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Temporal trends in within-city inequities in COVID-19 incidence rate by area-level deprivation in Madrid, Spain

Pedro Gullón [a,b,*,1], Daniel Cuesta-Lozano [c,1], Carmen Cuevas-Castillo [a], Mario Fontán-Vela [a,d], Manuel Franco [a,e]

[a] *Universidad de Alcalá, Facultad de Medicina y Ciencias de La Salud, Departamento de Cirugía, Ciencias Médicas y Sociales, Grupo de Investigación en Epidemiología y Salud Pública, Alcalá de Henares, Madrid, Spain*
[b] *Centre for Urban Research, RMIT University, Melbourne, Australia*
[c] *Universidad de Alcalá, Facultad de Medicina y Ciencias de La Salud, Departamento de Enfermería y Fisioterapia, Alcalá de Henares, Madrid, Spain*
[d] *Instituto de Lengua, Literatura y Antropología, Consejo Superior de Investigaciones Científicas, Madrid, Spain*
[e] *Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Md, 21205-2217, USA*

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ABSTRACT

Patterns of exposure and policies aiming at reducing physical contact might have changed the social distribution of COVID-19 incidence over the course of the pandemic. Thus, we studied the temporal trends in the association between area-level deprivation and COVID-19 incidence rate by Basic Health Zone (minimum administration division for health service provision) in Madrid, Spain, from March 2020 to September 2021. We found an overall association between deprivation and COVID-19 incidence. This association varied over time; areas with higher deprivation showed higher COVID-19 incidence rates from July to November 2020 and August–September 2021, while, by contrast, higher deprivation areas showed lower COVID-19 incidence rates in December 2020 and July 2021.

1. Background

In December 2019, Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was identified as the cause of COVID-19(Zhu et al., 2020). 266,366,269 cases and 5,260,338 deaths have been notified to the World Health Organization worldwide by December 6th, 2021 (World Health Organization, 2020). However, despite some initial declarations that "we are all in this together", mounting evidence shows that the COVID-19 pandemic has hit harder in vulnerable communities either in incidence (Marí-Dell'olmo et al., 2021; Whittle and Diaz-Artiles, 2020), hospitalizations (Jannot et al., 2021) and mortality (Bilal et al., 2021b), as it has happened historically with other pandemics and other diseases throughout history (Bambra et al., 2020). Specifically, studies using measures of area-level (e.g. neighborhood) deprivation have shown that high-deprivation areas have had greater COVID-19 incidence and mortality (Chaudhuri et al., 2021; K C et al., 2020; Vandentorren et al., 2022).

Spain has been one of the European countries most severely affected by the ongoing COVID-19 pandemic. As of December 6th, 2021, Spain has confirmed 5,202,958 cases and 88,159 deaths (World Health Organization, 2020). Within Spain, the region of Madrid has been especially affected according to confirmed cases, deaths, and seroprevalence studies (Pollán et al., 2020). Madrid lost between 2.56 and 3.67 of annual life expectancy in 2020 as compared with 2019, being the region with the steepest decline after the first epidemic wave for both men and women compared to the rest of the country (Díaz-Olalla et al., 2021; Trias-Llimos et al., 2020). After the first wave, Madrid has adopted less restrictive measures against COVID-19 compared with other regions (Candel et al., 2021) as regional authorities were responsible for most control measures (Monge et al., 2021); in fact, in Madrid there have not been any stay-at-home orders or closure of bars and restaurants since the end of the first wave.

There is evidence of the unequal impact of the COVID-19 pandemic in Spain (Aguilar-Palacio et al., 2021; Baena-Díez et al., 2020; Díaz-Olalla et al., 2021; Marí-Dell'olmo et al., 2021; Trias-Llimos et al., 2020). However, there is less information about how these inequities have changed during the pandemic. In Barcelona, social inequities in COVID-19 incidence were wider during the second wave of the

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[*] Corresponding author. Public Health and Epidemiology Research Group, School of Medicine, University of Alcalá, Alcalá de Henares, Madrid, 28871, Spain.
E-mail address: pedro.gullon@uah.es (P. Gullón).

[1] Both authors contributed equally to this work.

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pandemic (Marí-Dell'olmo et al., 2021). Mobility inequities also increased in Madrid after the first wave (Glodeanu et al., 2021), suggesting a higher exposure to COVID-19 of more deprived areas after the easing of lockdowns when regional governments were responsible for COVID-19 public health measures (Han et al., 2020; Monge et al., 2021). An analysis of how COVID-19 inequities change over time is warranted to understand the effect of different policies on mitigating COVID-19 as well as promoting equity through these policies (Malmusi et al., 2022; Morrissey et al., 2021). Thus, in this manuscript, we aim to study the temporal trends of inequities by area-level deprivation in COVID-19 incidence in the region of Madrid, Spain.

2. Methods

2.1. Setting

We used data on the confirmed cases by Basic Health Zone (BHZ) of residence in the Madrid Autonomous Region through September 28th' 2021. Madrid region has a total population of 6.7 million inhabitants and is divided into 286 BHZ, each BHZ having an average population of 22,216 individuals. The BHZ is the most basic geographic delimitation stablished by the Health Care Administration. These are delimited considering the distance to health services, population dispersion, epidemiologic characteristics of the population, and the availability of health services in the area. Usually, the population living in each BHZ ranges between 5000 and 25,000 inhabitants (Cebrecos et al., 2019) This research did not involve individual data on human subjects and it was conducted under the Declaration of Helsinki principles.

2.2. Outcome

Our main outcome variable was the incidence rate of COVID-19 confirmed cases per 100,000 persons. COVID-19 is a mandatory reporting disease, and cases diagnosed both in public and private medicine were reported to the regional surveillance system. Rapid antigen tests (RAT) became publicly available in pharmacies in the summer of 2021. Individuals diagnosed using a RAT should be confirmed (and thus, reported) with another diagnostic test in the regional health system to get the paid sick leave and be isolated. We obtained data on confirmed cases from the Madrid Region Open Data (Comunidad de Madrid, 2021), which provides BHZ aggregated weekly registered confirmed COVID-19 cases in the COVID-19 epidemiological mandatory reporting system. Cases were assigned to a BHZ according to the residence of the case. To calculate incidence we divided confirmed cases by the 2020 BHZ population obtained from *Padrón* (a continuous and universal census collected for administrative purposes)(Instituto Nacional de Estadística, 2020). We calculated the cumulative incidence rate from the first confirmed COVID-19 cases (March 2020) until September 28th, 2021. We also calculated the monthly COVID-19 incidence rate.

2.3. Predictor

Our predictor variable was a socioeconomic deprivation index developed by the Spanish Epidemiology Society (Sociedad Española de Epidemiología, SEE) using data from the 2011 Spanish census (Cebrecos et al., 2018; Duque et al., 2021). Previous studies have shown that area-level deprivation in Madrid is associated with a higher mortality risk. (Borrell et al., 2010; Rodríguez-Fonseca et al., 2013). This index includes six census indicators selected with principal component analysis. The indicators include variables on occupation (manual workers and occasional salaried workers), unemployment, education (incomplete compulsory education, both in the general population and in the population aged 16–29), and lack of internet access. This deprivation index was constructed by extracting the first component of the principal components analysis, standardized to a mean of 0 and a standard deviation of 1. Specific details of the deprivation index used are described elsewhere (Duque et al., 2021). Since this index was available at the census section level (the smallest statistical area in Spain), we aggregated the index to the BHZ by averaging the value of each census section in each BHZ, weighted by the population of the census section in 2020 by *Padron*.

2.4. Statistical analyses

We followed two steps in the statistical analyses. First, we examined the association between the deprivation index and COVID-19 incidence in the whole period. To do so, we considered using a Poisson model; however, after finding evidence of overdispersion (Cameron and Trivedi, 1990), we decided to use a negative binomial regression model (Hilbe, 2017). We also checked for spatial auto-correlation of the COVID-19 incidence using a global Moran I statistic (Bivand and Wong, 2018), finding evidence of spatial auto-correlation (Moran $I = 0.31$, p-value<0.001). To account for the spatial autocorrelation, we used a Besag–York–Mollie conditional autoregressive model (Blangiardo and Cameletti, 2015), including a structured and unstructured BHZ random effect, a similar approach as the one followed by Bilal et al. (2021b). In this model, deprivation was introduced as categorical divided in quintiles, where the reference value was the quintile with the lowest deprivation values (or, in other words, the highest socioeconomic quantile), so the results should be interpreted as the rate ratio of the aggregated COVID-19 incidence (from March 2020 to September 2021) between a given deprivation quintile with the lowest deprivation quintile. To account for the role of age in determining testing practices and influencing the probability of transmission, we adjusted for the percentage of people aged 65 years or older in the BHZ. During the first wave, testing was only available for hospitalized patients, and, as hospitalization increases with age (Romero Starke et al., 2021), this could mean that, during the first wave (but not after that), the probability of getting tested was higher in older people. Second, to describe the time trends of inequities by deprivation in COVID-19 confirmed cases, we fitted the same type of models by month. In these models, the deprivation index was scaled from 0 to 1 and treated as continuous so it can be interpreted as the monthly Relative Index of Inequality (RII)(Sergeant, 2005). We also estimated the monthly Slope Index of Inequality (Sergeant, 2005) in COVID-19 incidence with linear Conditional Autoregressive Models (Bivand et al., 2013) as sensitivity analysis.

We conducted all analyses and plots with R V4.1.3. Overdispersion was checked with the AER package (Kleiber and Zeileis, 2020) and the spatial analyses were conducted using the spdep (Bivand, 2022) and R-INLA (R-INLA Development Team, 2022) packages.

2.5. Patient and public involvement

Data was collected through secondary datasets and any members of the public were not included directly in the design of the study.

3. Results

From the beginning of the pandemic (March 2020) up to the end of the study period (September 28th, 2021) there were 864,471 georeferenced confirmed COVID-19 cases in the region of Madrid (Supplementary file 1). Deprivation has a north-to-south pattern, where the highest deprivation BHZ can be found in the south of the Madrid Region (See Fig. 1). COVID-19 rates followed a center-to-periphery pattern, where Madrid's region center (corresponding to Madrid city) had a higher COVID-19 incidence rate; within this center, southern areas showed a greater incidence of accumulated COVID-19 cases until September 28, 2021 (See Fig. 1).

We found a dose-response association between the deprivation index and COVID-19 incidence using aggregated incidence from March 2020 to September 2021 (Table 1). BHZ in the Q3, Q4 and Q5 of the

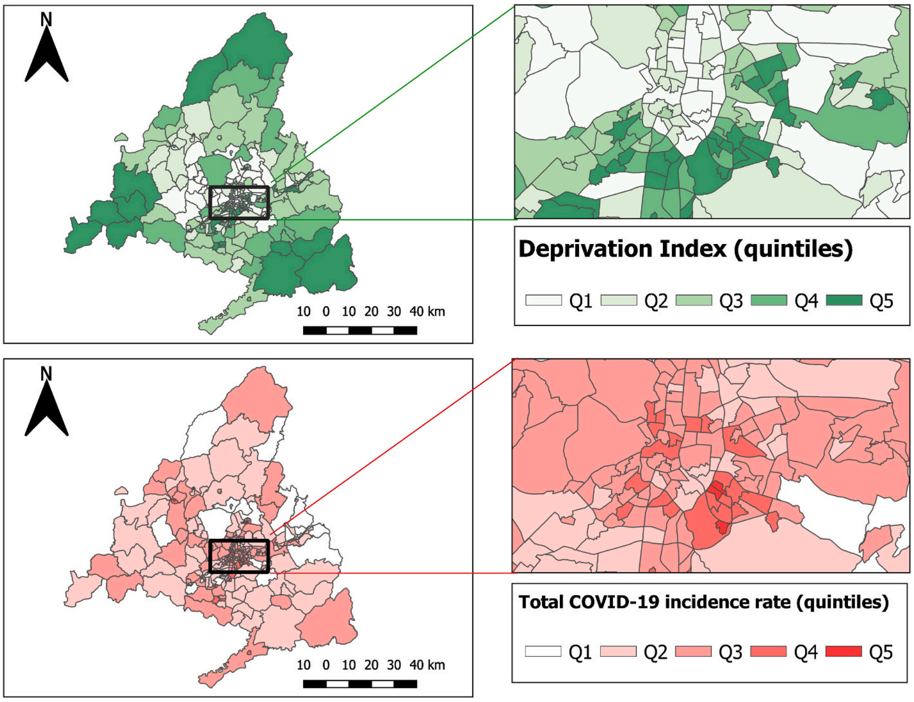

Fig. 1. Spatial distribution of COVID-19 rate (A) and deprivation index (B) by Basic Health zones. Inset show the city center of the city of Madrid.

Table 1
Rate Ratios for COVID-19 incidence by deprivation level.

Deprivation index	Unadjusted Rate Ratio	95% CI	Age-adjusted Rate Ratio	95% CI
Q1 (lowest deprivation)	1 (ref)		1 (ref)	
Q2	1.03	(0.99–1.08)	1.03	(0.99–1.04)
Q3	1.04	(1.00–1.09)	1.05	(1.00–1.10)
Q4	1.13	(1.08–1.18)	1.13	(1.08–1.18)
Q5 (highest deprivation)	1.17	(1.12–1.23)	1.17	(1.11–1.24)

Values shown are Rate Ratio and 95% confidence intervals (95% CI) for negative binomial conditional autoregressive models by deprivation level quintiles of deprivation.

deprivation index had a corresponding 5% (Rate Ratio 95% CI 1.00–1.10), 13% (Rate Ratio 95% CI 1.08–1.18) and 17% (Rate Ratio 95% CI 1.11–1.24) increase in aggregated COVID-19 incidence rate from March 2020 to September 2021.

The association between deprivation and COVID-19 incidence rate changed over time as seen in Fig. 2 by the temporal variability of the Relative Index of Inequality (RII). In March and April 2020 the RII was 1.07 (CI 95% 0.86–1.36) and 1.40 (CI 95% 1.09–1.79), respectively. Then, from May to July 2020 the RII decreased, and then in August 2020 peaked (RII = 4.73, 95% CI 3.68–6.08). From August to December 2020 the RII decreased and even reversed in December (RII = 0.74, 95% CI 0.62–0.89) meaning that there is an inverse inequality pattern (COVID-

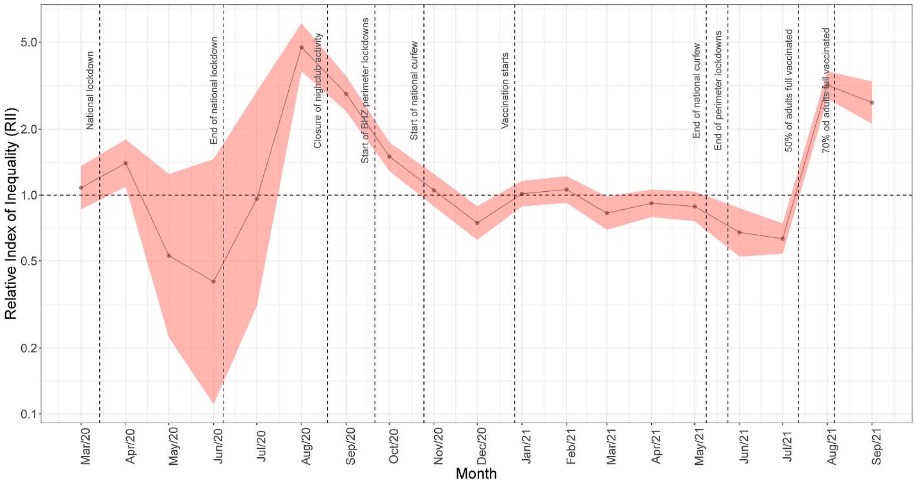

Fig. 2. Temporal trends in the Relative Index of Inequality by deprivation of COVID-19 incidence rate.s

19 incidence rate was higher in the least deprived areas). From January to May 2021 the RII was close to the null value and not significant. In June and July there was an inverse inequality (RII below 1 and statistically significant), and then it increased again in August and September 2021, with a RII of 3.18 (95% CI 2.66–3.67) and 2.64 (95% CI 2.11–3.30).

As a sensitivity analysis, we estimated the Slope Index of Inequality (SII) and we found a similar pattern. Absolute inequities in COVID-19 incidence rate measured with SIII were wider from July to September 2020 and August–September 2021, and narrower in December 2020 and July 2021 (Supplementary file 2).

4. Discussion

This study found that areas with a higher deprivation index showed a higher COVID-19 cumulated incidence rate up to September 28th, 2021 in the Autonomous Region of Madrid. We also found that these inequities in COVID-19 incidence rates varied over time; highest inequities by area-level deprivation were found in the period July–November 2020 and August–September 2021, while we found inverse inequities in December 2020 and July 2021.

Previous studies showed an association between area-level deprivation or socioeconomic status and COVID-19 incidence rate (Baena-Díez et al., 2020; Bilal et al., 2021b; K C et al., 2020; Marí-Dell'olmo et al., 2021; Vandentorren et al., 2022; Whittle and Diaz-Artiles, 2020), consistent with our results. Several potential mechanisms may explain the association between area-level deprivation and COVID-19. These mechanisms include both differential exposure to COVID-19 and differential susceptibility to infection. Residents of higher deprivation areas might have greater exposure to COVID-19 by means of working conditions or the impossibility to work from home. In fact, according to the results of a survey in Madrid, more than 70% of individuals with a monthly income higher than 4000 € had the possibility of working from home during the COVID-19 pandemic, compared with a 13% and a 0% for those earning between 500 and 1000 € and less than 500 €, respectively (Ayuntamiento de Madrid, 2020). Also, during the lockdown period of March–May 2020, a study using cell phone data showed inequities in mobility in Madrid by deprivation level, suggesting that residents living in more deprived areas had to leave their homes to work more than residents from low deprivation areas (Glodeanu et al., 2021). Likewise, residents of higher deprivation areas might have greater exposure to COVID-19 due to housing conditions (e.g. overcrowding) (Ahmad et al., 2020). Some neighborhood characteristics, such as population density, could also explain a higher exposure to COVID-19 in high-deprivation areas (López-Gay et al., 2021). Regarding differential susceptibility, previous research has shown that stress linked to disadvantaged populations might be associated with the likelihood of developing respiratory infections after exposure (Cohen et al., 1991); however, it is unclear that differential susceptibility can play a significant role in explaining differences in COVID-19 incidence rate.

Few studies have analyzed how these inequities have changed during the pandemic (Malmusi et al., 2022; Marí-Dell'olmo et al., 2021; Morrissey et al., 2021; Vandentorren et al., 2022). These studies analyzed how social inequities changed mostly during 2020 and early 2021; however, our work encompassed a period (September 2021) when most of the non-pharmacological interventions implemented during the pandemic were lifted. Also, the experience of Madrid is quite different from other areas, as Madrid adopted less restrictive measures against COVID-19 compared with other regions (Candel et al., 2021). We found that inequities increased after the first wave of the pandemic, then decreased and reversed during Spring 2021, and then increased again in August and September 2021. A study in Barcelona also found that inequities in COVID-19 incidence rate were wider during the second wave (Marí-Dell'olmo et al., 2021). There are two potential explanations for why inequities were wider during the second wave. First, the re-opening of the economy after the first wave lockdown might have increased the number of workers in high exposures jobs (such as retail and hospitality industries (Bilal et al., 2021a; Morrissey et al., 2021)) that were closed during lockdown; for instance, inequities in mobility by deprivation increased in Madrid during the second wave (Glodeanu et al., 2021). In fact, it has been previously theorized in public health that population-level interventions (Rose, 1985) can reduce health inequities (Benach et al., 2013; Frohlich, 2014; Frohlich and Potvin, 2008); this can mean that COVID-19 population-level measures (e.g. lockdowns or other restrictions) might reduce COVID-19 inequities (Torjesen, 2022). Second, the scarce availability of testing during the first wave might have biased inequities in COVID-19 incidence rate (Briggs and Fraser, 2020). This bias might affect by moving inequities towards the null because: (1) testing was only available to those that required hospitalization; (2) age is the main predictor of hospitalization (Romero Starke et al., 2021); and (3) life expectancy is higher in low-deprived areas (Borrell et al., 2010).

Inequities decreased after October 2020 and even reversed (meaning that higher deprivation was associated with a lower COVID-19 incidence rate) in December 2020 and July 2021. A similar pattern was found in the UK, where inequities by area-level deprivation in COVID-19 incidence rate reversed in December 2020 (Morrissey et al., 2021). There are no clear explanations for those observed results. One potential explanation is that curfews applied in Spain might have reduced inequities by protecting workers from nightlife activities; however, this wouldn't explain why the same trend continued after the end of the curfew in Madrid (May 2021). A second potential explanation is that place-based policies applied in Madrid from October 2020 (selective perimeter lockdowns by BHZ) might have reduced incidence in high-deprivation areas; however, previous research showed that these BHZ perimeter lockdowns did not have a significant impact on COVID-19 incidence rate (David et al., 2022; Fontán-Vela et al., 2021a, 2021b). Thirdly, vaccination could have had a role in reducing COVID-19 inequities as they partially reduce transmission; however, evidence in Barcelona (that followed the Spanish national vaccination strategy as Madrid) found inequities in vaccination (Malmusi et al., 2022), which we can hypothesize would have increased COVID-19 inequities in 2021, contrary to our findings. Fourthly, adaptation to COVID-19 measures where physical distance is not possible (e.g. schools, offices) as well as the role of previous natural immunity acquired after the previous waves might have shifted the relative importance of places where outbreaks and cases are declared, moving from working-related places to outbreaks associated with leisure activities (such as indoor dining). Previous research showed that there are social inequities in leisure time (Sevilla et al., 2012), which could partially explain why COVID-19 incidence rate was higher in less deprived areas in 2021 (Malmusi et al., 2022); however, this hypothesis cannot explain why inequities increased again in August and September 2021. Lastly, the increasing availability of rapid antigen tests in pharmacies (not free) during 2021 might have changed testing behaviours, meaning that wealthy individuals were tested more frequently and had a greater probability of being detected when being asymptomatic. Future studies should analyse the potential effect of these elements to explain the temporal trends of COVID-19 inequities by deprivation in order to inform policies that mitigate the impact of social inequities in COVID-19.

We are aware that this study includes several limitations. First, an important limitation is the underestimation of cases during the first wave of the pandemic due to lack of testing and the potential impact that this has had on COVID-19 inequities. Second, we used ecologic data at the BHZ level for our analysis, and BHZ might be an imperfect proxy for neighborhoods. Third, variability in social composition within BHZ might have affected inequities analyses; however, we explored the variability of deprivation between and within BHZ using an Intraclass Correlation Coefficient (ICC) from an empty multilevel model (Merlo, 2005), and we found that 55% of the variability in deprivation is accounted for by the BHZ. Fourth, differences on testing rate by deprivation could represent a differential information bias through time; however, testing data in Madrid is not available at the BHZ level.

5. Conclusions

In Madrid, we found evidence of unequal distribution in COVID-19 incidence by area-level deprivation; areas with a higher deprivation index showed a higher COVID-19 cumulated incidence rate up to September 28th, 2021. These inequities in COVID-19 incidence rates varied over time; areas with higher deprivation areas showed higher COVID-19 incidence rates from August to November 2020 and August–September 2021, while higher deprivation areas showed lower COVID-19 incidence rates in December 2020 and July 2021. These differential trends might be explained by regional policies, differential mobility or previous immunity. Future studies should analyse the potential effect of these elements to explain the temporal trends of the association between area-level deprivation and COVID-19 incidence rate.

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Contributors

PG and DCL conceived the idea. CCC, MFV and MF did the bibliographic search. DCL prepared and cleaned the data. PG did the statistical analysis. PG and DCL prepared the first draft of the manuscript. All authors all authors completed the manuscript and approved it. PG acts as guarantor for the manuscript.

Data sharing

Outcome data (COVID-19 cases) is available through the Madrid Open Data Portal (https://datos.comunidad.madrid/catalogo/dataset/covid19_tia_zonas_basicas_salud). Exposure data (deprivation index) is available through the Sociedad Española de Epidemiología website (https://seepidemiologia.es/determinantes-sociales-de-la-salud/).

Declaration of competing interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2022.102830.

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