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Dynamics of influenza-like illness under urbanization procedure and COVID-19 pandemic in the subcenter of Beijing during 2013–2021

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Abstract

Influenza-like illness (ILI) varies in intensity year by year, generally keeping a stable pattern except for great changes of its epidemic pattern. Of the most impacting factors, urbanization has been suggested as shaping the intensity of influenza epidemics. Besides, growing evidence indicates the nonpharmaceutical interventions (NPIs) to severe acute respiratory syndrome coronavirus 2 offer great advantages in controlling infectious diseases. The present study aimed to evaluate the impact of urbanization and NPIs on the dynamic of ILI in Tongzhou, Beijing, during January 2013 to March 2021. ILI epidemiological surveillance data in Tongzhou district were obtained from Beijing Influenza Surveillance Network and separated into three periods of urbanization and four intervals of coronavirus disease 2019 pandemic. Standardized average incidence rates of ILI in each separate stages were calculated and compared by using Wilson method and time series model of seasonal ARIMA. Influenza seasonal outbreaks showed similar epidemic size and intensity before urbanization during 2013–2016. Increased ILI activity was found during the process of Tongzhou's urbanization during 2017–2019, with the rate difference of 2.48 (95% confidence interva [CI]: 2.44, 2.52) and the rate ratio of 1.75 (95% CI: 1.74, 1.76) of ILI incidence between preurbanization and urbanization periods. ILI activity abruptly decreased from the beginning of 2020 and kept at the bottom level almost in every epidemic interval. The top decrease in ILI activity by NPIs was shown in 5–14 years group in 2020–2021 influenza season, as 92.2% (95% CI: 78.3%, 95.2%). The results indicated that both urbanization and NPIs interrupted the epidemic pattern of ILI. We should pay more attention to public health when facing increasing population density, human contact, population mobility, and migration in the process of urbanization. NPIs and influenza vaccination should be implemented as necessary measures to protect people from common infectious diseases like ILI.

KEYWORDS
China, COVID-19, influenza-like illness, nonpharmaceutical interventions, urbanization

Chao Wang and Yan-Na Yang contributed equally to this study.

1 | INTRODUCTION

Outbreaks of influenza-like illness (ILI) have led to huge socio-economical and health burden, of which three to five million cases experience severe illness. Influenza virus is one of the most common pathogen that cause respiratory diseases, such as ILI, particularly in autumn and winter seasons in China.[1] About 290–450 thousand deaths are attributed to seasonal influenza worldwide.[2,3] Among the most impacted countries, three million ILI cases and over 80 000 ILI-related deaths were estimated annually, even though marvelous efforts have been made to mitigate its impacts, such as etiological detection, routine epidemiological surveillance, or vaccination extension.[4]

Increasing concerns have underscored the importance of linkages between the threats of infectious diseases and fast-spreading urbanization.[5] In particular, of the most impacting factors, urbanization has been suggested as shaping the intensity of influenza epidemics, due to the increasing population density, human contact, population mobility, migration, and so forth.[6–8] As a mushrooming subcenter of Beijing, Tongzhou district has been initialing its urbanization, with a boosting population increase from 1.25 million in 2013 to 1.65 million in 2020.[9] Since its urbanization was accelerated from 2017 and came on stream from 2019,[10] local reports have indicated intensified seasonal ILI epidemic and sporadic infections.[11] However, at the initial stage of urbanization of Tongzhou district, the dynamic pattern of ILI in this area remains uninvestigated before, during or after its urbanization procedure, as well as population difference.

One year after the official operation of Tongzhou subcenter at the beginning of 2020, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has caused ongoing huge damage to human health.[12] Before massive vaccination to SARS-CoV-2 by March 2021, the nonpharmaceutical interventions (NPIs), including social distancing, mask-wearing, shelter-in-place, travel restrictions, school closure, and so forth has been orientated to be the main measurements in preventing the pandemic.[13,14] Studies have explored the impact of COVID-19 pandemic and related NPIs on respiratory diseases like influenza, since they share similar transmission modes and symptoms.[15,16] Several studies indicated that the activity of ILI generally decreased by NPIs in the short run.[17–19] However, the impact of NPIs on ILI dynamic after the first wave was still needed to be illustrated.

In the present study, the local ILI epidemiological surveillance data were extracted from the interval during 2013–2021, with four periods as preurbanization, interim, urbanization, and pandemic era. Epidemic patterns of ILI within such four periods, as well as the impact of urbanization and NPIs on the dynamic of ILI, were analyzed and compared. The findings will contribute to our understanding of how urbanization influences the epidemiological pattern of local diseases and offer a clue for ILI NPIs' prevention at the initial of urbanization.

2 | METHODS

2.1 | Data source

ILI epidemiological surveillance data in Tongzhou district were obtained from Beijing Influenza Surveillance Network (BISN), administrated by Beijing Center for Disease Control and Prevention (CDC). All the municipal hospitals were involved into the network in which clinics of internal medicine, pediatric, fever, and emergency were set as the sentinel spots. Epidemiological surveillance data were required to be registered and reported every 24 h by sentinel hospitals and verified by local CDCs. ILI epidemiological surveillance data were recorded by age groups of 0–4, 5–14, 15–24, 25–59, and ≥60 years.[20] Demographic data including population size of each age group was collected from Beijing Statistical Yearbook from 2013 to 2020.[9] As influenza vaccine was integrated into the local immunization plan for school aged children and the elders, vaccination data among those aged 5–14 years and ≥60 years was further extracted from public database from Tongzhou CDC, Beijing, to provide insight into the influence of influenza vaccination on the dynamic change of ILI cases in this area.

2.2 | Definition of ILI cases and epidemiological periods

Individuals with either cough or sore throat with temperature ≥38.0°C were recorded as ILI cases. We extracted and summarized the ILI cases in BISN from January 2013 to March 2021 for present study.[20] In line with the administration rule of BISN, the period from the beginning of October (the 40th week) to the end of March (the 12th week) of next year was defined as a complete influenza epidemic season, and the rest time of a natural year was defined as the nonepidemic influenza season (from the 13th week to 39th week with 1 calendar year). Moreover, considering the process of urbanization in Tongzhou district, we categorized the time interval into preurbanization period (2013–2016), transition period (2017–2018), and urbanization period (2019). The years of 2020 and 2021 were not included into consideration since COVID-19 pandemic was sustained from the beginning of 2020 till now.

2.3 | Statistical analysis

Weekly incidence rates of ILI were based on the total cases and age-specified population sizes within 1 week and were illustrated within our study interval between January 2013 and March 2021. To demonstrate the impact of urbanization on the epidemic patterns of ILI, population standardized average incidence rates of ILI in the three separate urbanization stages were calculated. The average incidence rates of ILI among three urbanization periods were then compared by using rate difference and rate ratio with Wilson method, as well as

their 95% confidence interval (95% CI).[21] Then, we quantified the effect of the COVID-19 related NPIs on ILI during the pandemic from the beginning of 2020 to March 2021 by fitting a time series model of seasonal autoregressive integrated moving average (SARIMA).[22] The time series stationary, time difference, seasonal difference, and residual were analyzed for model fitting, and model comparison between different model indexes extracted by series analysis was conducted to choose the best model for the subsequent analysis, basing on the model indexes of Akaike information criterion, Schwarz's Bayesian criterion, R^2, and absolute model error. Simulated rates of ILI in the counterfactual scenario without NPIs during this interval were estimated and compared with the observed rates of ILI. The cumulative impact of NPIs on ILI was defined as the difference in the area under the curve (AUC) between the observed epidemic curve and the model-predicted curve within the four-time intervals of the second half influenza season of 2019–2020 (1st week to 12th week of 2020), nonepidemic season of 2020 (13th week to 39th week of 2020), epidemic season of 2020–2021 (40th week to 52th week of 2020 plus 1st week to 12th week of 2021), and the whole period. We used Pearson's correlation test to detect the corresponding relationship between vaccination coverage and the cumulative rates of ILI among those aged 5–14 years and ≥60 years, which were lagged for 1 year as we suppose vaccination in the current year would have an impact on the situation of ILI in next year. Data description and analysis were conducted using R 3.6.1 and SAS JMP Pro 14 and MS Office 2019. Graphpad Prism 8.0 was used for figure plotting and AUC calculation.

3 | RESULTS

3.1 | ILI activity within study interval

Totally 389 717 ILI cases have been reported over the period during January 2013 to March 2021. Before COVID-19 pandemic, ILI activity had similar pattern in each of the surveillance year, and peaked at winter–spring epidemic season (Table 1 and Figure 1). Nearly all of ILI activity among different age groups peaked at 2019. The average incidence rates of ILI generally increased from 3.9 per 100 person·years to 5.8 per 100 person·years during 2013–2019 among the whole population, and decreased to 2.2 per 100 person·years in 2020. Among 0–14 years population, the highest ILI activity was observed compared to other age groups. However, a relatively low ILI activity has been detected during urbanization transition period of 2017–2018, which was not observed in other age groups. Those aged 15–59 years showed low levels of ILI activity across the preurbanization period of 2013–2018 with all of the incidence rates below 5 per 100 person·years, which peaked at the officially urbanization year of 2019 and sharply dropped to 3.9 or 1.3 per 100 person·years in the COVID-19 pandemic year of 2020.

3.2 | Impact of urbanization on ILI activity

The prepandemic years from 2013 to 2019 were categorized into three periods (Table 2 and Figure 1). Among the total population, the rate difference of ILI incidence between preurbanization and urbanization period was 2.48 (95% CI: 2.44, 2.52) per 100 person·years, and the rate ratio was 1.75 (95% CI: 1.74, 1.76). The largest rate difference was detected as 13.83 (95% CI: 13.55, 14.12) per 100 person·years among those aged 5–14 years, followed by that among 0–4 years as 8.17 (95% CI: 7.78, 8.56) per 100 person·years. The population aged 15–24 years showed the largest rate ratio as 3.07 (95% CI: 3.00, 3.14), and those aged 60 years or above presented stable ILI activity with the rate ratio as 1.05 (95% CI: 1.02, 1.08) between preurbanization and urbanization period. For those aged 0–14 years, average ILI rates were lower in the transition period than in preurbanization period. The rate differences were −16.61 (95% CI: −16.85, −16.37) per 100 person·years for 0–4 years or −2.8 (95% CI: −2.95, −2.64) per 100 person·years for 5–14 years, and the rate ratios were 0.35 (95% CI: 0.34, 0.36) or 0.69 (95% CI: 0.67, 0.70), respectively. However, among the population aged 15 years or above, ILI activity increased in the transition period comparing

TABLE 1 Population size and cumulative rate of influenza infection between six groups during 2013–2020 (per 100 person·years).

Years	Total population		0–4 years		5–14 years		15–24 years		25–59 years		60 years or above	
	No.	CRI	No.	CRI	No.	CRI	No.	CRI	No.	CRI	No.	CRI
2013	1 249 446	3.9	51 586	49.3	65 230	10.4	203 351	1.8	769 207	1.5	160 072	1.1
2014	1 277 827	2.9	52 758	16.0	66 710	7.1	207 970	2.7	786 673	1.8	163 716	2.3
2015	1 300 383	3.3	53 668	22.9	67 848	8.5	211 659	3.1	800 389	1.7	166 820	3.1
2016	1 378 000	3.1	56 476	15.6	71 406	9.7	221 762	3.1	838 775	1.7	189 581	3.1
2017	1 379 522	2.9	64 061	8.5	80 994	7.0	217 890	3.2	824 111	1.9	192 467	3.6
2018	1 507 999	2.9	71 863	9.5	90 854	5.4	235 371	3.3	890 168	2.0	219 743	3.2
2019	1 577 999	5.8	72 842	33.8	99 581	22.8	114 131	8.3	1 015 645	2.7	275 801	2.6
2020	1 644 502	2.2	72 029	12.5	108 265	5.7	99 397	3.9	1 071 831	1.3	292 981	1.1

Abbreviations: No., number of the total population within the current group; CRI, the cumulative rate of influenza infection during the current year (per 100 person·years).
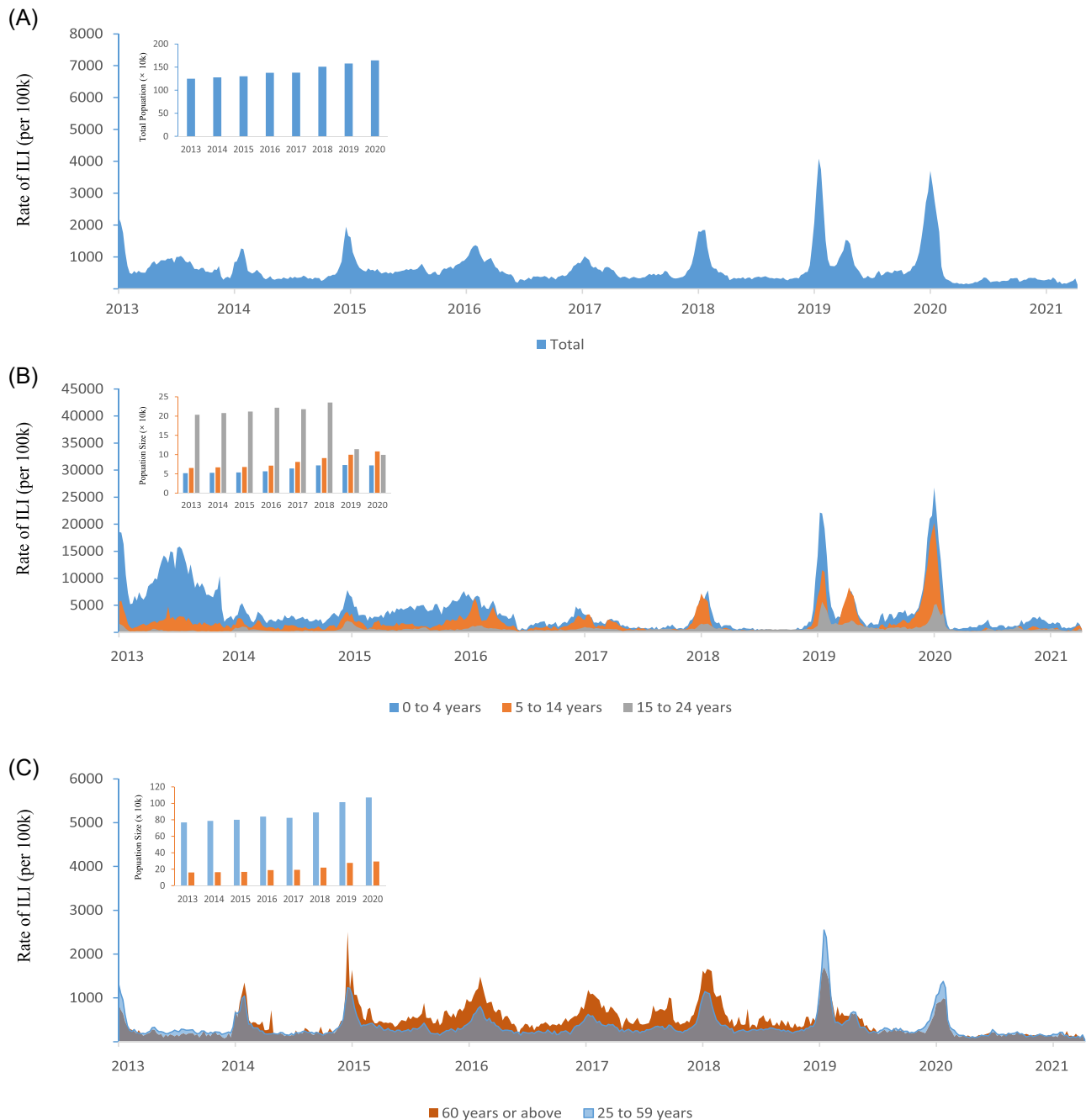
FIGURE 1 Activity of ILI among different age groups with population size during January 2013 to March 2021. (A) Activity of ILI among the total population during January 2013 to March 2021. (B) Activity of ILI among the population aged between 0 and 24 years during January 2013 to March 2021. (C) Activity of ILI among the population aged over 25 years during January 2013 to March 2021. ILI, influenza-like illness.

to the preurbanization period. The rate differences ranged from 0.25 to 0.89 per 100 person·years, and the rate ratios varied from 1.15 to 1.37.

3.3 | Effect of NPIs on the activity of ILI

Postpandemic period was analyzed from the beginning of 2020 to March 2021, including the second half of 2019–2020 influenza season, the whole noninfluenza season in 2020 and the whole influenza season

of 2020–2021. Compared to the estimated ILI activity of counterfactual scenario basing on SARIMA model when the COVID-19 pandemic did not occur and therefore strict NPIs were not used, and the observed ILI activity decreased by 76.2% (95% CI: 48.6%, 84.5%) for the whole postpandemic period, 53.4% (95% CI: 26.8%, 65.8%) for the second half of 2019–2020 season and 87.0% (95% CI: 77.1%, 90.9%) for the influenza season of 2020–2021 in total population (Table 3, Figure 2, and Supporting Information: Figures S1 and S2). For different age groups, the top two decrease in ILI activity by NPIs was

TABLE 2 Cumulative rate of ILI of different stages of urbanization in Tongzhou District from 2013 to 2019 (per 100 person·years).

Age group	Cumulative rate (per 100 person·years)	Rate difference (per 100 person·years)	Rate ratio
Total population			
Preurbanization	3.3	Reference	Reference
Transition period	2.9	−0.39 (−0.41, −0.39)	0.88 (0.87, 0.89)
Urbanization	5.8	2.48 (2.44, 2.52)	1.75 (1.74, 1.76)
Pandemic period	2.1	−1.23 (−1.25, −1.20)	0.64 (0.63, 0.65)
0–4 years old			
Preurbanization	25.6	Ref.	Ref.
Transition period	9.0	−16.61 (−16.85, −16.37)	0.35 (0.34, 0.36)
Urbanization	33.8	8.17 (7.78, 8.56)	1.32 (1.30, 1.34)
Pandemic period	11.8	−13.8 (−14.1, −13.6)	0.46 (0.44, 0.48)
5–14 years old			
Preurbanization	8.9	Reference	Reference
Transition period	6.1	−2.8 (−2.95, −2.64)	0.69 (0.67, 0.70)
Urbanization	22.8	13.83 (13.55, 14.12)	2.55 (2.51, 2.59)
Pandemic period	5.6	−3.3 (−3.5, −3.1)	0.63 (0.61, 0.65)
15–24 years old			
Preurbanization	2.7	Reference	Reference
Transition period	3.3	0.55 (0.49, 0.62)	1.21 (1.18, 1.23)
Urbanization	8.3	5.57 (5.41, 5.74)	3.07 (3.00, 3.14)
Pandemic period	3.7	1.02 (0.91, 1.13)	1.37 (1.34, 1.40)
25–59 years old			
Preurbanization	1.7	Reference	Reference
Transition period	1.9	0.25 (0.22, 0.27)	1.15 (1.13, 1.16)
Urbanization	2.7	1.03 (1.00, 1.07)	1.61 (1.59, 1.64)
Pandemic period	1.2	−0.48 (−0.50, −0.45)	0.71 (0.70, 0.72)
60 years or above			
Preurbanization	2.5	Reference	Reference
Transition period	3.3	0.89 (0.83, 0.96)	1.37 (1.34, 1.40)
Urbanization	2.6	0.12 (0.05, 0.19)	1.05 (1.02, 1.08)
Pandemic period	1.1	−1.37 (−1.42, −1.32)	0.45 (0.43, 0.46)

Note: Preurbanization stage refers to years between 2013 to the end of 2016. Transition period refers to years of 2017 and 2018. Urbanization stage targeted to 2019 since COVID-19 pandemic initialed at the beginning of 2020.

Abbreviation: ILI, influenza-like illness.

shown in 0–4 and 5–14 years groups in 2020–2021 influenza season, as 90.7% (95% CI: 83.4%, 93.5%) and 92.2% (95% CI: 78.3%, 95.2%). Significant ILI activity decrease was also detected during 2020–2021 season among those aged over 15 years. Except for younger age groups, older population that aged over 25 years showed no significant decrease in ILI activity during the second half influenza season in 2019–2020. Significant ILI decrease was shown in the group aged 0–4 years in noninfluenza season of 2020, as 88.0% (95% CI: 51.1%, 93.2%), which was not observed in other age groups.

3.4 | Impact of influenza vaccination on the activity of ILI

The vaccination related rates of ILI were lagged for 1 year. During prepandemic period of 2014–2019, influenza vaccination coverage ranged from 65.9% to 45.2%, or 22.8% to 16.4% among the population aged 5–14 and ≥60 years, respectively. The trends of vaccination coverage and ILI activity were obviously opposite during the prepandemic period from 2014 to 2019 (Figure 3). We found

TABLE 3 Impact of COVID-19 and nonpharmaceutical interventions on the rates of ILI from 2020 to the end of influenza season in 2021.

Time period	Total population (% decreased, 95% CI)	0-4 years old (% decreased, 95% CI)	5-14 years old (% decreased, 95% CI)	15-24 years old (% decreased, 95% CI)	25-59 years old (% decreased, 95% CI)	>60 years old (% decreased, 95% CI)
Beginning of 2020 to the end of influenza season of 2021	76.2 (48.6, 84.5)	85.7 (70.3, 90.6)	86.6 (51.7, 92.2)	71.9 (35.9, 82.0)	64.8 (−2.2, 78.9)	62.8 (−62.7, 80.0)
The second half of 2019–2020 influenza season	53.4 (26.8, 65.8)	70.3 (53.9, 78.1)	74.3 (61.4, 80.8)	54.3 (31.6, 65.6)	31.2 (−28.8, 53.0)	44.4 (−14.2, 63.5)
Noninfluenza Season in 2020	75.7 (−41.3, 86.9)	88.0 (51.1, 93.2)	88.9 (−76.3, 95.3)	70.9 (−51.1, 83.9)	62.5 (−99.7, 81.2)	52.4 (−174.3, 79.8)
Influenza season of 2020–2021	87.0 (77.1, 90.9)	90.7 (83.4, 93.5)	92.2 (78.3, 95.2)	82.1 (62.6, 88.2)	81.9 (59.5, 88.4)	78.4 (14.1, 87.6)

Abbreviation: ILI, influenza-like illness.

negative correlation between vaccination coverage and ILI rates as the correlation coefficient of −0.46 and −0.39 among these two age groups, no statistical significance was found due to the limited sample size (Supporting Information: Table S1).

4 | DISCUSSION

Generally, the increased ILI activity was found during the process of Tongzhou's urbanization during 2017–2019, especially among children and adolescents. However, the COVID-19 pandemic averted the epidemic trend of ILI among population since 2020. In terms of influencing effects on ILI activity, we found that the implementation of NPIs during COVID-19 pandemic generally overweighted the influence of urbanization, dropping the epidemic activity of ILI below its level before urbanization. On the other side, urbanization and NPIs showed similar pattern with their influence on ILI activity in lower age groups.

ILI seasonal outbreaks showed similar epidemic size and intensity before urbanization during 2013–2016, despite the ongoing changes of local climate or influenza virus mutation. We suppose this might due to the stable resident population and limited human mobility that restricted the internal and external transmission routes of the virus.[23] During the transition period of urbanization from 2017 to 2018, ILI intensity showed a generally transient decrease. It was mainly attributed to the declined rate of ILI among children and adolescents in terms of their less advanceable clinic access among this population.[5,24]

However, with the increasing immigrants and population size as urbanization started in 2019, the activity of ILI in the subcenter showed a sharp increase in 2019. Changes in urbanization has led to specific changes in the intensity of influenza epidemics.[25–27] Under the stronger interconnection among intensive population with different living conditions, dynamic of ILI was confirmed to be aggravated, particularly among those susceptible populations like children and adolescents under 25 years.[15,28,29] ILI activity among people aged over 25 years remained at a low level, which is in line with previous studies.[15,29,30] It suggests that influenza prevention and control in newly developed urbanization areas should be focused at places like schools and kindergartens in facing the assault of increasing population diversity, mobility, and human contact.[11,15,28,29] However, we found the lowest ILI activity among the elder population within our study interval comparing to other age groups. This might be due to the influenza vaccination strategies conducted in Beijing that vaccination to influenza was largely encouraged and free of charge for each older adult aged over 60 years and school-aged children for more than one decade.[31] As older adults aged over 65 years were claimed to be with the highest burden of influenza-related death, the current prevention measures should be maintained as a solid issue.[1] And the correlation analysis further suggested that influenza vaccination offered positive efforts in preventing the school-aged and elder population from ILI infection. This is in also in line with previous studies that indicate influenza vaccination shows effectiveness in ILI prevention.[32,33]
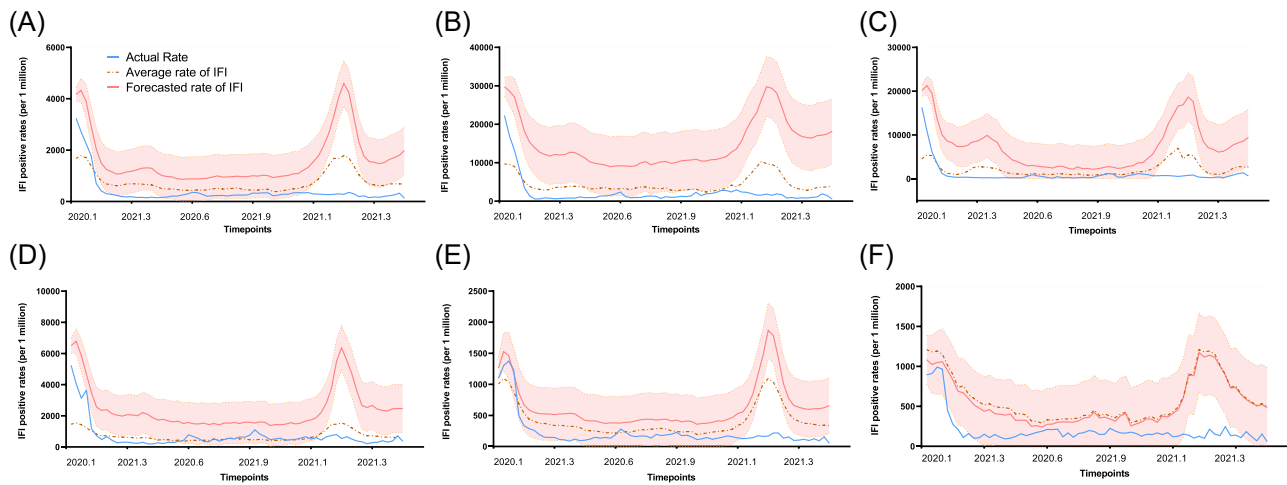
FIGURE 2 The comparison of ILI activity between observed rates, average rate and forecasted rates of ILI within different age groups during January 2020 to March 2021. (A) Total population; (B) age group of 0–4 years; (C) age group of 5–14 years; (D) age group of 15–24 years; (E) age group of 25–59 years; (F) age group of ≥60 years. ILI, influenza-like illness.

FIGURE 3 The relationship between influenza vaccination coverages and ILI activities during the study period. (A) Age group of 5–14 years; (B) age group of ≥60 years. ILI, influenza-like illness.
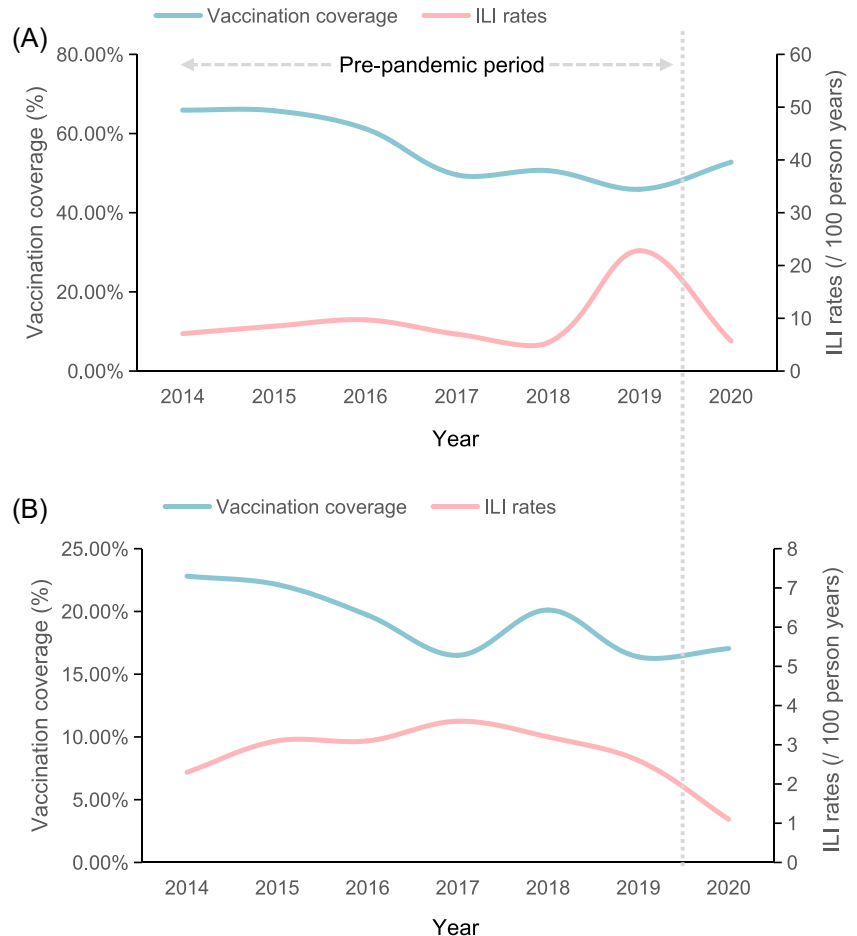
Moreover, because large cities are also hubs in the intercity travel network, spatial aggregation of populations in such initialed urban could be a proxy for the intensity of influenza infectious contact both within and among cities.[34–36] Thus, those virus-resistant population

like adults might act as an important media in the process of virus transmission, since they are more active in social life. As indirect protection of adults by vaccinating children has been demonstrated in other countries, during the process of new urbanization, vaccination

on influenza among the youth and adults might be a supplementary measure in protecting the whole population from ILI infection, besides NPIs or personal protection measures.[37,38]

In contrast to preurbanization period or urbanization period, the activity and spread of influenza virus were considerably interrupted during COVID-19 pandemic period, particularly during influenza epidemic season. Studies have offered similar results in other countries or areas like Canada,[39] America,[40] Southeastern Asia,[41] eastern Asia,[42,43] Europe,[44] as well as China[15,16] considering the circulation level of influenza or similar infectious respiratory diseases. The situation is suggested largely attributed to the widespread implementation of NPIs since COVID-19 became a serious concern to population health.[16] Under the stressful health pressure, people also began to acquire more self-protective measures to avoid the infection of COVID-19.[15] ILI incidence rate remained lower than that in historical years, and its epidemic pattern had even been changed showing no seasonal peaks throughout the pandemic period, regardless of age groups.

The decline of ILI activity was detected even greater among school-aged children in each subperiod during COVID-19 pandemic. On the one hand, it was attributed to school closing and mass gathering restriction, particularly during the first wave of COVID-19.[45,46] Chances for virus transmission has been largely limited since NPIs were with the strictest compliance among this population by their parents.[47,48] On the other hand, ILI activity showed no rebounds during the periods that school was open, suggesting that NPIs among this population were kept strictly even the COVID-19 situation was well controlled in Beijing. On the contrary, ILI among adults presented less decline during the same period. Generally, ILI decrease was detected throughout the pandemic period, but significant decline was only detected during the 2020–2021 influenza season. We suppose this situation is attributed to the low basic ILI dynamics as well as their lack of clinic sensitivity to influenza infection.

Comparing to the impact of urbanization on the activity increase of ILI in Tongzhou district, the COVID-19 related interventions and NPIs showed stronger effect on ILI prevention. Urbanization means increasing population intensity, human mobility and contact, more possibility for virus transmission and incubation. However, it also brings better medical and living conditions, more medical resources and better health education. During COVID-19 period, NPIs offers the chance to mitigate those drawbacks for virus transmission, but still keeps the health advantages of this newly developed urban. It also offers a clue in city planning in terms of its health system.

There are some limitations of this study. First, our analysis was based on historical data and no causal relationships would be concluded. Second, the ILI activity was calculated based on the data from BISN whose sensitivity to influenza infection was not included for analysis. Thus, the concluded relationship between ILI activity, urbanization and COVID-19 related NPIs might not be a confirmatory one, since it should be influenced by circulating virus strains, clinical diagnosis, and healthcare-seeking behaviors, and so forth. Also, the genetic diversity of influenza virus and their antigenic characteristics were not included for analysis. Third, the counterfactual estimates by SARIMA model might overestimate the fact if

COVID-19 did not occur during 2020–2021, since this model suggested not much suitable for long term simulation. Moreover, since we could not access to the personal influenza vaccination data during our study period, the effectiveness of influenza vaccination among the study population could not be calculated and taken into account with our time series analysis, and its accurate effectiveness could not be tested or discussed which might be resolved in future related studies.

5 | CONCLUSION

Evidence of our analysis verified the fact that urbanization increased the possibility of virus transmission among population, while social strategies and personal NPIs might be the solution for population's health during city management at any developing stage. And influenza vaccination might be a necessary supplement for controlling ILI at urban sites.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The original data set can be directed to the corresponding authors.

ETHICS STATEMENT

The following information was supplied relating to ethical approvals: The Peking University Institutional Review Board Office granted Ethical approval to carry out the study within its facilities (IRB00001052-19005).

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REFERENCES

1. Li J, Chen Y, Wang X, Yu H. Influenza-associated disease burden in mainland China: a systematic review and meta-analysis. *Sci Rep*. 2021;11(1):2886.
2. Hay AJ, McCauley JW. The WHO global influenza surveillance and response system (GISRS)—a future perspective. *Influenza Other Respir Viruses*. 2018;12(5):551-557.
3. Iuliano AD, Roguski KM, Chang HH, et al. Estimates of global seasonal influenza-associated respiratory mortality: a modelling study. *Lancet*. 2018;391(10127):1285-1300.
4. Gong H, Shen X, Yan H, et al. Estimating the disease burden of seasonal influenza in China, 2006–2019. *Zhonghua Yi Xue Za Zhi*. 2021;101(8):560-567.
5. National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Global Health; Forum on Microbial Threats. *Urbanization and Slums: Infectious Diseases in the Built Environment: Proceedings of a Workshop*. National Academies Press; 2018.
6. Alirol E, Getaz L, Stoll B, Chappuis F, Loutan L. Urbanisation and infectious diseases in a globalised world. *Lancet Infect Dis*. 2011; 11(2):131-141.
7. Casanovas-Massana A, Costa F, Riediger IN, et al. Spatial and temporal dynamics of pathogenic Leptospira in surface waters from the urban slum environment. *Water Res*. 2018;130:176-184.
8. Gao X, Wei J, Cowling BJ, Li Y. Potential impact of a ventilation intervention for influenza in the context of a dense indoor contact network in Hong Kong. *Sci Total Environ*. 2016;569-570:373-381.
9. Beijing Statistics Bureau. *Beijing Statistical Yearbook 2021*. China Statistics Press; 2021.
10. People's Government of Tongzhou District. Work report of People's Government of Tongzhou District, Beijing Municipality in 2021;2021.
11. Zhang QFWS. Epidemiological characteristics of influenza among people of different ages in eastern part of Beijing in winter and spring of 2016–2019. *Lab Med Clin*. 2020;17(17):2507-2510.
12. World Health Organization. WHO coronavirus (COVID-19) dashboard. 2022. Accessed January 20, 2022. https://covid19.who.int/
13. Tian H, Liu Y, Li Y, et al. An investigation of transmission control measures during the first 50 days of the COVID-19 epidemic in China. *Science*. 2020;368(6491):638-642.
14. Sun J, Shi Z, Xu H. Non-pharmaceutical interventions used for COVID-19 had a major impact on reducing influenza in China in 2020. *J Travel Med*. 2020;27(8):taaa064.
15. Li ZJ, Yu LJ, Zhang HY, et al. Broad impacts of COVID-19 pandemic on acute respiratory infections in China: an observational study. *Clin Infect Dis*. 2021:ciab942. https://doi.org/10.1093/cid/ciab942
16. Feng L, Zhang T, Wang Q, et al. Impact of COVID-19 outbreaks and interventions on influenza in China and the United States. *Nat Commun*. 2021;12(1):3249.
17. Cowling BJ, Ali ST, Ng T, et al. Impact assessment of non-pharmaceutical interventions against coronavirus disease 2019 and influenza in Hong Kong: an observational study. *Lancet Public Health*. 2020;5(5):e279-e288.
18. Sakamoto H, Ishikane M, Ueda P. Seasonal influenza activity during the SARS-CoV-2 outbreak in Japan. *JAMA*. 2020;323(19):1969-1971.
19. Lee HH, Lin SH. Effects of COVID-19 Prevention measures on other common infections, Taiwan. *Emerg Infect Dis*. 2020;26(10):2509-2511.
20. Beijing Municipal Bureau of health. *Beijing influenza surveillance program*. 2011.
21. Newcombe RG. Interval estimation for the difference between independent proportions: comparison of eleven methods. *Stat Med*. 1998;17(8):873-890.
22. Benvenuto D, Giovanetti M, Vassallo L, Angeletti S, Ciccozzi M. Application of the ARIMA model on the COVID-2019 epidemic dataset. *Data Brief*. 2020;29:105340.
23. Liu T, Wang P, Meng F, et al. Incidence, circulation, and spatiotemporal analysis of seasonal influenza in Shandong, China, 2008-2019: a retrospective study. *Influenza Other Respir Viruses*. 2022;16:594-603.
24. Zhang Q, Feng S, Wong I, Ip D, Cowling BJ, Lau E. A population-based study on healthcare-seeking behaviour of persons with symptoms of respiratory and gastrointestinal-related infections in Hong Kong. *BMC Public Health*. 2020;20(1):402.
25. Qing Chun P, Zheng Hao T, Yong Sheng Y, Min X, Guo Qing Z. Influenza prevention and control under the situation of new urbanization. *J Microbes Infect*. 2020;15(2):108-114.
26. Dalziel BD, Kissler S, Gog JR, et al. Urbanization and humidity shape the intensity of influenza epidemics in U.S. cities. *Science*. 2018; 362(6410):75-79.
27. Morris SE, Freiesleben DBB, Viboud C, Wesolowski A, Bjørnstad ON, Grenfell BT. Analysis of multi-level spatial data reveals strong synchrony in seasonal influenza epidemics across Norway, Sweden, and Denmark. *PLoS One*. 2018;13(5):e197519.
28. Lafond KE, Nair H, Rasooly MH, et al. Global role and burden of influenza in pediatric respiratory hospitalizations, 1982-2012: a systematic analysis. *PLoS Med*. 2016;13(3):e1001977.
29. Guo R, Zheng H, Huang L, et al. Epidemiologic and economic burden of influenza in the outpatient setting: a prospective study in a subtropical area of China. *PLoS One*. 2012;7(7):e41403.
30. Lafond KE, Porter RM, Whaley MJ, et al. Global burden of influenza-associated lower respiratory tract infections and hospitalizations among adults: a systematic review and meta-analysis. *PLoS Med*. 2021;18(3):e1003550.
31. FuHua W. Analysis of free influenza vaccination and differences between urban and rural residents registered residence in Beijing. *J Peking Univ Health Sci*. 2013;45(03):432-436.
32. Zhang Y, Muscatello DJ, Cao Z, et al. A model of influenza infection and vaccination in children aged under 5 years in Beijing, China. *Hum Vacc Immunother*. 2020;16(7):1685-1690.
33. Zhang Y, Cao Z, Costantino V, et al. Influenza illness averted by influenza vaccination among school year children in Beijing, 2013-2016. *Influenza Other Respir Viruses*. 2018;12(6):687-694.
34. Zinder D, Bedford T, Baskerville EB, Woods RJ, Roy M, Pascual M. Seasonality in the migration and establishment of H3N2 Influenza lineages with epidemic growth and decline. *BMC Evol Biol*. 2014;14:272.
35. Martinez PP, King AA, Yunus M, Faruque AS, Pascual M. Differential and enhanced response to climate forcing in diarrheal disease due to rotavirus across a megacity of the developing world. *Proc Natl Acad Sci USA*. 2016;113(15):4092-4097.
36. Hill NJ, Hussein ITM, Davis KR, et al. Reassortment of influenza A viruses in wild birds in Alaska before H5 clade 2.3.4.4 outbreaks. *Emerg Infect Dis*. 2017;23(4):654-657.
37. Pebody RG, Sinnathamby MA, Warburton F, et al. Uptake and impact of vaccinating primary school-age children against influenza: experiences of a live attenuated influenza vaccine programme, England, 2015/16. *Euro Surveill*. 2018;23(25):1700496.
38. Ghendon YZ, Kaira AN, Elshina GA. The effect of mass influenza immunization in children on the morbidity of the unvaccinated elderly. *Epidemiol Infect*. 2006;134(1):71-78.
39. Maharaj AS, Parker J, Hopkins JP, et al. The effect of seasonal respiratory virus transmission on syndromic surveillance for COVID-19 in Ontario, Canada. *Lancet Infect Dis*. 2021;21(5):593-594.
40. Rodgers L, Sheppard M, Smith A, et al. Changes in seasonal respiratory illnesses in the United States during the coronavirus

disease 2019 (COVID-19) pandemic. *Clin Infect Dis*. 2021;73(suppl 1):S110-S117.

41. Mott JA, Fry AM, Kondor R, Wentworth DE, Olsen SJ. Re-emergence of influenza virus circulation during 2020 in parts of tropical Asia: implications for other countries. *Influenza Other Respir Viruses*. 2021;15(3):415-418.

42. Fujita J. *Mycoplasma pneumoniae* pneumonia and respiratory syncytial virus infection in Japan during the severe acute respiratory syndrome coronavirus 2 pandemic. *Respir Investig*. 2021;59(1):5-7.

43. Yum S, Hong K, Sohn S, Kim J, Chun BC. Trends in viral respiratory infections during COVID-19 pandemic, South Korea. *Emerg Infect Dis*. 2021;27(6):1685-1688.

44. Adlhoch C, Mook P, Lamb F, et al. Very little influenza in the WHO European Region during the 2020/21 season, weeks 40 2020 to 8 2021. *Euro Surveill*. 2021;26(11):2100221.

45. Hammerstein S, König C, Dreisörner T, Frey A. Effects of COVID-19-related school closures on student achievement—a systematic review. *Front Psychol*. 2021;12:746289.

46. Li H, Wang L, Zhang M, Lu Y, Wang W. Effects of vaccination and non-pharmaceutical interventions and their lag times on the COVID-19 pandemic: comparison of eight countries. *PLoS Negl Trop Dis*. 2022;16(1):e10101.

47. Ye Q, Wang D. Epidemiological changes of common respiratory viruses in children during the COVID-19 pandemic. *J Med Virol*. 2022;94:1990-1997.

48. Liu W, Yang Q, Xu Z, et al. Impact of the COVID-19 pandemic on neonatal admissions in a tertiary children's hospital in southwest China: an interrupted time-series study. *PLoS One*. 2022;17(1): e262202.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.