion

Our results indicated that there were some significant sociodemographic factors that may contribute to the disparities in geographic clustering of vaccination status. This is in line with new literature

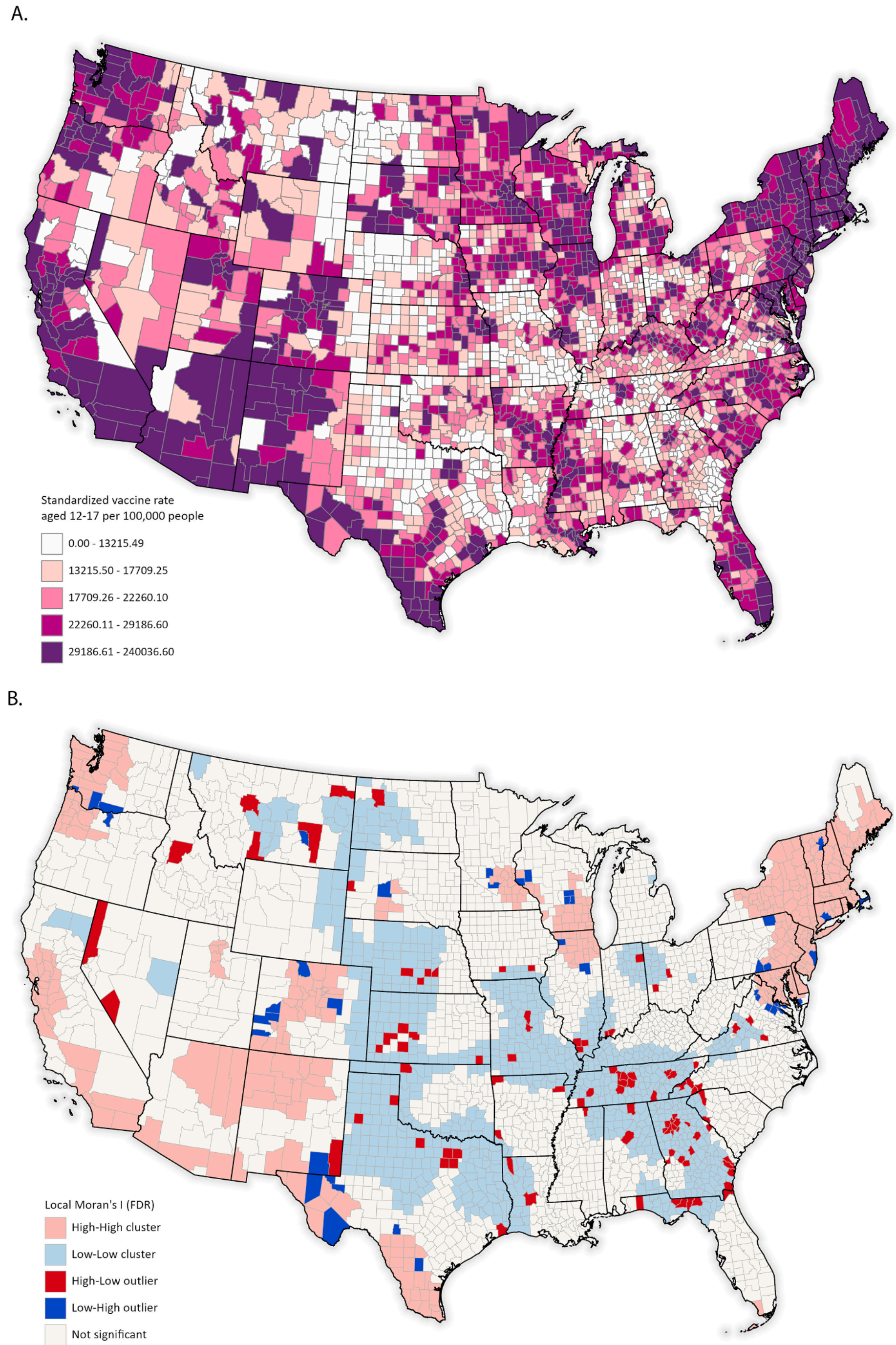

Fig. 1. (Panel A) United States Crude COVID-19 Vaccine Proportion Prevalence and (Panel B) Geospatial Distribution of Vaccine Clusters amongst Adolescents ages 12–17 Note: The results are based on Anselin Local Moran's I values. For Connecticut, vaccine rates among adolescents aged 12–17 years and the total adolescent population data did not match due to change in county FIPS code. Adolescent population data from 2021 were only used for Connecticut. Adolescent population data from 2022 were used for all other states in the analysis. FDR: False Discovery Rate could potentially decrease the false positives for critical p-value and its related confidence interval.

depicting the inequitable distribution of the COVID-19 response on the county level which point to social, economic, and demographic variables being associated with variations in vaccination rates. (Mollalo and Tatar, 2021) As supported by the literature, those who live in poverty, are uninsured, or have a high CCVI score were less likely to be fully vaccinated. (Brown et al., 2021; de Oliveira et al., 2021; Morales et al., 2022) These results highlight the disproportional burden that COVID-19 has placed on socially vulnerable populations not only in disease prevalence (Andrews et al., 2021) and availability of therapeutic drugs (Shishkov et al., 2023) but in vaccination status. For instance, a recent study indicated that non-Hispanic Asian adolescents had the highest vaccination coverage followed by Hispanic adolescents, while non-Hispanic Black and White adolescents aged 12–17 years had similar vaccine coverage. (Valier et al., 2023) Somewhat consistent with the finding of low vaccine clusters with high SVI value in the present study, those aged 5–17 years living in high SVI value had lower vaccine coverage among non-Hispanic Black and White children. (Valier et al., 2023) Furthermore, a recent study indicated that non-Hispanic blacks compared to non-Hispanic White respondents had a higher percentage of unvaccinated children; however, they reported they planned on

Table 1
Cluster Characteristics for Adolescents Aged 12–17 Years.

	Unclustered (n = 1,658)	High COVID-19 Vaccination clusters[a] (n = 408)	Low COVID-19 Vaccination clusters[b] (n = 900)	High COVID-19 Vaccination clusters Outlier[c] (n = 98)	Low COVID-19 Vaccination clusters Outlier[d] (n = 44)
Race/Ethnicity (S.D.)[g]					
Number of Black people/ 100,000	10,121.9 (16,485.1)	5,123.9 (7,820.3)***	7,885.8 (11,545.5)***	16,627.6 (18,264.2)***	5,522.6 (10,018.1)**
Number of Hispanic people/100,000	8,068.9 (11,704.7)	18,123.6 (22,382.8)***	8,304.6 (11,022.5)	11,188.1 (13,136.2)*	12,960.5 (18,231.6)
Community Characteristics (S.D.)[g]					
Number of individual in poverty/100,000	23,749.6 (8,060.7)	19,173.9 (8,705.8)***	25,727.0 (6,975.3)***	22,259.3 (6,526.4)*	19,476.5 (7,523.3)***
Number of uninsured individuals/100,000	8,594.7 (4499.8)	7,310.1 (5,401.9)***	11,109.9 (4,821.8)***	10,572.4 (4,404.5)***	8,649.3 (5,429.2)
SVI[e]	0.49 (0.29)	0.41 (0.27)***	0.57 (0.28)***	0.53 (0.26)	0.40 (0.26)*
CCVI[f]	0.48 (0.29)	0.43 (0.26)**	0.57 (0.29)***	0.58 (0.25)***	0.32 (0.23)***

Note: T-tests were used to compare values for each "Unclustered Counties" to each remaining group.
Boldface P-values indicate statistical significance: *** <0.001; ** <0.01*<0.05; S.D. = Standard Deviation
[a] High COVID-19 vaccination clusters: Counties with high vaccination status.
[b] Low COVID-19 vaccination clusters: Counties with low vaccination status.
[c] High COVID-19 vaccination clusters outlier: counties with high vaccination rates that are surrounded by counties with low vaccination rates.
[d] Low COVID-19 vaccination clusters outlier: counties with low vaccination rates that are surrounded by counties with high vaccination rates.
[e] SVI: 2020 Social Vulnerability Index: A list of 16 social factors grouped into four themes used to determine the relative social vulnerability of each county.
[f] CCVI: COVID-19 Community Vulnerability Index: An index used to determine communities more vulnerable to COVID-19 using SVI and CDC data.
[g] Race/Ethnicity and Community Characteristics: Data were measured at the county level and included all ages.

getting their children vaccinated. This may point to potential systemic barriers (e.g., lack of transportation and physical access) that were preventing vaccination. (Lendon et al., 2021) Similarly, research has shown that the lower rates of COVID vaccination amongst minorities and rural populations was initially blamed on vaccine hesitancy; however, other systemic barriers, such as access to vaccinations sites, should also be considered. (Hernandez et al., 2022) Finally, in addition to systemic barriers, other factors may also play a role in the geographic variation in vaccine uptake including parental education, age, gender, and medical mistrust, (Andrews et al., 2020; Liu et al., 2022) which could be incorporated into the regression modeling for the future research.

4.1. Limitations

This study comes with limitations. One limitation is that county-level measures (as compared to census tracts or block level measures) may propose a modifiable areal unit problem, which could lead to biased results. (Andrews et al., 2020) Another limitation is that sociodemographic data, reported on the county level, is representative of the entire county population, not just adolescents which may skew our results as we are only studying adolescents between the ages of 12 and 17. Additionally, the county characteristics reflect the population at a county level, not the characteristics of those who received the vaccination. This analysis assumes that individuals receive the vaccine in the state that they reside. This might not be the case, and especially so for counties that border other states. Future work should explore whether individuals receive vaccines in the state that they reside in and whether vaccination rates differ for counties that border other states. Furthermore, census data are periodically updated. Thus, these analyses should be performed with the most updated data. Finally, our analysis did not account for confounding factors such as local public health interventions regarding vaccination in different communities.

5. Conclusion

Our findings suggest that there are some sociodemographic variables that may be associated with higher and lower county-level COVID-19 vaccination proportions. These results may be useful for public health officials and policymakers in decreasing vaccine inequity due to racial and/or economic barriers across the U.S, thus developing strategies for efficient resource allocation to counties with lower adolescent vaccination rates. Overall, these results can be used to prioritize limited resources to communities who are subject to low vaccine proportion incidence to promote vaccine confidence and uptake in socially vulnerable populations across U.S. counties. Finally, by identifying spatial clusters, public health officials will be able to effectively monitor where COVID-19 vaccinations are lacking and where interventions are needed the most to increase vaccination rates, thus mitigating spread.

CRediT authorship contribution statement

Sophie R. Alphonso: Conceptualization, Writing – original draft. **Marcus R. Andrews:** Formal analysis, Methodology, Writing – review & editing. **Seann D. Regan:** Formal analysis, Methodology. **Alyssa Shishkov:** Writing – review & editing. **Jonathan H. Cantor:** Conceptualization, Writing – review & editing. **Tiffany M. Powell-Wiley:** Writing – review & editing. **Kosuke Tamura:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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