frontiers in Environmental Science

ORIGINAL RESEARCH
published: 07 February 2022
doi: 10.3389/fenvs.2022.828408

The Burden of Neonatal Diseases Attributable to Ambient PM 2.5 in China From 1990 to 2019

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Background: Air pollution exposure is an environmental risk to public health. And the available data on relationships of air pollution and neonatal disease burden are scarce. This study assessed neonatal disease burden attributable to Particulate Matter 2.5 (PM 2.5) pollution in China.

Methods: This is a retrospective analysis with data from the GBD2019 database. Data of PM 2.5 pollution exposure levels and neonatal disease burden attributable to PM 2.5 in China from 1990 to 2019 were obtained from the Global Burden of Disease Study 2019 (GBD 2019); Data of PM2.5 concentration was collected from the Bulletin of the State of the Ecological Environment in China; Data of perinatal mortality was collected from the Chinese Maternal and Child Health Surveillance Network. Deaths, Disability-adjusted life years (DALYs), Year of life lost (YLLs), and Years lived with disability (YLDs) are primary indicators used to assess neonatal diseases burden. The correlation of PM2.5 pollution and neonatal death was analyzed. Average Annual Percentage Change (AAPC) and increment were used to assess exposure levels and disease burden trends.

Results: PM 2.5 pollution exposure level of newborns in China is much higher than global average, 32.08 per 100 people (95% UI: 26.57–38.06) in 2019 compared to 1990 (15.86 per 100 people, 95% UI: 6.83–30.88), with an increase of 102.27%. And it is statistically verified PM2.5 concentration was positively correlated with neonatal disease deaths ($r = 0.9534$, $p = 0.0009$) and DALYs ($r = 0.9534$, $p = 0.0009$). The overall disease burden of neonatal diseases attributed to PM 2.5 pollution in China has decreased from 1990 to 2019, with a decrement of 5738.34 deaths (decreased: 56.85%), 51.01 person/years (decreased: 56.84%) for DALYs, 51.23 person/years (decreased: 57.11%) for YLLs and an increase of 150.69 person/years (increased: 31.71%) for YLDs.

Conclusion: There exists positive correlation between environmental pollution and neonatal diseases in China. The number of neonatal disease deaths, DALYs, and YLLs due to PM 2.5 pollution showed a decreasing trend with the environmental pollution control. For the rising YLDs, there is a need to improve survival rates while focusing on prognosis of neonatal disease and reducing the burden of disease brought on by disability. Controlling environmental pollution is likely to help reduce neonatal disease burden, especially premature birth and neonatal encephalopathy.

Keywords: particulate matter pollution, PM 2.5, neonates, disease burden, GBD2019

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Specialty section:
This article was submitted to Atmosphere and Climate, a section of the journal Frontiers in Environmental Science

Received: *03 December 2021*
Accepted: *17 January 2022*
Published: *07 February 2022*

Citation:
Yuan J, Shi L, Li H, Zhou J, Zeng L, Cheng Y and Han B (2022) The Burden of Neonatal Diseases Attributable to Ambient PM 2.5 in China From 1990 to 2019. Front. Environ. Sci. 10:828408. doi: 10.3389/fenvs.2022.828408

INTRODUCTION

Newborns' first 28 days of life (neonatal period) are the most vulnerable period for a child's survival, with approximately 2.5 million children dying each year in the first month of life (EF et al., 2017). Newborns may suffer from various diseases in this stage, such as prematurity, neonatal encephalopathy, jaundice, and sepsis. The main causes of newborns' death are preterm birth and intrapartum-related complications and infections, such as sepsis, meningitis, and pneumonia. The global neonatal mortality rate decreased from 3.66% in 1990 to 1.80% in 2017, with China decreasing from 2.95% in 1990 to 0.47% in 2017. In the United States, the neonatal mortality rate decreased from 0.58% in 1990 to 0.36% in 2017, while in Japan, it decreased from 0.25% in 1990 to 0.09% in 2017. In 2017, neonatal diseases were ranked ninth in the YLL ranking of the 25 leading causes of death of newborns in China (Zhou et al., 2019). Neonatal diseases are complex, and the mortality rate has decreased significantly with the development of medical and neonatal care; however, the potential for developmental disability cannot be ignored. The impact of neonatal disease on quality of life increases the burden of disease.

Air pollution has a negative impact on human health. Particulate Matter 2.5 (PM 2.5) is one of the main air pollutants. It has been shown that PM 2.5 pollution impacts maternal health during pregnancy and affects the outcome of birth, especially the birth weight and the preterm birth (Jacobs et al., 2017). Ambient particulate matter pollution was one of the top 4 risk factors for deaths and DALY percentages in China in 2017 where age-standardized Summary Exposure Values (SEV) have increased from 1990 to 2017, which is the largest change of age-standardized SEV among the top 10 risk factors in China (Zhou et al., 2019). The Chinese government has been actively combating air pollution over the past few years; even PM 2.5 pollution has been controlled strictly and its concentration has decreased obviously. Moreover, the long-term average absolute level of air pollution in China is still high, and the burden of disease due to those air pollution has decreased, but some areas are still on the rise (Huang et al., 2018; Yin et al., 2020; Zhang et al., 2021).

In recent years, the health effects of air pollution on newborns have received increasing attention. Therefore, this study aimed to assess the burden of neonatal diseases caused by PM 2.5 pollution in China from 1990 to 2019. Furthermore, to understand more systematically the burden of neonatal diseases attributable to PM 2.5 pollution in China and explore the pattern of change over the past 30 years; And the analysis results will provide a basis for rational allocation of health resources and the formulation of health policies.

MATERIALS AND METHODS

Data Sources

The 2019 Global Burden of Disease (GBD) project comprehensively assesses the disease burden for 87 risk factors in 204 countries and territories worldwide. The GBD publishes data on attributable mortality, disability-adjusted life years (DALYs), years of life lost (YLLs), and years lived with disability (YLDs) data. The current data is given for 1990–2019 (Murray et al., 2020). YLL was estimated by multiplying the estimated number of deaths by the patient's age with the standard life expectancy at that corresponding age. The YLD due to disease-induced disability was estimated by multiplying the disease prevalence with different disability weights, and the DALY was obtained by summing YLD and YLL (Liu et al., 2019). The rates were all age-standardized using the world standard population developed by the GBD research (Feigin et al., 2015).

In the GBD database, the primary data used to estimate mortality in China were obtained from the Chinese Center for Disease Control and Prevention, the Chinese Disease Surveillance Point System (DSPs), the Chinese Maternal and Child Health Surveillance Network, the Chinese Health Statistical Yearbook, and data from published and unpublished studies and reports (Luo et al., 2017). The GBD $PM_{2.5}$ values were derived from the integration of satellites combined with a chemical transport model, surface measurements, and geographical data at a 0.1° × 0.1° (approximately 11 km × 11 km at the equator) resolution, and then aggregated to national-level population-weighted means to produce a national exposure estimate (Brauer et al., 2016; Cohen et al., 2017; Liu et al., 2021).

Data Analysis Parameters

The data used in this study was obtained from GBD 2019 through the Global Health Data Exchange query tool (GHDx, http://ghdx.healthdata.org/gbd-results-tool) with data refinement distinguishing between years, genders, attributions, and ages (Liu et al., 2021). The PM2.5 exposure data and the neonatal disease burden data attributable to PM2.5 from 1990 to 2019 were extracted from the GHDx. Deaths, DALYs, YLLs, and YLDs, were the main indicators used to assess the disease burden in newborns. Neonatal diseases are divided into five categories: neonatal preterm birth, neonatal encephalopathy due to birth asphyxia and trauma, hemolytic disease, neonatal jaundice, neonatal sepsis, and other neonatal infections and disorders.

The data on China's PM2.5 concentration comes from the Bulletin of the State of the Ecological Environment in China issued by the Ministry of Ecology and Environment of the People's Republic of China (https://www.mee.gov.cn/). The data on perinatal mortality in China comes from the Chinese Maternal and Child Health Surveillance Network (http://www.mchscn.cn/).

Statistical Analysis

The annual percentage change (APC) and average annual percentage change (AAPCs) were used to evaluate the change trend of PM2.5 exposure from 1990 to 2019. APCs were used to detect specific segments of the linear trend throughout the study. AAPCs were used to estimate the overall change. APC, AAPC, and its 95% CI were calculated using Joinpoint Regression Program 4.9.0.0, and differences were considered significant at $p < .05$.

GraphPad prism 5 was used to plot the figures and describe population exposure levels of PM2.5 pollution and its changes in

TABLE 1 | Trends in PM 2.5 exposure of the whole population globally and in China from 1990 to 2019 (SEV, 95%UI).

Year	Whole population		Neonates	
	Global	China	Global	China
1990	15.65 (10.62–21.58)	16.92 (7.57–30.64)	13.27 (8.22–19.58)	15.86 (6.83–30.88)
1991	15.82 (10.81–21.61)	17.47 (7.99–31.46)	13.38 (8.45–19.52)	16.31 (7.21–30.71)
1992	16.02 (11.06–21.71)	18.08 (8.54–32.19)	13.50 (8.63–19.60)	16.80 (7.71–30.61)
1993	16.24 (11.26–22.04)	18.75 (8.97–32.77)	13.65 (8.76–19.57)	17.34 (8.11–30.91)
1994	16.48 (11.49–22.28)	19.47 (9.45–33.45)	13.81 (8.95–19.66)	17.92 (8.70–31.39)
1995	16.73 (11.74–22.50)	20.23 (10.01–34.34)	14.00 (9.16–19.77)	18.56 (8.94–32.60)
1996	17.03 (12.08–22.63)	21.08 (10.90–34.64)	14.22 (9.37–19.89)	19.28 (9.71–33.12)
1997	17.43 (12.49–23.05)	22.08 (11.98–35.34)	14.53 (9.70–20.15)	20.11 (10.73–33.33)
1998	17.89 (12.98–23.52)	23.15 (13.39–36.02)	14.91 (9.97–20.57)	20.98 (11.62–34.56)
1999	18.34 (13.46–23.98)	24.19 (14.36–37.50)	15.27 (10.31–20.95)	21.83 (12.48–35.22)
2000	18.73 (13.70–24.45)	25.12 (15.26–38.25)	15.58 (10.64–21.36)	22.6 (13.13–35.62)
2001	19.01 (13.96–24.56)	25.92 (16.37–38.27)	15.78 (10.85–21.55)	23.26 (14.24–36.09)
2002	19.27 (14.28–24.61)	26.72 (17.61–38.25)	15.94 (11.03–21.53)	23.93 (14.92–36.25)
2003	19.53 (14.62–24.63)	27.54 (18.43–38.03)	16.13 (11.23–21.79)	24.64 (15.54–36.02)
2004	19.83 (14.95–24.87)	28.38 (19.00–38.93)	16.35 (11.45–21.85)	25.38 (16.36–36.80)
2005	20.17 (15.32–25.30)	29.25 (19.78–39.58)	16.64 (11.73–22.18)	26.13 (17.23–37.27)
2006	20.60 (15.73–25.50)	30.21 (21.74–38.97)	16.99 (12.19–22.26)	26.94 (18.55–36.50)
2007	21.15 (16.38–25.82)	31.38 (23.72–39.15)	17.44 (12.74–22.75)	27.91 (20.33–36.28)
2008	21.77 (17.06–26.28)	32.64 (25.40–39.47)	17.96 (13.29–23.20)	28.97 (21.98–36.18)
2009	22.40 (17.74–26.96)	33.88 (26.74–40.28)	18.50 (13.89–23.71)	30.04 (23.55–36.43)
2010	22.98 (18.28–27.62)	34.98 (27.90–41.25)	19.04 (14.40–24.30)	30.98 (24.61–37.40)
2011	23.64 (18.87–28.21)	36.10 (29.21–42.30)	19.74 (15.11–24.81)	31.97 (25.68–38.30)
2012	24.45 (19.64–28.95)	37.36 (30.42–43.49)	20.71 (16.03–25.85)	33.11 (26.84–39.42)
2013	25.27 (20.42–29.85)	38.54 (31.63–44.66)	21.63 (16.78–26.83)	34.17 (27.84–40.43)
2014	25.92 (21.01–30.52)	39.45 (32.57–45.67)	22.27 (17.37–27.66)	34.93 (28.56–41.14)
2015	26.19 (21.27–30.80)	39.83 (33.24–45.94)	22.72 (17.88–28.15)	35.22 (28.97–41.34)
2016	25.80 (20.97–30.21)	38.77 (32.44–44.65)	22.48 (17.80–27.72)	33.91 (28.03–39.90)
2017	25.41 (20.73–29.73)	37.53 (31.57–43.28)	21.99 (17.29–27.11)	32.44 (26.73–38.42)
2018	25.64 (21.01–29.90)	37.35 (31.64–43.08)	22.04 (17.42–27.04)	32.11 (26.58–38.02)
2019	26.22 (21.57–30.50)	37.57 (31.94–43.25)	22.60 (17.96–27.69)	32.08 (26.57–38.06)

China and globally from 1990 to 2017. And Pearson Correlation was analyzed to directly explore the correlation between PM2.5 pollution concentration and the neonatal death rate, also used to analyze the current level of mortality and disease burden attributable to PM 2.5 pollution among Chinese newborns from 1990 to 2019, as well as the magnitude of their changes.

RESULTS

Trends in PM 2.5 Exposure of the Whole Population

The PM 2.5 SEV in Global whole population increased from 15.65 (95% UI:10.62–21.58) per 100 population in 1990 to 26.22 (95% UI:21.57–30.50) per 100 population in 2019. Although a decreasing trend was observed from 2015 to 2017, the global average exposure level of PM 2.5 steadily increased between 1990 and 2019, with an increase of 71.20%. The global AAPC in PM 2.5 exposure level was 1.8% (95% CI: 1.7–1.9%) with an overall increasing trend. There existed a fastest increasing period from 2006 to 2014, with a statistically significant APC of 3.0% (95% CI: 2.9–3.1%).

Conversely, the PM 2.5 SEV in whole population of China was 16.92 (95% UI: 7.57–30.64) per 100 population in 1990, which is close to the global SEV, but has been increasing since then at a much higher rate than the global average. The SEV value increased to 37.57 (95% UI: 31.94–43.25) per 100 population in 2019, with a downward trend starting in 2015; however, an overall upward trend of 133% was observed from 1990 to 2019 and has remained high compared to the global average. The AAPC of PM 2.5 exposure level in China was 2.8% (95% CI: 2.6–2.9%). An overall increasing trend with the fastest increasing period being from 1995 to 1999 with an APC of 4.6% (95% CI: 3.5–5.7%) and a decreasing trend in 2014–2019 with an APC of −1.4% (95% CI: −1.9-0.9%), which was statistically significant (**Tables 1**, **2**; **Figure 1**).

Trends of Neonatal PM 2.5 Exposure Levels

The PM 2.5 SEV in Global newborns population increased from 13.27 (95% UI:8.22–19.58) per 100 people in 1990 to 22.60 (95% UI:17.96–27.69) per 100 people in 2019. The average exposure level showed an overall upward trend from 1990 to 2019 with an increase of 71.11%. The global AAPC in neonatal PM 2.5 exposure levels was 1.8% (95% CI: 1.5–2.1%). An overall increasing trend with the fastest increasing period being from 2010 to 2014 with a statistically significant APC of 4.3% (95% CI: 3.0–7.4%).

PM 2.5 exposure levels among Chinese newborns increased from 16.88 (95% UI: 7.55–30.62) per 100 people in 1990 to 32.08 (95% UI:26.57–38.06) per 100 people in 2019. A downward trend

TABLE 2 | The analysis of trends in PM 2.5 exposure of the whole population globally and in China from 1990 to 2019 according to the APC and the AAPC.

Location	Period	Index	General population			Neonates		
			Value	95% CI	*p* Value	Value	95% CI	*p* Value
Global	1990–1995	APC	1.3[a]	1.2–1.5	<.001	1.0[a]	0.5–4.1	.001
	1995–2000		2.3[a]	2.1–2.5	<.001	2.2[a]	1.5–6.2	<.001
	2000–2006		1.5[a]	1.4–1.7	<.001	1.2[a]	0.4–3.4	.005
	2006–2014		3.0[a]	2.9–3.1	<.001	2.8[a]	2.0–7.7	<.001
	2014–2017		−0.6	−1.3–0.0	.060	4.3[a]	3.0–7.4	<.001
	2017–2019		1.2[a]	0.5–1.9	.002	−.2	−0.7~-0.7	.522
	1990–2019	AAPC	1.8[a]	1.7–1.9	<.1	1.8[a]	1.5–2.1	<.1
China	1990–1995	APC	3.6[a]	3.1–4.2	<.001	3.1[a]	2.3–3.9	<.001
	1995–1999		4.6[a]	3.5–5.7	<.001	4.0[a]	3.2–4.8	<.001
	1999–2014		3.4[a]	3.3–3.5	<.001	3.3[a]	3.1–3.4	<.001
	2014–2019		−1.4[a]	-1.9~-0.9	<.001	−2.0[a]	-2.6~-1.5	<.001
	1990–2019	AAPC	2.8[a]	2.6–2.9	<.1	2.4[a]	2.2–2.6	<.1

[a]*Represents p < .05, the difference is statistically significant.*

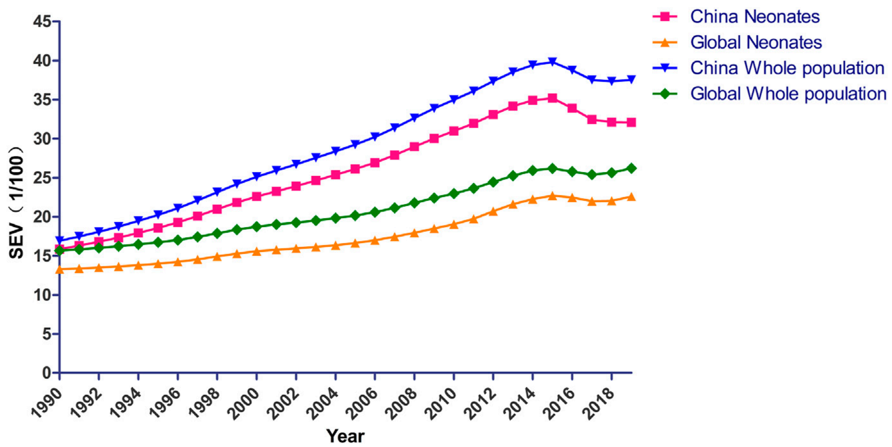

FIGURE 1 | Trends in PM 2.5 exposure of the whole population and newborns globally and in China from 1990 to 2019.

began in 2015; however, the overall trend over the period of 1990–2019 showed an upward trend with an increase of 102.27% and was beyond the global average. The mean AAPC in PM 2.5 exposure levels for newborns in China was 2.4% (95% CI: 2.2–2.6%). An overall increasing trend with the fastest increasing period from 1994 to 1999 with an APC of 4.0% (95% CI: 3.2–4.8%) and a decreasing trend from 2014 to 2019 with an APC of - 2.0% (95% CI: 2.6% to −1.5%), which is statistically significant. (**Tables 1**, **2**; **Figure 1**).

Correlation Analysis Between PM2.5 Concentration and Neonatal Disease Burden

The PM2.5 concentration is positively correlated with the burden of neonatal disease by Pearson Correlation analysis, showing that the data in GBD is consistent with the data from the China Maternal and Child Health Surveillance Network. Data from GBD shows that both neonatal disease deaths (r = 0.9534, p = 0.0009) and DALYs (r = 0.9534, p = .0009) in China are positively correlated with PM2.5 concentrations. Data obtained from the Chinese Maternal and Child Health Surveillance Network shows that the perinatal mortality rate is positively correlated with the concentration of PM2.5 (r = 0.9134, p = .004) (**Figure 2**).

Neonatal Disease Burden Attributable to PM 2.5 Pollution in China

From 1990 to 2019, the overall neonatal disease deaths, DALYs, and YLLs due to PM 2.5 pollution in China showed a decreasing trend, while YLDs showed an increasing trend (**Figure 2**). Compared to 1990, the number of deaths in 2019 decreased by 5738.34 cases, which is a decrement of 56.85%; DALYs decreased by 51.01, which is a decrement of 56.84%; YLLs decreased by 51.23, a 57.11% drop, and the YLDs increased by 150.69, which is an increment of 31.71%. Moreover, compared to

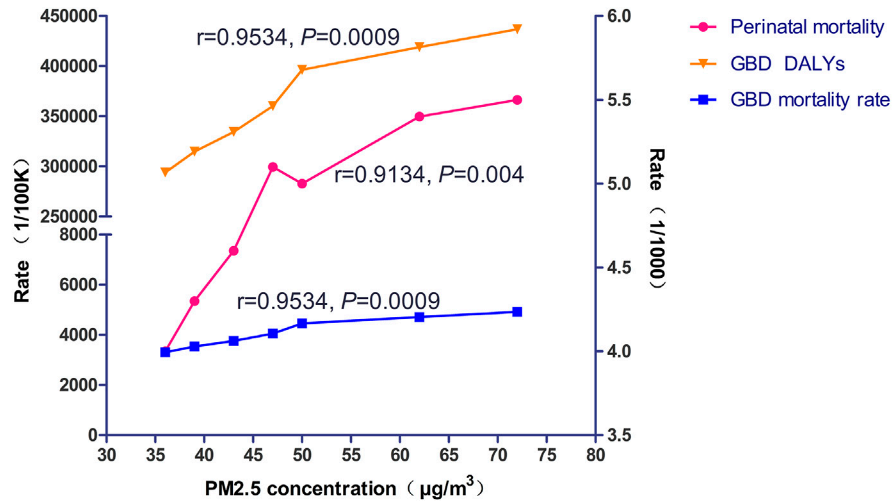

FIGURE 2 | Correlation between pm2.5 concentration and neonatal disease burden.

TABLE 3 | Neonatal disease burdens (in mortality, DALYs, YLDs, and YLLs) attributable to PM 2.5 exposure in China in 1990 and 2019.

	1990	2019	Increment	%
Mortality (person,95%UI)				
A	5476.80 (2537.60–9464.55)	2214.69 (1653.17–2782.82)	–3262.11	–59.56
B	3573.77 (1573.65–6351.33)	1484.47 (1111.38–1898.03)	–2089.30	–58.46
C	231.65 (103.94–413.66)	64.84 (47.92–84.61)	–-166.81	–72.01
D	166.3 (75.81-1–299.01)	164.91 (124.45–209.46)	–1.39	–0.84
E	645.5 (295.61–1131.09)	422.78 (315.76–544.35)	–222.72	–34.50
Total	10094.03 (4589.31–17883.13)	4351.69 (3282.10–5478.61)	–5738.34	–56.85
DALYs (person/10000/year,95%UI)				
A	48.69 (22.56–84.14)	19.71 (14.72–24.76)	–28.98	–59.52
B	31.76 (13.98–56.44)	13.19 (9.88–16.87)	–18.57	–58.47
C	2.06 (0.93–3.68)	0.58 (0.43–0.75)	–1.48	–71.84
D	1.48 (0.68–2.66)	1.48 (1.12–1.88)	–.00065	–0.04
E	5.74 (2.63–10.06)	3.77 (2.82–4.85)	–1.97	–34.32
Total	89.74 (40.80–158.97)	38.73 (29.24–48.76)	–51.01	–56.84
YLDs (person/year,95%UI)				
A	294.85 (129.99–521.18)	300.16 (209.60–407.37)	5.31	1.80
B	31.92 (11.13–75.18)	23.34 (13.31–37.56)	–8.58	–26.88
C	26.49 (9.73–63.81)	25.17 (9.16–65.39)	–1.32	–4.98
D	62.13 (22.61–129.12)	178.94 (108.98–265.40)	116.81	188.01
E	59.80 (27.39–105.86)	98.27 (66.42–135.02)	38.47	64.33
Total	475.19 (218.62–826.69)	625.88 (440.90–834.91)	150.69	31.71
YLLs (person/10000/year,95%UI)				
A	48.66 (22.55–84.10)	19.68 (14.69–24.73)	–28.98	–59.56
B	31.76 (13.98–56.44)	13.19 (9.88–16.87)	–18.57	–58.47
C	2.06 (0.92–3.68)	0.58 (0.43–0.75)	–1.48	–71.84
D	1.48 (0.67–2.66)	1.47 (1.11–1.86)	–.01	–0.68
E	5.74 (2.63–10.05)	3.76 (2.81–4.84)	–1.98	–34.49
Total	89.70 (40.78–158.90)	38.67 (29.16–48.68)	–51.23	–57.11

Note.: A, preterm birth; B, neonatal encephalopathy due to birth asphyxia and trauma; C, hemolytic disease and other neonatal jaundice; D, neonatal sepsis and other neonatal infections; E, Other neonatal disorders.

DALYs, Disability-adjusted life years; YLDs, Years lived with disability; YLLs, Years of life lost.

TABLE 4 | Different neonatal disease burdens and the rank in mortality, DALY, YLD, and YLL attributable to PM 2.5 exposure in China in1990 and 2019 (rate/100k).

Disease	Mortality				DALY				YLD				YLL			
	1990		2019		1990		2019		1990		2019		1990		2019	
	Rank	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank	Rate
A	1	300.74	1	194.73	1	26738.98	1	17329.83	1	16.19	1	26.39	1	26722.79	1	17303.43
B	2	196.24	2	130.53	2	17439.53	2	11600.44	4	1.75	5	2.05	2	17437.78	2	11598.39
C	4	12.72	5	5.70	4	1131.59	5	508.71	5	1.45	4	2.21	4	1130.14	5	506.50
D	5	9.13	4	14.50	5	814.75	4	1304.04	2	3.41	2	15.73	5	811.34	4	1288.30
E	3	35.45	3	37.17	3	3152.71	3	3311.65	3	3.28	3	8.64	3	3149.42	3	3303.01

Note: A, Preterm birth; B, Neonatal encephalopathy due to birth asphyxia and trauma; C, Hemolytic disease and other neonatal jaundice; D, Neonatal sepsis and other neonatal infections; E, Other neonatal disorders; DALYs, Disability-adjusted life years; YLDs, Years lived with disability; YLLs, Years of life lost.

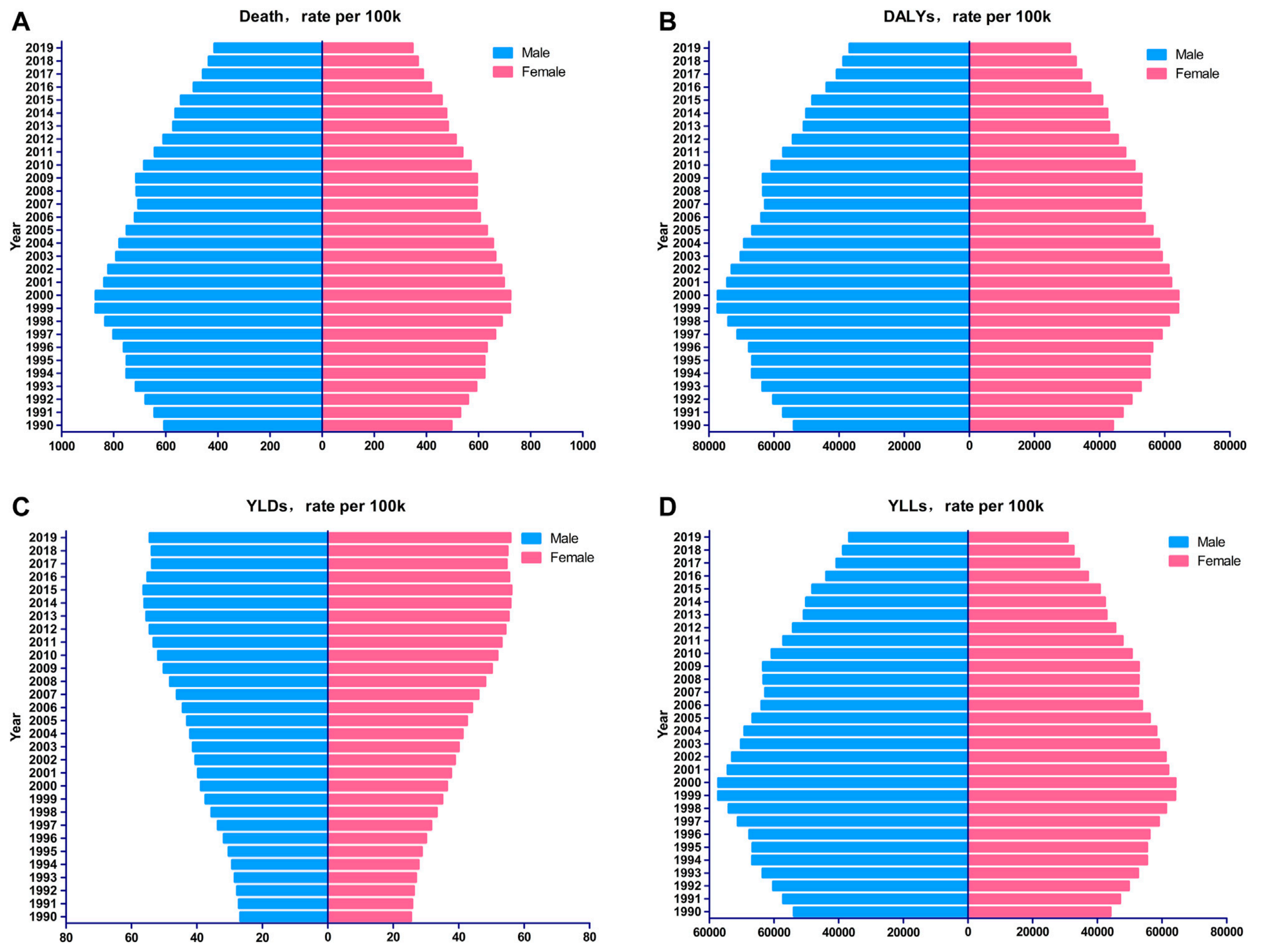

FIGURE 3 | The trends of neonatal disease burdens attributable to PM 2.5 exposure in China from 1990 to 2019 [**(A)**, mortality; **(B)**, DALYs; **(C)**, YLDs; **(D)**, YLLs].

1990, the number of deaths, DALYs, and YLLs for all types of neonatal diseases attributed to PM 2.5 pollution in China in 2019 decreased to various degrees, as shown in **Table 3**. YLDs indicators revealed a different scenario with increases of 5.31 person/years (1.8% increase), 116.81 person/years (188.01% increase), and 38.47 person/years (64.33% increase) for preterm birth, sepsis, and other infections and neonatal diseases, respectively; however, decreases of 8.58 person/years (26.88% decrease) and 1.32 person/years (4.98% decrease) for neonatal encephalopathy and hemolytic disease and jaundice, respectively were observed.

Mortality rate, DALY, YLL, and YLD rate of preterm neonatal birth due to PM 2.5 pollution in China in 1990 and 2019 is the highest among all types of neonatal diseases. Neonatal

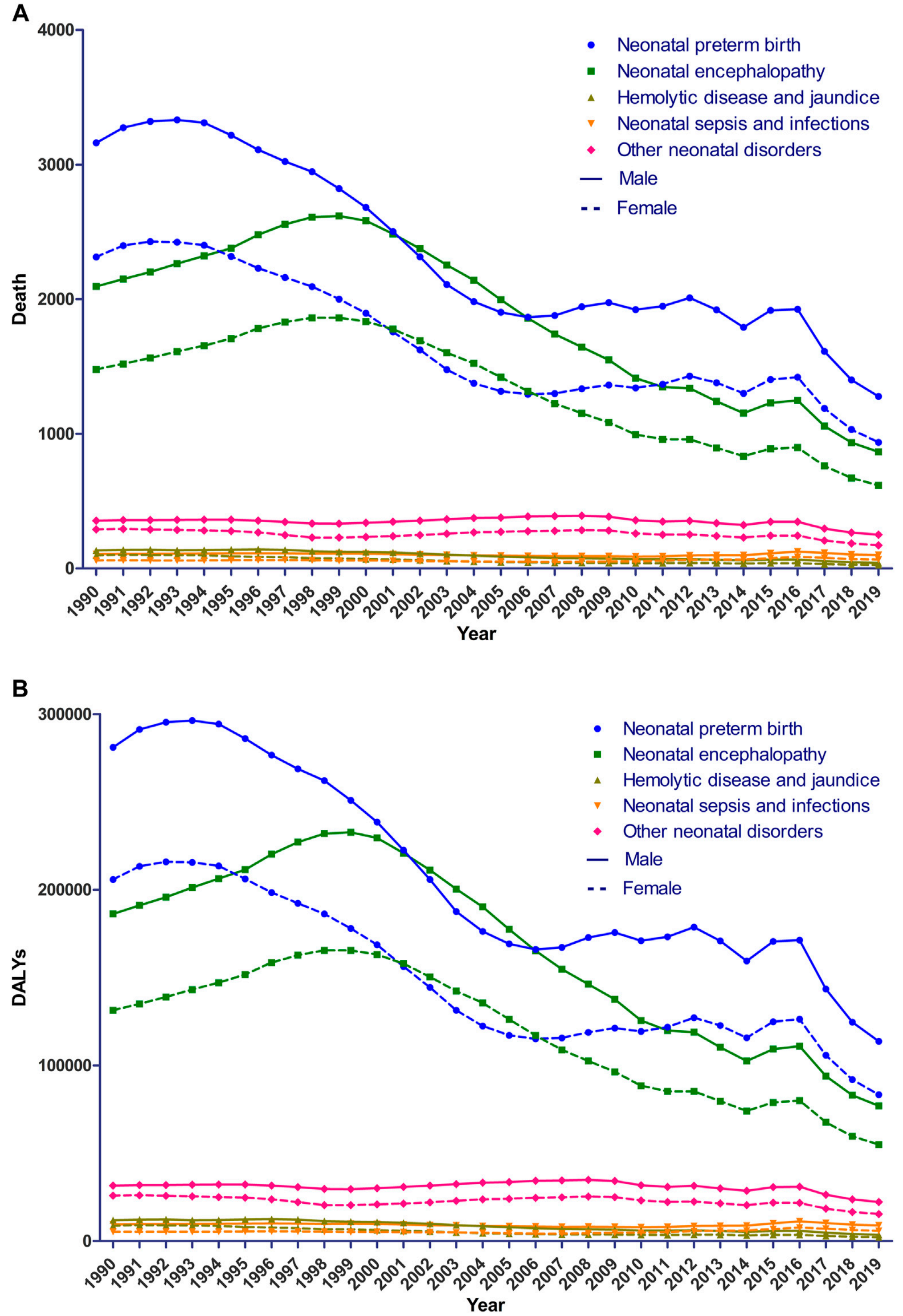

FIGURE 4 | The trends of different neonatal disease burdens in different genders attributable to PM 2.5 exposure in China from 1990 to 2019 [**(A)**, mortality; **(B)**, DALYs].

encephalopathy has the second highest mortality rate, DALY, and YLL. Sepsis and other infections had the second highest rate of YLD (**Table 4**).

The overall disease burden indicators for male infants are slightly higher than for female infants. The number of cases of death in 2019 was 2533.45 and 1818.24 for males and females, respectively. The mortality rates for males and females were 413.50 per 100K, and 346.58 per 100K, respectively. The DALYs were 225,449.84 person/years and 161,856.02 person/years for males and females, respectively (**Figure 3**). The burden of neonatal diseases attributable to PM 2.5 pollution in China decreases year to year, but the most predominant neonatal diseases are still preterm birth and neonatal encephalopathy (**Figure 4**).

DISCUSSION

As the source of various health problems, numerous scientific studies have explained the environmental risk to public health caused by particle exposure. And the available data on the relationships of particulate matter air pollution and neonatal disease burden, particularly in China, are scarce. This study assessed neonatal disease burden of attributable to PM 2.5 pollution in China from 1990 to 2019 using data related to PM 2.5 pollution exposure and neonatal disease obtained from the GBD research.

In this study, PM 2.5 pollution exposure levels among Chinese newborns were much higher than the global average and more than doubled in 2019 compared to 1990. Environmental PM2.5 concentration is positively correlated with neonatal disease burden. Though the overall disease burden of neonatal diseases attributed to PM 2.5 pollution in China has decreased from 1990 to 2019. Deaths, DALYs, and YLLs, decreased to various degrees, but YLDs for preterm birth, sepsis, and other infections and other neonatal diseases showed varying degrees of increase, which deserved more attention.

The global number of deaths attributable to PM 2.5 exposure in 2015 was 4.2 million, with 1.1 million deaths coming from China, accounting for more than a quarter of all deaths caused by PM 2.5 exposure. The mortality rate attributable to PM 2.5 pollution in China was 84.3 per 100K, more than four times that of the United States 18.5 per 100K people (Cohen et al., 2017). Globally, more than 250 million people live in highly polluted areas, primarily in east-central China and the Ganges Plains of India (Cheng et al., 2016). In 2013, China implemented the Action Plan for the Prevention and Control of Air Pollution, focusing on treatment mainly in the eastern and central regions (Huang et al., 2018). There is a decreasing trend of PM 2.5 exposure among Chinese newborns in 2014–2019 with an APC of–2.0% (95% CI: −2.6% to −1.5%, $p < .001$)., and there is a decreasing trend of mortality of neonatal diseases attributable to PM 2.5 in 2015–2019 with an APC of −6.4% (95% CI: −7.7% to −5.1%, $p < .001$). This study shows that the PM 2.5 exposure levels in China slowed down after 2013 and declined in 2015. Furthermore, the disease burden attributable to PM 2.5 pollution among newborns has also shown a significant decrease, However, China still has a severe PM 2.5 pollution problem and needs to further intensify its treatment and control efforts to reduce the damage of PM 2.5 pollution on population health.

Our research verified the data obtained in China and the GBD data, and the results showed that PM2.5 pollution does have a certain relationship with the burden of neonatal disease. One study found that short-term exposure to PM 2.5 adversely affects neonatal and postnatal mortality, specifically mortality related to respiratory causes (Yorifuji et al., 2016). A strong association between PM 2.5 and infant mortality has also been demonstrated for neonatal mortality in low- and middle-income countries (Anwar et al., 2019; Goyal et al., 2019). Several studies have also shown that PM 2.5 exposure during pregnancy or the postpartum period has adverse effects on neonatal health and results in adverse outcomes such as preterm birth, low birth weight, neonatal death, and impaired lung development (Proietti et al., 2013; Gauderman et al., 2015; Korten et al., 2017; Smith et al., 2017; Heft-Neal et al., 2018; Zhang et al., 2019; Macchi et al., 2021).

The leading causes of neonatal death are prematurity, birth-related complications, and infections such as sepsis, meningitis, and pneumonia. According the estimates from World Health Organization (WHO), 35% of all neonatal deaths in 2017 were due to complications of prematurity, 24% of deaths were related to delivery (intrapartum events), such as birth asphyxia, and 14% of deaths were due to sepsis or meningitis (Hug et al., 2019). From 1990 to 2017, there has been a significant improvement in neonatal survival globally, a 51% reduction in neonatal mortality, and a reduction in deaths from 5 million to 2.5 million per year (Hug et al., 2019). Despite this, 2.5 million newborns died in 2017 alone, with significant variation in neonatal mortality across regions and countries.

Preterm birth is an important global health issue. An estimated 15 million neonates are born preterm each year, and the rate of preterm birth has been steadily increasing worldwide (Blencowe et al., 2012). The World Health Organization's Birth Too Soon: Global Action Report on Preterm Birth, released on 02 May, 2012, states that 15 million preterm babies are born worldwide each year with more than 1 million dying soon after birth. Those who survive often endure a lifetime of accompanying illness (Hua et al., 2015). Preterm birth complications are the leading cause of death in children under 5 years of age. Approximately 1 million people died worldwide in 2015 (Liu et al., 2016). Air pollution has been shown to influence preterm birth (Sun et al., 2015; Li et al., 2017; Guan et al., 2019; Wang et al., 2020). This study shows that China has the highest mortality and disease burden of preterm births attributable to PM 2.5 pollution, with 197,100 person/years for DALYs, 300.16 person/years for YLDs, and 196,800 person/years for YLLs. It is suggested that the main contribution to the disease burden attributable to PM 2.5 neonatal preterm birth in China is currently YLL. Therefore, it is vital to target preterm birth complications with the necessary interventions to reduce deaths due to preterm birth.

Neonatal sepsis is an acute infectious disease with a very high morbidity and mortality rate. The widespread application of antibiotics has led to a significant increase in drug-resistant strains of pathogenic bacteria (Jia et al., 2017). In 2019, the rate of neonatal sepsis and other infectious diseases YLD attributed to PM 2.5 pollution ranked second, increasing 142.31% compared to 1990. The death rate was the fourth highest, with a reduction of 14.29% compared to 1990. The results show that the burden of disability caused by neonatal sepsis is increasing, suggesting that early diagnosis, timely and rational antimicrobial drug treatment, as well as attention to its treatment prognosis leading to the possibility of disability should be achieved.

With improvements in obstetric and neonatal care, the number of children who survived high-risk neonatal illness with neurodevelopmental disorders and disabilities has increased. The risk of having at least one impairment during development after a perinatal injury is estimated to be approximately 40% (Kohli-Lynch et al., 2019). Sometimes, improper application of technical interventions, such as induction of labor without adequate monitoring during labor, may result in a higher incidence of injured survivors. In these settings, YLDs accounts for a larger proportion of the total DALYs (21% in East Asia/Pacific and Middle East/North Africa, and 9% in sub-Saharan Africa/South Asia) (Lee et al., 2013). This study found that the number of neonatal disease deaths, DALYs, and YLLs due to PM 2.5 pollution in China decreased from 1990 to 2019, while YLDs increased by 31.71% in 2019 compared to 1990. Developmental disabilities caused by neonatal diseases increase the burden of disease. It is suggested that reducing the burden of disease in the neonatal stage requires not only improving neonatal survival but also requires further attention. Moreover, we need to focus on the prognosis of neonatal diseases, paying attention to child developmental issues, and reducing the burden of disease caused by disability.

There have certain limitations in our research for using the available database. The data of PM2.5 concentration in China and the data of perinatal mortality in China are not detailed enough, and there are differences in the spatial distribution. Further cohort studies are needed to verify the relationship between PM2.5 pollution and neonatal disease burden.

CONCLUSION

This study assessed neonatal disease burden of attributable to PM 2.5 pollution in China from 1990 to 2019 using data related to PM 2.5 pollution exposure and neonatal disease obtained from the GBD research. The results show a high level of PM 2.5 pollution exposure in China. Environmental PM2.5 concentration is positively and strongly correlated with neonatal disease burden. With the control of PM2.5 pollution, although the burden of disease of newborns is reducing, the burden of disease caused by disability is increasing, which indicates that the long-term effects of PM2.5 exposure may contribute to the disability of newborns. The results of our study suggest that various measures should continue to be taken to improve air quality, and focus on the prognosis and developmental disabilities during improving the neonatal survival.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All authors contributed to data interpretation, wrote and revised various parts of the paper. JY, LS, HL, and YC conducted the work presented here and performed data analysis; JY and BH drafted the manuscript. LZ, JZ, and YC revised the overall paper; YC and BH supervised the work. All authors read and approved the final manuscript.

FUNDING

This work was financially supported by the National Natural Science Foundation of China (82173526), and the Natural Science Basic Research Plan of the Shaanxi Province (2020JQ-547). The funding body played no role in the design of the study, in the collection, analysis, and interpretation of data, or in writing the manuscript.

ACKNOWLEDGMENTS

The authors thank AiMi Academic Services (www.aimieditor.com) for the English language editing and review services.

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