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Under-5, infant, and neonatal mortality trends and causes of death, 1991–2022: Findings from death surveillance in Xicheng district of Beijing, China

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ABSTRACT

Overall, China has made substantial progress in improving child survival over the past few decades, but a detailed understanding of child mortality trend at local level is limited. This study aimed to present a comprehensive analysis of under-5, infant, and neonatal mortality rates and its trend in Xicheng district of Beijing, China. We used the surveillance data of under-5 children reported by Preventive Health Department of Xicheng District Community Health Service Center from 1991 to 2022. The data was collected based on the Child Death Reporting Card of the Beijing Under-5 Mortality Rate Surveillance Network. Data check was performed by each community health service center and related medical institutions. We extracted data included maternal age, date of death, date of birth, gender, census register, classification of any causes of death, and utilization of healthcare services before death and doubly input it in the Excel 2016 program. Categorization of the causes of death was adapted by the International Categorization of Diseases (ICD-10). Mortality rates and distribution of the leading causes of death were analyzed with descriptive statistics and the Pearson's Chi-square test using SAS 14.0 software. The Chi-square trend test was used to explore the trends in mortality. Interrupted time series analysis (ITSA) was conducted to assess the impact of the two-child policy on mortality using STATA statistical packages. From 1991 to 2022, totally, there were 166,061 live births and 793 (4.78 ‰) under-5 deaths. The mortality rates of under-5 children, infants and neonates in Xicheng district decreased from 14.75 ‰, 11.25 ‰ and 8.00 ‰ to 1.03 ‰, 0.83 ‰ and 0.41 ‰ respectively. All mortality rates showed an overall significant decline trend (χ^2 trend for neonatal = -15.8136, P trend for neonatal < 0.001; χ^2 trend for infant = -17.6652, P trend for infant < 0.001; χ^2 trend for under-5 = -18.9103, P trend for under-5 < 0.001). The leading causes of death among under-5 children were congenital heart disease (1.65 ‰), birth asphyxia (1.44 ‰), and other congenital abnormalities (except congenital heart disease and down's syndrome) (1.36 ‰). ITSA results showed that the two-child policy did not change the overall decreased trend of child mortality rates. Future preventive measures for child healthcare should give a priority for congenital heart disease, birth asphyxia, and other congenital abnormalities.

1. Introduction

Worldwide, it is a long-term priority for improving child survival. The under-5 mortality rate (U5MR) is an important indicator that mirrors the health of children (GBD, 2017 Mortality Collaborators, 2018; United Nations, 2019). Yet by the conclusion of the Millennium Development Goals (MDGs), which aimed to reduce under-5 mortality rate (U5MR) by two-thirds from 1990 to 2015, only 57 of 195 countries and territories worldwide met or exceeded the pace of progress required to achieve MDG during that period (United Nations, 2019; Perin et al., 2022; GBD, 2019 Under-5 Mortality Collaborators, 2021; GBD, 2016 Mortality Collaborators, 2017). China has made substantial progress in declining the U5MR over the past few decades, reflecting the commitment and investment to improve child survival (Wang et al., 2016). According to the "China's Health Development Statistical Bulletin in 2021", infant mortality rate (IMR) and U5MR have declined to 5.0 ‰

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and 7.1 ‰ in China, a reduction of about 50 % compared to 2012 (China NHCO, 2021). In addition, national mortality rates, although conducive to macro-level comparison, obscure variations in child survival at lower subnational districts, the levels at which most health program planning and implementation will be carried out (India State-Level Disease Burden Initiative Child Mortality Collaborators, 2020). In this sense, a better understanding of subnational monitoring for levels and trends of child mortality at district level is needed to robustly push forward the precise intervention, and to optimally provide funding and targeting interventions for the populations who most need them.

As the capital city of China, Beijing has experienced the most rapid healthcare developments. In 1992, Beijing Under-5 Mortality Rate Surveillance Network was settled (Han et al., 2017). As the core functionally capital area, Xicheng District's healthcare service is in the forefront of the whole city. It took the lead in establishing this monitoring network in 1991, a year earlier than Beijing citywide (He et al., 2022). Currently, the system routinely capture data on child deaths from monitoring system together with the Child Death Reporting Cards information from communities and hospital. Such work brought an opportunity to unveil the initial magnitude of all-cause child deaths and facilitated assessments of efficacy for child healthcare at district even community level. With the implementation of the 'Selective Two-child Policy' in 2014 (BMPC, 2016a) and the 'Entire Two-child Policy' in 2016 (BMPC, 2016b) in Beijing, growth in live births quantity emerged (Xue, 2015). Whether or not policy changes will pose an obstacle to substantial effort and resources that have been dedicated to healthcare improvements remains unknown. At the city level, previous study has showed that U5MR has increased by 7.0 % from 2013 to 2015 in Beijing, China (Han et al., 2017). What is the level and trend of U5MR in Xicheng district of Beijing? Of note, Xicheng District has a high level of economic development. Accordingly, we expect the health services in Xicheng district could play a leading role as well. However, a comprehensive understanding of child mortality trends at this geographical region is not available from a longer-range time-serial perspective.

Although China as a nation has achieved the MDG 4 goal by reducing the under-5 mortality rate, much less is known about its performance at the district level. In addition, the trends over time in relation to the China National Health Policy and Sustainable Development Goal (SDG) 2030 targets, and the causes of death, using accessible data sources from district level surveillance data, has not been comprehensively reported. Therefore, the primary aim of this study was to present a detailed analysis of trends of child mortality and the distribution of the causes of death in Xicheng district of Beijing, China by using all accessible data from 1991 to 2022. This study was expected to provide valuable information to highlight the importance of district level surveillance data which could be changed into actionable information, and to promote the exploration of suitable intervention strategies for child death causes.

2. Methods

2.1. Study design and setting

This study was based on the data of the deaths of under-5 children in Xicheng district of Beijing, China. Overall, the monitoring data covered all community health service center (including Desheng, Jinrongjie, Shichahai, Xichanganjie, Xinjiekou, Yuetan, Zhanlanlu) in original Xicheng district. In this sense, the present study was a population-based epidemiology study. As a designated national monitoring site for maternal and child health, Xicheng district has been conducting monitoring of under-5 mortality since 1991. Due to the efforts of maternal and child health practitioner, valuable data has been obtained, which providing a basis for related decision-making and in-depth scientific research.

No further ethical approval was required for the present study, due to the data were derived from the surveillance system. However, informed consent was obtained from the guardians of the death child during data collection. The study followed the principles of anonymity and confidentiality, and the data were de-privatized.

2.2. Data sources

We used the surveillance data between 1991 and 2022 from the Under-5 Mortality Rate Surveillance Network, established in 1992 in community health service center in original Xicheng district, Beijing, China. The scope of monitoring covered all under-5 children in local household registration of Xicheng district. Live births and death were both under surveillance and registered based on case reports regularly. As soon as the mother was pregnant, maternal and infant file should be set up at the hospital. Therefore, live births were mainly reported by related medical system. Only live births of household registration in Xicheng district were captured and follow-up. There were two pathway of under-5 children death reporting: communities (such as community health service center) and medical institutions (such as general hospital, maternal and child health care hospital). The surveillance contents including maternal age, number of deaths, causes of death, timing of death, place of death, age of children, household registration of parents. Diagnosis of death was mainly assessed and determined by a panel of specialized clinical doctors based on clinical evaluation. However, for children who did not die in hospitals, the causes of death were primarily reported by the community. Categorization of the causes of death was adapted by the International Categorization of Diseases (ICD-10).

According to the requirements of the monitoring work, the monthly check of child death was performed by each community health service center and related medical institution. After keeping records, the death data should be reported to the Maternal and Child Health Hospital of Xicheng District (XDMCHH). Regularly self-inspection would be conducted from two aspects: organization and management of life monitoring and data verification. In addition, to better guarantee the quality of data, XDMCHH performed monthly field supervision of community health service centers and medical institutions, and quarterly reconciliated data with multiple departments such as the Center for Disease Control and Prevention.

2.3. Data extraction

The Child Death Reporting Card was in paperboard from 1991 to 2002. To ensure the accuracy of the data, two authors (LXR, LYG) independently extracted data from reporting card. Double entries and consistency checks in the Epidata 3.1 software were applied. Discrepancies between two entries need to be verified through consulting the original information card by a third author (WB). Electronic cards have been used since the information system was established in 2003. Therefore, data collected between 2003 and 2022 were directly exported from the system. Extracted data included maternal age, date of death, date of birth, gender, census register, classification of any causes of death, and utilization of healthcare services before death. All extracted data were input in the Excel 2016 program to form a final analysis dataset.

2.4. Outcomes

Live birth was defined as a fetus born after 28 weeks of gestation (or with a birth weight > 1000 g) with at least one of the following vital signs: heartbeat, breathing, pulsation of the umbilical cord or contraction of voluntary muscle. Only live births of household registration in Xicheng district were included. Specifically, the U5MR was defined as the number of deaths within 5 years from birth per 1000 live births (as defined by the National Centre for Health Statistics). The mortality rate of children aged 1–4 years was defined as the number of deaths within 1–4 years from birth per 1000 live births. The infant mortality rate (IMR) was defined as the number of deaths within 1 year from birth per 1000 live births. The neonatal mortality rate (NMR) was defined as the

Table 1
Mortality rates in early neonates, neonates, infants, children aged 1–4 years and under 5 years in Xicheng district, Beijing, China, 1991–2022.

Year	Gender	Live births	Early neonates		Neonates		Infants		Children aged 1–4 years		Under 5 years	
			Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)
1991	All	3999	NA	NA	32	8.00	45	11.25	14	3.50	59	14.75
1992	All	5434	NA	NA	42	7.73	55	10.12	9	1.66	63	11.59
1993	All	4332	NA	NA	33	7.62	42	9.70	3	0.69	45	10.39
1994	Male	2030	11	5.42	14	6.90	20	9.85	1	0.49	24	11.82
1994	Female	1854	7	3.78	11	5.93	16	8.63	2	1.08	19	10.25
1994	All	3884	18	4.63	25	6.44	36	9.27	3	0.77	43	11.07
1995	Male	1970	12	6.09	13	6.60	18	9.14	6	3.05	24	12.18
1995	Female	1806	7	3.88	9	4.98	15	8.31	0	0.00	15	8.31
1995	All	3776	19	5.03	22	5.83	33	8.74	6	1.59	39	10.33
1996	Male	1863	5	2.68	9	4.83	12	6.44	1	0.54	13	6.98
1996	Female	1719	11	6.40	13	7.56	17	9.89	2	1.16	19	11.05
1996	All	3582	16	4.47	22	6.14	29	8.10	3	0.84	32	8.93
1997	Male	1925	10	5.19	13	6.75	16	8.31	2	1.04	18	9.35
1997	Female	1845	7	3.79	7	3.79	10	5.42	3	1.63	13	7.05
1997	All	3770	17	4.51	20	5.31	26	6.90	5	1.33	31	8.22
1998	Male	1611	3	1.86	4	2.48	9	5.59	1	0.62	10	6.21
1998	Female	1406	2	1.42	3	2.13	5	3.56	3	2.13	8	5.69
1998	All	3017	5	1.66	7	2.32	14	4.64	4	1.33	18	5.97
1999	Male	1577	4	2.54	8	5.07	11	6.98	1	0.63	12	7.61
1999	Female	1510	5	3.31	8	5.30	14	9.27	2	1.32	16	10.60
1999	All	3087	9	2.92	16	5.18	25	8.10	3	0.97	28	9.07
2000	Male	1765	6	3.40	9	5.10	9	5.10	2	1.13	11	6.23
2000	Female	1516	3	1.98	8	5.28	10	6.60	1	0.66	11	7.26
2000	All	3281	9	2.74	17	5.18	19	5.79	3	0.91	22	6.71
2001	Male	1454	3	2.06	5	3.44	5	3.44	2	1.38	7	4.81
2001	Female	1359	6	4.42	9	6.62	14	10.30	1	0.74	15	11.04
2001	All	2813	9	3.20	14	4.98	19	6.75	3	1.07	22	7.82
2002	Male	1679	7	4.17	13	7.74	14	8.34	2	1.19	16	9.53
2002	Female	1553	4	2.58	5	3.22	8	5.15	1	0.64	9	5.80
2002	All	3232	11	3.40	18	5.57	22	6.81	3	0.93	25	7.74
2003	Male	1235	4	3.24	7	5.67	12	9.72	2	1.62	14	11.34
2003	Female	1161	3	2.58	5	4.31	6	5.17	1	0.86	7	6.03
2003	All	2396	7	2.92	12	5.01	18	7.51	3	1.25	21	8.76
2004	Male	1358	6	4.42	9	6.63	11	8.10	2	1.47	13	9.57
2004	Female	1254	3	2.39	3	2.39	3	2.39	0	0.00	3	2.39
2004	All	2612	9	3.45	12	4.59	14	5.36	2	0.77	16	6.13
2005	Male	1824	5	2.74	7	3.84	10	5.48	3	1.64	13	7.13
2005	Female	1713	1	0.58	1	0.58	2	1.17	1	0.58	3	1.75
2005	All	3537	6	1.70	8	2.26	12	3.39	4	1.13	16	4.52
2006	Male	1906	2	1.05	3	1.57	6	3.15	0	0.00	6	3.15
2006	Female	1746	5	2.86	7	4.01	7	4.01	2	1.15	9	5.15
2006	All	3652	7	1.92	10	2.74	13	3.56	2	0.55	15	4.11
2007	Male	2522	0	0.00	0	0.00	4	1.59	0	0.00	4	1.59
2007	Female	2203	3	1.36	4	1.82	9	4.09	0	0.00	9	4.09
2007	All	4725	3	0.63	4	0.85	13	2.75	0	0.00	13	2.75
2008	Male	2753	8	2.91	13	4.72	18	6.54	0	0.00	18	6.54
2008	Female	2503	0	0.00	7	2.80	9	3.60	2	0.80	11	4.39
2008	All	5256	8	1.52	20	3.81	27	5.14	2	0.38	29	5.52
2009	Male	2884	6	2.08	7	2.43	8	2.77	2	0.69	10	3.47
2009	Female	2652	2	0.75	3	1.13	6	2.26	3	1.13	9	3.39
2009	All	5536	8	1.45	10	1.81	14	2.53	5	0.90	19	3.43
2010	Male	2921	7	2.40	9	3.08	12	4.11	0	0.00	12	4.11
2010	Female	2684	2	0.75	4	1.49	6	2.24	5	1.86	11	4.10
2010	All	5605	9	1.61	13	2.32	18	3.21	5	0.89	23	4.10
2011	Male	3213	5	1.56	6	1.87	11	3.42	1	0.31	12	3.73
2011	Female	3015	4	1.33	4	1.33	7	2.32	0	0.00	7	2.32
2011	All	6228	9	1.45	10	1.61	18	2.89	1	0.16	19	3.05
2012	Male	3937	6	1.52	6	1.52	9	2.29	2	0.51	11	2.79
2012	Female	3589	4	1.11	5	1.39	7	1.95	1	0.28	8	2.23
2012	All	7526	10	1.33	11	1.46	16	2.13	3	0.40	19	2.52
2013	Male	3812	4	1.05	5	1.31	8	2.10	1	0.26	9	2.36
2013	Female	3545	6	1.69	8	2.26	12	3.39	1	0.28	13	3.67
2013	All	7357	10	1.36	13	1.77	20	2.72	2	0.27	22	2.99
2014	Male	4495	9	2.00	12	2.67	15	3.34	1	0.22	16	3.56
2014	Female	4266	7	1.64	9	2.11	11	2.58	3	0.70	14	3.28
2014	All	8761	16	1.83	21	2.40	26	2.97	4	0.46	30	3.42
2015	Male	4309	4	0.93	5	1.16	10	2.32	3	0.70	13	3.02
2015	Female	4120	4	0.97	5	1.21	8	1.94	3	0.73	11	2.67
2015	All	8429	8	0.95	10	1.19	18	2.14	6	0.71	24	2.85
2016	Male	4814	4	0.83	5	1.04	8	1.66	1	0.21	9	1.87
2016	Female	4478	5	1.12	8	1.79	13	2.90	1	0.22	14	3.13
2016	All	9292	9	0.97	13	1.40	21	2.26	2	0.22	23	2.48
2017	Male	5257	6	1.14	7	1.33	10	1.90	2	0.38	12	2.28

(*continued on next page*)

Table 1 (*continued*)

Year	Gender	Live births	Early neonates		Neonates		Infants		Children aged 1–4 years		Under 5 years	
			Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)	Deaths	Rate (‰)
2017	Female	4840	5	1.03	8	1.65	9	1.86	2	0.41	11	2.27
2017	All	10,097	11	1.09	15	1.49	19	1.88	4	0.40	23	2.28
2018	Male	3945	2	0.51	5	1.27	7	1.77	0	0.00	7	1.77
2018	Female	3700	1	0.27	1	0.27	1	0.27	3	0.81	4	1.08
2018	All	7645	3	0.39	6	0.78	8	1.05	3	0.39	11	1.44
2019	Male	3860	1	0.26	1	0.26	4	1.04	2	0.52	6	1.55
2019	Female	3646	3	0.82	4	1.10	6	1.65	1	0.27	7	1.92
2019	All	7506	4	0.53	5	0.67	10	1.33	3	0.40	13	1.73
2020	Male	2934	2	0.68	6	2.04	6	2.04	5	1.70	11	3.75
2020	Female	2893	1	0.35	3	1.04	7	2.42	0	0.00	7	2.42
2020	All	5827	3	0.51	9	1.54	13	2.23	5	0.86	18	3.09
2021	Male	2583	0	0.00	1	0.39	3	1.16	0	0.00	3	1.16
2021	Female	2444	1	0.41	1	0.41	2	0.82	1	0.41	3	1.23
2021	All	5027	1	0.20	2	0.40	5	0.99	1	0.20	6	1.19
2022	Male	2505	1	0.40	2	0.80	3	1.20	1	0.40	4	1.60
2022	Female	2335	0	0.00	0	0.00	1	0.43	0	0.00	1	0.43
2022	All	4840	1	0.21	2	0.41	4	0.83	1	0.21	5	1.03
χ^2 trend				−13.4717		−15.8136		−17.6652		−6.7513		18.9103
P trend				<0.001		<0.001		<0.001		<0.001		<0.001

number of deaths within 28 days from birth per 1000 live births. The early neonatal mortality rate (ENMR) was defined as the number of deaths within 7 days from birth per 1000 live births.

2.5. Statistical analysis

Analyses were performed using Statistical Analysis System 9.2 (SAS Institute Inc., Cary, NC, USA) and STATA statistical packages (V14.0, Biostat, Englewood, NJ, USA). We analyzed the U5MR, mortality rate of children aged 1–4 years, IMR, NMR, and ENMR. A descriptive statistical analysis was conducted on the mortality rates and cause of death. The Pearson's Chi-squared test was used to compare the different distribution of the categorical variables, such as comparisons for the annual distribution of the causes of death. Cochran-Armitage (trend chi-square test) tests were used to test the linear trend of annual mortality rate during the 32 years period. In addition, we used interrupted time series analysis with segmented linear regression to assess the impact of the two-child policy on mortality, considering the interruption point in 2015. Our model parameters included an intercept term (β0 is the level of explained variables at the beginning), pre-policy trend (β1 estimates the baseline trend before the policy), a trend shift in 2015 (β2 estimates the effect of the policy implemented on the change of intercept) and a slope change term after 2015 (β3 reflects the changed trend after the policy implemented compared with the pre-policy slope). We used Stata's 'newey' command to calculate Newey-West standard errors to account for autocorrelation and heteroskedasticity. A two-sided significance level of 0.05 was considered reaching statistical significance.

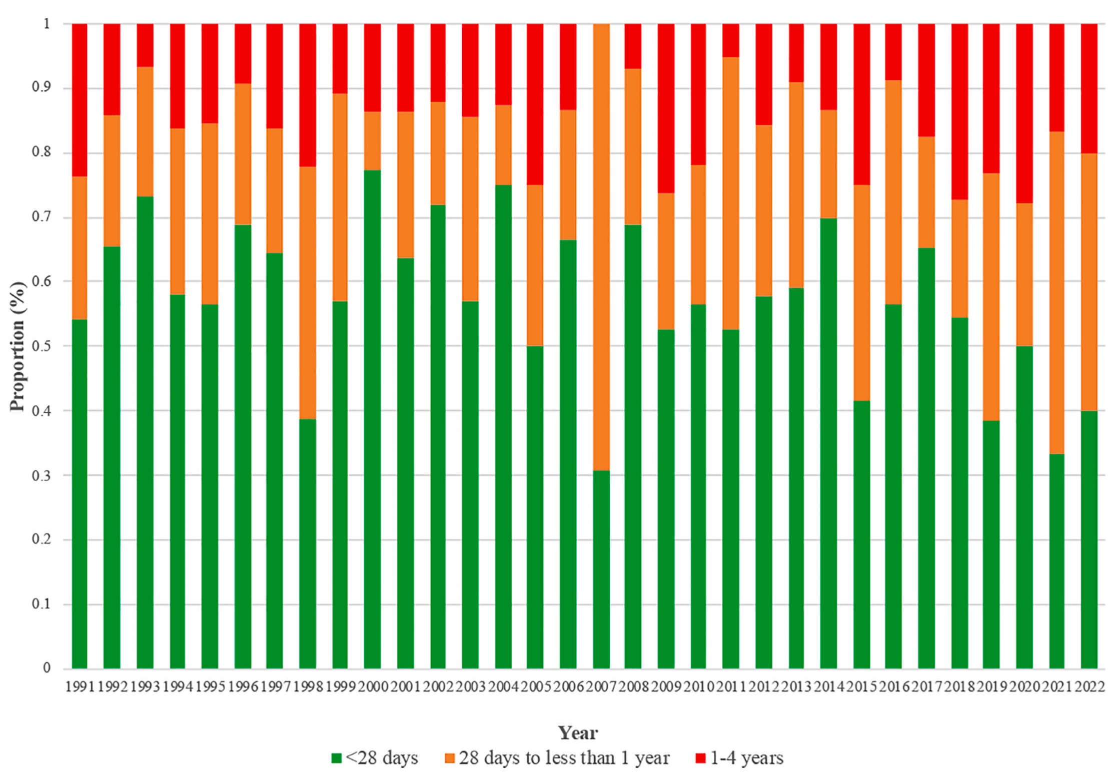


Fig. 1. Age composition of the children death in Xicheng district of Beijing, China, 1991–2022.

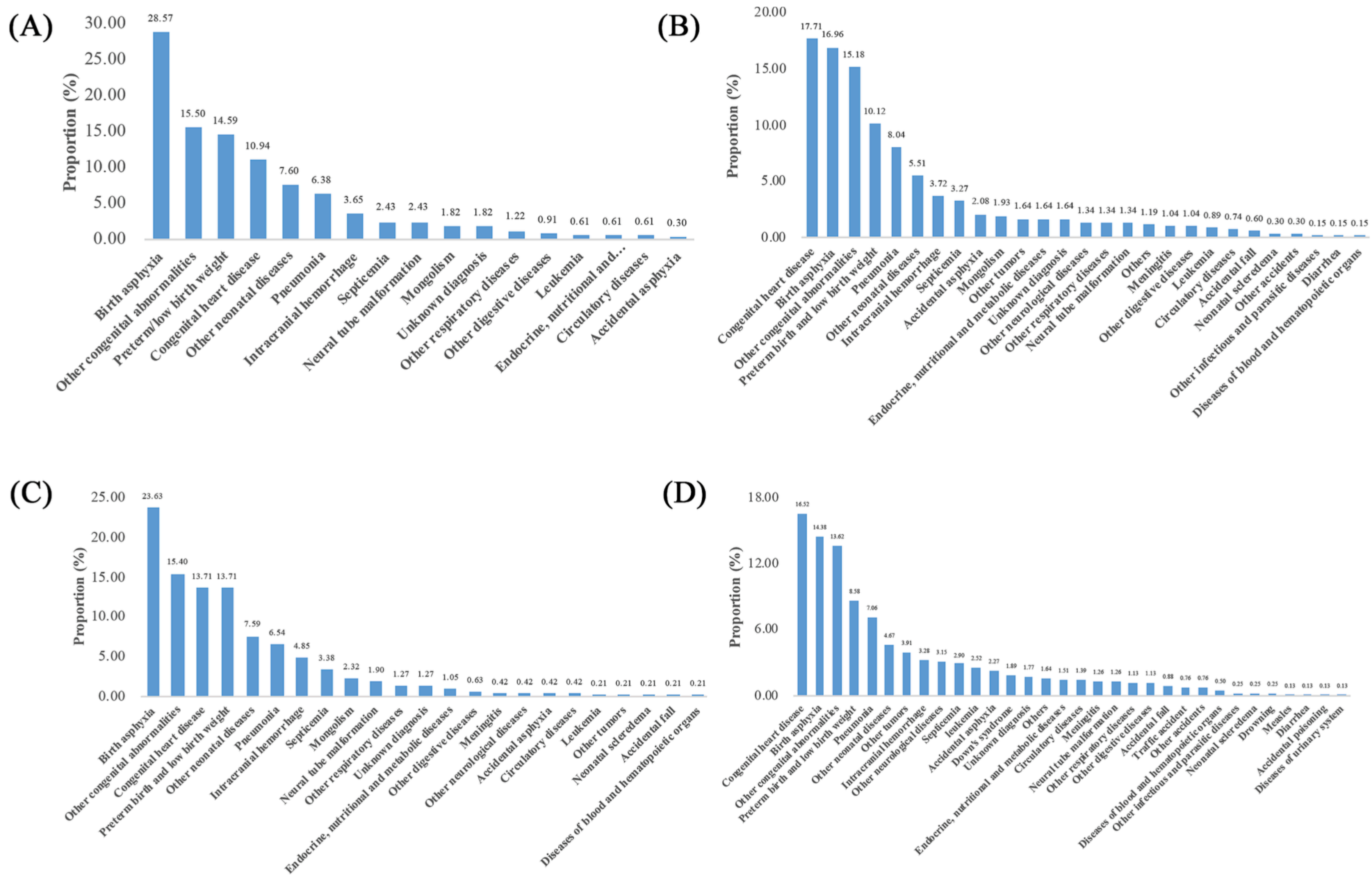


Fig. 2. The proportion of cause-specific mortality rates among children of different ages in Xicheng district of Beijing, China, 1991–2022: (A) children aged < 7 days; (B) neonates (<28 days); (C) 28 days to < 1 year; (D) 1–4 years.

3. Results

3.1. Mortality and trends in under-5, children aged 1–4 years, infant, neonatal and early neonatal

Table 1 presented the mortality rates in U5MR, death of children aged 1–4 years, IMR, NMR, and ENMR in Xicheng district from 1991 to 2022. Totally, there were 166,061 live births and 793 (4.78 ‰) under-5 deaths, of which no gender-specific data for 1991, 1992 and 1993. Therefore, among 625 under-5 deaths between 1994 and 2022, 338 (54.08 %) were males and 287 (45.92 %) were females. The total number of deaths in death of children aged 1–4 years, infant, neonatal, and early neonatal was 117 (0.58 ‰), 672 (3.31 ‰), 474 (2.33 ‰), and 255 (1.25 ‰), respectively. Both infant and neonate mortality accounted for more than 50 % of all deaths among under-5 children. Specifically, infant deaths accounted for 84.74 % of deaths of under-5 children, and neonatal deaths accounted for 70.54 % of deaths of infants. All mortality rates showed an overall significant decline trend (χ^2 trend for early neonatal trend for = -13.4717, *P* trend for early neonatal < 0.001; χ^2 trend for neonatal = -15.8136, *P* trend for neonatal < 0.001; χ^2 trend for infant = -17.6652, *P* trend for infant < 0.001; χ^2 trend for aged 1-4 years = -6.7513, *P* trend for aged 1-4 years < 0.001; χ^2 trend for under-5 = -18.9103, *P* trend for under-5 < 0.001).

Fig. 1 showed the different age groups (children aged < 28 days; 28 days to 1 year; and 1–4 years) of death in children under-5 years from 1991 to 2022. In total, deaths in neonates accounted for more than 50 % of all deaths among under-5 children during the 32 consecutive years under investigation.

3.2. Distribution of the leading causes of death

Fig. 2 presented the cause-specific mortality rates among different age groups (children aged < 7 days; aged < 28 days; 28 days to 1 year; and 1–4 years) in the past 32 years. Totally, there were 32 types of causes of death for under-5 children (Fig. 2A). As shown in Table 2, during the past 32 years, the top five leading death causes of under-5 children were congenital heart disease (n = 131), birth asphyxia (n = 114), other congenital abnormalities (n = 108), preterm/low birth weight (n = 68), and pneumonia (n = 56). In 1991, intracranial hemorrhage (n = 9), birth asphyxia (n = 8), and pneumonia (n = 7) were the top three leading death causes for under-5 children. However, it did not show a significant order feature in 2022 and only 5 deaths were reported totally.

For U5MR, particularly, preterm/low birth weight increased from the tenth place (3.39 %, 2/59) in 1991 to second place in 2020 (27.28 %, 5/18). Congenital heart disease climbed from fourth place (10.17 %, 6/59) to first place (20.00 %, 1/5) during the same period, and continued to be the leading cause of death for consecutive years from 1991 to 2018. Among the five leading causes of death during this period, a total decline trend was observed. In addition, the top five causes of infant death were congenital heart disease (119/672, 17.71 %), birth asphyxia (114/672, 16.96 %), other congenital abnormalities (102/672, 15.18 %), prematurity and low birth weight (68/672, 10.12 %), and pneumonia (54/672, 8.04 %).

In addition, for children aged < 7 days and 28 days, birth asphyxia was the main death cause (Fig. 2A and 2B), but different from those among the age groups 28 days to 1 year and 1–4 years. The overall trend of decline in mortality rates and particularly the top five leading death causes of under-5 children were slightly similar to those observed in age

Table 2
Rank and proportion of the leading causes of death in children under 5 years old in Xicheng district of Beijing, China, 1991–2022.

Year	Congenital heart disease Deaths (n, %)	Rank	Birth asphyxia Deaths (n, %)	Rank	Other congenital abnormalities Deaths (n, %)	Rank	Preterm/low birth weight Deaths (n, %)	Rank	Pneumonia Deaths (n, %)	Rank
1991	6 (10.17)	4	8(13.56)	2	4(6.78)	5	2(3.39)	10	7(11.86)	3
1992	10(15.63)	2	12(18.75)	1	6(9.38)	4	2(3.13)	8	8(12.50)	3
1993	11(24.44)	1	4(8.89)	6	5(11.11)	3	3(6.67)	8	8(17.78)	2
1994	7(16.28)	2	6(13.95)	3	9(20.93)	1	1(2.33)	9	4(9.30)	4
1995	6(15.38)	1	6(15.38)	1	4(10.26)	3	6(15.38)	1	5(12.82)	2
1996	5(15.63)	2	5(15.63)	2	9(28.13)	1	2(6.25)	4	1(3.13)	5
1997	7(22.58)	1	4(12.90)	2	3(9.68)	3	4(12.90)	2	2(6.45)	4
1998	4(22.22)	2	0(0)	–	7(38.89)	1	0	–	2(11.11)	3
1999	10(35.71)	1	3(10.71)	3	4(14.29)	2	4(14.29)	2	0(0)	–
2000	4(18.18)	2	6(27.27)	1	3(13.64)	3	2(9.09)	4	2(9.09)	4
2001	3(13.64)	2	6(27.27)	1	3(13.64)	2	3(13.64)	2	2(9.09)	3
2002	10(40.00)	1	4(16.00)	2	2(8.00)	4	1(4.00)	5	0(0)	–
2003	6(28.57)	1	6(28.57)	1	1(4.76)	2	1(4.76)	2	0(0)	–
2004	3(18.75)	2	6(37.50)	1	1(6.25)	4	1(6.25)	4	0(0)	–
2005	1(6.25)	3	2(12.50)	2	2(12.50)	2	2(12.50)	2	1(6.25)	3
2006	2(13.33)	2	3(20.00)	1	2(6.67)	2	1(6.67)	3	1(6.67)	3
2007	5(38.46)	1	0(0)	–	0(0)	–	1(7.69)	3	1(7.69)	3
2008	3(10.34)	2	3(10.34)	2	3(10.34)	2	3(10.34)	2	4(13.79)	1
2009	3(15.79)	2	2(10.53)	3	1(5.26)	4	1(5.26)	4	1(5.26)	4
2010	2(8.70)	2	1(4.35)	3	1(4.35)	3	4(17.39)	1	1(4.35)	3
2011	2(10.53)	3	5(26.32)	1	4(21.05)	2	1(5.26)	3	1(5.26)	4
2012	2(10.53)	1	1(5.26)	2	2(10.53)	1	1(5.26)	2	1(5.26)	2
2013	6(27.27)	1	3(13.64)	2	3(13.64)	2	2(9.09)	3	0(0)	–
2014	5(16.7)	2	6(20.00)	1	2(6.7)	3	5(16.70)	2	0(0)	–
2015	4(16.67)	1	4(16.67)	1	4(16.67)	1	0(0)	–	0(0)	–
2016	1(4.35)	4	5(21.74)	1	5(21.74)	1	3(13.04)	2	0(0)	–
2017	1(4.35)	4	2(8.70)	3	5(21.74)	1	3(13.04)	2	1(4.35)	4
2018	1(9.09)	2	0(0)	–	1(9.09)	2	2(18.18)	1	1(9.09)	2
2019	0(0)	–	1(7.69)	3	4(30.77)	1	2(15.38)	2	0(0)	–
2020	0(0)	–	0(0)	–	6(33.33)	1	5(27.78)	2	1(5.56)	4
2021	0(0)	–	0(0)	–	2(33.33)	1	0(0)	–	1(16.67)	2
2022	1(20.00)	1	0(0)	–	1(20.00)	1	0(0)	–	0(0)	–
Total	131 (16.52)	–	114 (14.38)	–	108 (13.62)	–	68 (8.58)	–	56 (7.06)	–
χ^2	140.9479		131.8749		94.5538		95.3845		87.6592	
P	<0.001		<0.001		<0.001		<0.001		<0.001	

groups 28 days to 1 year (Fig. 2C), but different from those among those aged 1–4 years, which other tumors, leukemia and traffic accident ranked top five (Fig. 2D).

3.3. Impact of maternal age and the two-child policy on under-5 child mortality rate in Xicheng district of Beijing, China

In current study, only a small fraction of maternal age at delivery were only available from 2013. A slight upward trend of mean maternal age was found before and after 2015 (30.6 years vs 32.1 years). Due to the limited data for maternal age, we did not analyze its association with U5MR before and after 2015. Fig. 3 showed the interrupted time series analysis results of impact of two-child policy on under-5 child mortality rates. It showed that the mortality rates have been decreased annually by 0.04 ‰, 0.27 ‰, 0.36 ‰, 0.07 ‰ and 0.43 ‰ for early neonatal (p = 0.519), neonatal ($p < 0.001$), infants ($p < 0.001$), children aged 1–4 years (p = 0.010), and under-5 children (p = 0.010) before 2015, respectively. After 2015, only the slope changing of mortality rates in infants and under 5 years decreased significantly by 0.16 ‰ (p < 0.001) and 0.19 ‰ (p = 0.003) per year, respectively.

3.4. Utilization of healthcare services before death for under-5 children

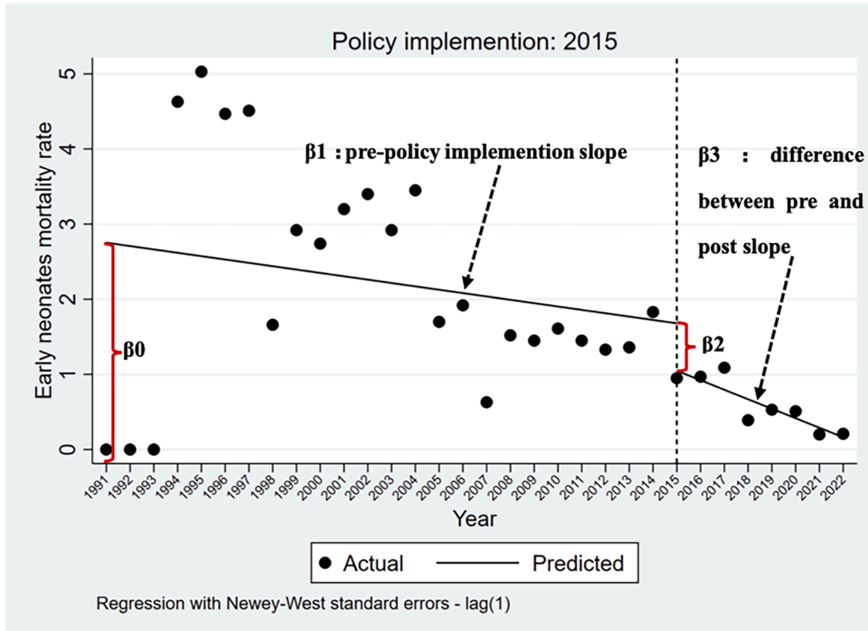
As shown in the Table 3, from 1991 to 2022, the proportion of hospitalization for under-5 children before death in Xicheng District of Beijing were 79.19 % (628/793). There were 11.73 % (93/793) cases were treated at outpatient, and 9.08 % (72/793) did not seek medical treatment. With regard to died place, 79.45 % (630/793) died in hospital. There were 122 (15.38 %) cases died in family; and 41 cases died on the way to hospital, accounting for 5.17 %.

4. Discussion

To the best of our knowledge, this is the first study to calculate the change in under-5 mortality using the time-serial Under-5 Mortality Rate Surveillance Network data in the Xicheng district of Beijing, China. We found that the mortality rates in early neonates, neonates, infants, children aged 1–4 years and U5MRs in the Xicheng district exhibited an overall trend of decline, with reductions by 93.02 %% from 1991 to 2022, respectively. The main causes for neonates and U5MR were birth asphyxia and intracranial hemorrhage, and intracranial hemorrhage in 1991, respectively. In 2022, no significant cause-specific death causes were observed with only 2 neonatal and 5 under-5 children death. The findings of this study showed that a considerable progress in reducing U5MRs was achieved over the past 32 years in Xicheng district of Beijing, China.

In 2009, the mortality rates in infants and under-5 children were reduced to 2.53 ‰ and 3.43 ‰, respectively, thereby achieving one of the aims (to reduce infant mortality to < 4 ‰ and the U5MR to < 5 ‰) of the Beijing Twelfth Five-year Period Children Development Plan (2011–2015) 6 years ahead of schedule. The U5MR in 2016 was further reduced to 2.48 ‰, which was lower than the levels in developed countries such as Japan (2.70 ‰) and Singapore (2.70 ‰) (World Health Organization, 2015; UNICEF, 2015). Remarkably, the low levels lasted during 2017–2019. Nevertheless, a reverse increase in U5MR (3.09 ‰) was observed in 2020 which might be related to the COVID-19 pandemic. Due to this crisis, the health system is overwhelmed by disrupting and constraining the access to routine health services such as interruption of newborn care, prevention, and treatment of childhood illnesses including immunization services, which could potentially contribute to plenty of additional under-5 children's deaths. The UN Department of Economic and Social Affairs reported COVID-19

A



Parameters	Coefficient	Newey-West standard error	t	*p*	95% CI
Baseline (β0)	2.75	1.13	2.45	0.021	0.447, 5.06
Pre-policy trend (β1)	-0.04	0.07	-0.65	0.519	-0.18, 0.10
Instant trends shift in 2015 (β2)	-0.63	0.58	-1.08	0.289	-1.83, 0.56
Slope change after 2015 (β3)	-0.08	0.07	-1.17	0.251	-0.22, 0.06

Fig. 3. The interrupted time series regression model with mortality rates changes among children of different ages in Xicheng district of Beijing, China, 1991–2022: (A) children aged < 7 days; (B) neonates (<28 days); (C) infants (<1 year); (D) 1–4 years; (E) under-5 children. Dots represent observed mortality rate per year, solid lines represent regression-predicted mortality rate. The vertical dashed line separates before and after the implementation of the two-child policy in 2015. CI: confidence interval.

threatens to reverse the progress of SDG 3 including childhood mortality as most countries halted childhood vaccinations and basic health services as a part of COVID-19 public health restrictions (the Lancet Public Health, 2020). Fortunately, with the collective efforts to curve the challenges resulting from COVID-19 pandemic, the U5MR declined and remained at about 1 ‰ in 2021–2022. It should be taken as an opportunity to spur efforts to continue efficiently in the next decade to meet the SDG target. Overall, Xicheng district has achieved SDGs and has also achieved the target requirements of the Beijing's '14th Five-Year Plan' for child development in advance, with the IMR below 3 ‰ and the U5MR below 4 ‰. The U5MR (1.03 ‰) of Xicheng district are significantly lower than that in Beijing in 2021 (2.21 ‰) and in China in 2020 (5.4 ‰) (Beijing Municipal Health Commission, 2022), as well as lower than that in Japan (2.58 ‰) and Germany (3.57 ‰) in 2020 (UNICEF, 2021). There were a series of interventions that have caused the huge drop in child mortality in Xicheng district. These might be lessons for other countries/districts in China which are still struggling with high child mortality. In the actual work, Xicheng district have been focused on strengthening the construction of neonatal resuscitation professionals, improving related equipment, and strengthening the training and assessment of neonatal resuscitation. In addition, midwifery institutions have adopted a series of concrete measures, including strengthening the level of collaboration between obstetrics and pediatrics, pediatricians participating in obstetrics, in high-risk maternal monitoring, and in the assessment and rescue of newborns. As for hospitals that do not have rescue conditions, high-risk newborns should be referred timely; improving their ability to resuscitate newborns would be a priority.

In 2014, the Selective Two-child Policy was implemented and the mean maternal age at childbirth increased in Beijing (Xue, 2015). Advanced maternal age might be a risk factor for many disorders in under-5 children (Chen et al., 2016; Liu et al., 2015). Inconsistent with results from Cao H et al (Han et al., 2017), no increase but a slightly decline was found in the U5MR, death of children aged 1–4 years, IMR, NMR, and ENMR in 2015 compared with 2014. Moreover, the cause-specific mortality rate of preterm/low birth weight did not increase during 2013–2015. Therefore, it may suggest that the Selective Two-child Policy did not induce an upward trend in the U5MR Xicheng district of Beijing. The finding might be explained by the high level of healthcare and medical treatment available. However, it did not mean we should let our guard down. The mortality indicators may reflect the socioeconomic development in certain areas. Previous studies showed that IMR in countries from the lowest gross domestic product (GDP) quintile were 4 times as high as those reported in countries from the highest quintile (Rosero-Bixby, 2004). Despite maternal and child healthcare still faces challenges and increasing healthcare expenditure should be provided, it is promising to see the further decline in U5MRs with the economic development over time.

Advanced maternal age has been shown to be a risk factor for prematurity and congenital abnormalities (Chen et al., 2016; Engle and

Table 3
Utilization of healthcare services before death in under-5 children in Xicheng district of Beijing, China, 1991–2022.

Year	Died place						Treatment					
	Hospital		Road to hospital		At home		Hospitalization		Outpatient treatment		No treatment	
	n	%	n	%	n	%	n	%	n	%	n	%
1991	49	83.05	1	1.69	9	15.25	49	83.05	3	5.08	7	11.86
1992	55	85.94	2	3.13	7	10.94	50	78.13	5	7.81	9	14.06
1993	36	80.00	0	0.00	9	20.00	38	84.44	3	6.67	4	8.89
1994	37	86.05	2	4.65	4	9.30	35	81.40	6	13.95	2	4.65
1995	31	79.49	3	7.69	5	12.82	34	87.18	4	10.26	1	2.56
1996	25	78.13	1	3.13	6	18.75	28	87.50	4	12.50	0	0.00
1997	27	87.10	0	0.00	4	12.90	23	74.19	7	22.58	1	3.23
1998	13	72.22	2	11.11	3	16.67	16	88.89	1	5.56	1	5.56
1999	22	78.57	2	7.14	4	14.29	24	85.71	1	3.57	3	10.71
2000	21	95.45	1	4.55	0	0.00	21	95.45	0	0.00	1	4.55
2001	19	86.36	2	9.09	1	4.55	18	81.82	3	13.64	1	4.55
2002	22	88.00	2	8.00	1	4.00	18	72.00	5	20.00	2	8.00
2003	19	90.48	0	0.00	2	9.52	14	66.67	5	23.81	2	9.52
2004	10	62.50	1	6.25	5	31.25	13	81.25	1	6.25	2	12.50
2005	14	87.50	0	0.00	2	12.50	13	81.25	2	12.50	1	6.25
2006	10	66.67	3	20.00	2	13.33	9	60.00	3	20.00	3	20.00
2007	7	53.85	2	15.38	4	30.77	9	69.23	1	7.69	3	23.08
2008	20	68.97	2	6.90	7	24.14	24	82.76	0	0.00	5	17.24
2009	15	78.95	1	5.26	3	15.79	14	73.68	4	21.05	1	5.26
2010	17	73.91	2	8.70	4	17.39	21	91.30	1	4.35	1	4.35
2011	14	73.68	0	0.00	5	26.32	17	89.47	2	10.53	0	0.00
2012	15	78.95	2	10.53	2	10.53	14	73.68	2	10.53	3	15.79
2013	14	63.64	2	9.09	6	27.27	13	59.09	5	22.73	4	18.18
2014	25	83.33	0	0.00	5	16.67	23	76.67	4	13.33	3	10.00
2015	18	75.00	1	4.17	5	20.83	16	66.67	7	29.17	1	4.17
2016	18	78.26	2	8.70	3	13.04	17	73.91	3	13.04	3	13.04
2017	17	73.91	0	0.00	6	26.09	20	86.96	1	4.35	2	8.70
2018	9	81.82	1	9.09	1	9.09	10	90.91	0	0.00	1	9.09
2019	8	61.54	2	15.38	3	23.08	11	84.62	1	7.69	1	7.69
2020	14	77.78	1	5.56	3	16.67	10	55.56	5	27.78	3	16.67
2021	5	83.33	1	16.67	0	0.00	3	50.00	3	50.00	0	0.00
2022	4	80.00	0	0.00	1	20.00	3	60.00	1	20.00	1	20.00
Total	630	79.45	41	5.17	122	15.38	628	79.19	93	11.73	72	9.08

Kominiarek, 2008). Also, the average age at delivery in Beijing has increased since the implementation of the Selective Two-child Policy in 2014. In our study, only a small fraction of maternal age at delivery were only available from 2013. A slight upward trend of mean maternal age was found before and after 2015 (30.6 years vs 32.1 years). However, no increasing but slight downward of NMR and U5MR was found during this corresponding period. Despite the slightly increasing maternal age was observed after 2015, our ITSA results showed that the Selective Two-child Policy did not induce a major boost in birth rate in Xicheng district, Beijing. Instead, the continued declining trend was found for IMR and U5MR after 2015. In addition, the declined NMR and U5MR after 2015 may be attributed mainly to the high level of healthcare and medical treatment available.

Overall, the top three causes of death among under-5 children in Xicheng district were congenital heart disease, birth asphyxia, and other congenital abnormalities (except congenital heart disease and congenital stupidity), which were consistent with the leading causes of death among under-5 children in Beijing (Beijing Municipal Health Commission, 2021). It was also consistent with the findings from Shanghai and Shenzhen city, which are two cities with substantially economic development in China. In Jinshan District of Shanghai from 2008 to 2017, the top two deaths of under-5 children were birth asphyxia and congenital heart disease (Ma, 2019). Preterm/low birth weight and birth asphyxia were ranked as the top two deaths of under-5 children in Bao 'an District of Shenzhen from 2011 to 2020 (Xing, 2020). Specifically, congenital heart disease has been the leading cause of death in under-5 children in Xicheng district in Beijing since 1993. However, the overall rate of death due to congenital heart disease is extremely low. There were no reported deaths caused by congenital heart disease during 2019 and 2022. In order to achieve early detection, diagnosis and treatment, Beijing has established a local children's congenital heart disease screening and referral network since 2009. Despite that, the fluctuated trend was observed from 2010 to 2018. Otherwise, we found that other congenital abnormalities were the third place in total death causes from 1991 to 2022. Therefore, we should further strengthen the ability of screening and treatment and accurately identify the potential risk factors in advance, then the objective of decreasing the occurrence of related congenital heart disease and improving the survival rate for under-5 children with this disease could be accomplished and persisted. Of note, birth asphyxia continued to be one of the five leading causes of death in under-5 children in Xicheng District of Beijing. However, a sharp decline in death due to birth asphyxia was found, especially since 2018. This might be explained by the increasing rate of caesarean sections (Han et al., 2017). Several studies suggested that the increase in the caesarean section rate could reduce the occurrence of birth asphyxia (Ramachandrappa and Jain, 2008; Pedro et al., 2011). More important, the rate of birth asphyxia has decreased in recent years, which is mainly due to the continuous efforts of neonatal resuscitation in Xicheng District. With the implementation of the Guidelines for the Care of Premature Infants issued by National Health Commission, we will continue to promote the health care management of premature infants, combining the three-level prevention strategy, and further enhance the ability of identifying the critical illness and making timely referral.

The level of access to medical care before the children death could reflect the local level of medical services, our results showed that most of the children died in hospital, which was consistent with the previous studies (Dan et al., 2020; Liu et al., 2020). Neonatal interfacility transport was an important part of regionalized perinatal care. It could enable ill or preterm neonates to receive the best possible care from medical staff with an appropriate level of expertise (Leemann et al., 2020). However, there were some children died without medical treatment. Therefore, in addition to strengthening the treatment of critically ill neonates, strengthening the health care and education of parents would be also important ways to ensure the safety of children (Lu et al., 2016).

Additionally, hospitals at all levels should focus on improve the skills of pediatricians and nursing staff in order to cope with emergency situations. In addition, the medical level of community hospitals should be improved to balance medical resources.

There were several limitations in this study. First, due to the availability and representativeness of data in our analysis, we only analyzed the death data of Xicheng District in Beijing, which limited us to generalize our results. The interpretation of our findings could be suitable for the specific Xicheng region. Second, the use of under-5 children death surveillance data sources also limited the statistical power of our analyses, precluding the use of rigorous multivariable analyses, because only partial characteristics data would be collected. Therefore, we still could not explore the variation in district-wise mortality and its relationship with social development. The mortality indicators in urban areas have their own unique set of problems (Kyu et al., 2013; Bhandari et al., 2002). Another limitation is that, due to the available child death surveillance data, our current analysis only focuses on level and change in U5MR at the district level in Beijing, China. The further analysis of child deaths associated with disease burden could not be performed. Rigorous analysis on this aspect should be undertaken using several data sources or survey that can better guide intervention efforts to reduce U5MR in local regions.

5. Conclusions

In conclusion, the mortality rate of under-5 children showed a fluctuated but overall declined trend in Xicheng District of Beijing, China from 1991 to 2022. Congenital heart disease and birth asphyxia were still the top two death reasons for under-5 children. It still suggests that maternal and child health-workers need to further strengthen and improve routine monitoring and quality management. Based on the coordination and linkage among families, communities and medical institutions, targeted interventions should be carried out for high-risk newborns group to effectively protect children's life safety and contribute to build a healthy China.

Authors contributions

HY. Chen and XW. Zhang conceived and planned the study. SQ. He and HR. Zhang carried out the statistical analyses and drafted the manuscript. XR. Liu and YG. Li extracted the data. YG. Li and B. Wang processed the data. All authors read and approved the final manuscript.

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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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