



# Rural–urban inequities in deaths and cancer mortality amid rapid economic and environmental changes in China

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## Abstract

**Objectives** This paper examines rural–urban inequities in mortality and cancer mortality amid rapid economic growth and environmental degradation in China.

**Methods** SPSS and Joinpoint Regression were used to analyze the 2002–2015 datasets from all death registries in China and associated economic and environmental data.

**Results** Death and cancer mortality rates among rural residents were higher and increased faster than urban residents. In particular, rural men 30–34 years old were 44% more likely to die from cancer and over 67% more likely to die from all causes, compared to their urban counterparts. Among rural women 15–19 years old, the death rate was 47% higher and the cancer mortality rate was 44% higher than among urban women. Death and cancer mortality rates tended to be positively associated with economic growth and air pollution variables.

**Conclusions** Rural–urban health inequities have widened in China, with rural youth at the greatest disadvantage. The anticipated health benefits from income growth may have been offset by the impact of air pollution, which calls for further investigation into the causes of rural–urban health inequities.

**Keywords** All-cause mortality · Cancer mortality · Youth health · Rural–urban health inequities

## Introduction

The widening of rural–urban health inequities has become a daunting global challenge, attracting growing attention in public health literature (Singh and Siahpush 2014; Herrero and Loza 2017). Authors disagree about how, and if, rurality matters in health inequities (Smith et al. 2008) or cancer mortality inequities (McLafferty and Wang 2009; Gartner et al. 2011; Nennecke et al. 2014; Singh and Siahpush 2014). For example, although rural areas were found to have lower cancer mortality rates (CMRs) than urban areas in Canada, the pattern was reversed in Australia (Pong et al. 2009). Significant rural–urban CMR

inequities were identified for South Korea (Choi 2016); however, contradicting rural–urban CMR patterns and trends have been reported for China (Zhao et al. 2016; Chen et al. 2014, 2015, 2016).

Consequently, rural–urban health inequities are still poorly understood, and there is a considerable gap in knowledge of the subject (Zeng et al. 2015). To help fill in this gap, this paper aims to explore the patterns and trends of rural–urban inequities in deaths from cancer and deaths from all causes in China. Mortality and cancer mortality are important indicators of public health (WHO 2012). According to the World Health Organization (WHO 2017a), “health inequities are *avoidable* inequalities in health between groups of people within countries and between countries.” Based on this definition, rural–urban health inequalities in China are health inequities, because they are avoidable and found between groups of people within a country. This paper specifically attempts to answer the following questions: Are rural–urban inequities in death rates and cancer mortality rates widening in China? What population cohorts experience the greatest inequities? Does rurality still matter in China? What are the

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possible economic and environmental drivers of such inequities? Answering these questions may enhance the understanding of rural–urban health inequities, which may in turn help determine the causes of such inequities and help public health policy makers and practitioners control the inequities.

Health inequities in China are particularly intriguing because the country, with over one-fifth of the world population, has experienced tremendous economic growth, income inequality (Xie and Zhou 2014), and environmental degradation in the past several decades (Liu 2013, 2018). The literature regarding health inequities has long debated over how public health is affected by economic growth (Pritchett and Summers 1996; Tang et al. 2008; Bakkeli 2016) and its associated income inequality (Macinko et al. 2003; WHO 2008; Biggs et al. 2010; De Maio et al. 2012; Bakkeli 2016; Ding et al. 2017). Environmental pollution, specifically air pollution, has been linked to 9 million, or 16% of all, deaths worldwide (Landrigan et al. 2017). The impact of air pollution may be short term and long term. For example, death rates rose during days with heavy smog and high ambient ozone levels in Chinese cities (Yin et al. 2017). PM<sub>2.5</sub> exposure has repeatedly been found to negatively affect population health in China (Landrigan et al. 2017; Ebenstein et al. 2017; Chen et al. 2013).

## Methods

### Data sources

This study used the causes of death data published by the National Health and Family Planning Commission of China (the Ministry of Health before 2013) (NHFPC 2003–2016). In this research, deaths refer to deaths of all causes (ICD-10) and cancer refers to all cancers (C00–C97). The data were collected with the Vital Registration (VR) system and the Disease Surveillance Points (DSP) system. In both systems, the local Center for Disease Control and Prevention (CDC) is charged to collect data using established urban and rural death registries. Urban areas refer to cities with a population 200,000 or more, while rural areas are rural counties with a population smaller than 200,000 (NBS 2017).

Since its establishment in 1978 by the Chinese CDC, the DSP system has greatly increased its coverage. By 1990, it had established 145 DSP in all 31 provincial-level regions in China, with a sample population of 10 million, about 1% of China's total population. By 2004, the DSP system covered 73 million, about 6% of China's total population. The DSP system is nationally representative in urban and rural areas, while data collected by the VR system do not cover remote western part of China, focusing on population

concentrations in eastern and central China (Liu et al. 2016).

By 2000, the VR system covered a population of around 110 million in 36 urban areas and 90 rural areas in 15 provinces. By 2012, 230 million people were covered. The sample size gradually increased to 141 urban areas and 350 rural counties in all 31 regions by 2012 (NHFPC 2016), covering nearly a quarter of Chinese cities/counties. The assumption was that these samples represent the whole country, regardless of their sizes. Furthermore, these are the only complete datasets available for examining trends from 2002 to 2015. A few cancer registries were set up in 2009, but these registries have not yet published any original datasets beyond summary reports (Chen et al. 2014, 2015, 2016). NHFPC has made efforts to improve data reliability and quality (NHFPC 2003–2016). Furthermore, the reliability of the data has also been supported by several publications (Liu et al. 2016).

Per capita gross domestic product (GDP) and urban and rural income were used as economic indicators, while rural–urban income ratios were used as indicators of income equality. Air pollution data were collected from the World Bank (2017) and Yale University (2017) databases. The indicators include total greenhouse gas emissions, total CO<sub>2</sub> emissions, CO<sub>2</sub> emissions from solid fuel, CO<sub>2</sub> emissions per capita, and annual average PM<sub>2.5</sub> exposure rate.

### Statistical analyses

The SPSS program was used to conduct the paired samples *T* test to compare all means to see if they were significantly different from each other in the urban–rural pairs: urban–rural all genders, urban–rural male, and urban–rural female. Correlation analyses were performed to determine the possible drivers of rural–urban health inequities. The Joinpoint Regression Program (National HI 17) was used to find the best-fit line through the 14 years of data and calculate the annual percentage change (APC) using log-linear regression model and test if the APC is significantly different from 0. This method was used to first examine all-age mortality rates and then to analyze age-specific mortality rates. Trends in rural–urban age-specific mortality disparities were further analyzed through comparing inequities in the averages of the earliest 3 years (2002–2004) with the latest 3 years (2013–2015). Three-year averages were used instead of single-year data to reduce the impact of possible data irregularity.

## Results

Annual average death rates from 2002 to 2015 were higher and increased faster, in rural areas than in urban districts (Table 1). For example, the annual average death rate for all genders was 3.17% higher, and the APC was 24% higher, in rural areas than in urban areas. Rural–urban inequities were worse for men than for women. Death rates were over 5%, and the APCs were nearly 46% higher for rural men than for urban men. APCs were also over 40% higher for rural women than for urban women. This suggests widening rural–urban inequities in death rates.

On the other hand, annual average CMRs were higher for urban areas than for rural areas. Urban CMRs displayed two trends: a rapid increase from 2002 to 2007 or 2008

with no increase afterward. Rural CMRs had a continual increase. As a result, the rural advantage shrank. For example, the urban-to-rural ratio of CMRs for men was 1–0.89 in 2002, but increased to 1–0.96 in 2015. If these trends continue, the rural advantage in CMRs is likely to disappear, at least for men.

GDP per capita trends indicate the slowing down of economic growth since 2010. However, both urban and rural per capita incomes have continued to increase, while urban–rural per capita income ratios went through three trends, declining in the 2012–2015 period. However, it should be noted that, in 2015, per capita income in urban districts was still over three times of that in rural areas, though rural income increased faster than urban income from 2006 to 2015. Air pollution variables show three

**Table 1** Annual averages and trends (Joinpoint analyses) in all-cause death and cancer mortality rates (per 100,000), income, and environmental variables, China, 2002–2015

Variable <sup>a</sup>	Annual average (2002–2015)	Joinpoint analyses (2002–2015)					
		Trend 1		Trend 2		Trend 3	
		Years	APC	Years	APC	Years	APC
1. Urban death rate all genders	588.16*	2002–2015	1.5 <sup>^</sup>				
2. Rural death rate all genders	606.81*	2002–2015	1.86 <sup>^</sup>				
3. Urban death rate male	655.24*	2002–2015	1.59 <sup>^</sup>				
4. Rural death rate male	688.72*	2002–2015	2.32 <sup>^</sup>				
5. Urban death rate female	515.57*	2002–2015	0.88 <sup>^</sup>				
6. Rural death rate female	521.14*	2002–2015	1.27 <sup>^</sup>				
7. Urban CMR all genders	152.58*	2002–2008	6.72 <sup>^</sup>	2008–2015	– 0.63		
8. Rural CMR all genders	139.91*	2002–2015	2.49 <sup>^</sup>				
9. Urban CMR male	190.54*	2002–2007	7.36 <sup>^</sup>	2007–2015	0.21		
10. Rural CMR male	180.48*	2002–2015	2.69 <sup>^</sup>				
11. Urban CMR female	113.21*	2002–2008	7.59 <sup>^</sup>	2008–2015	– 1.24		
12. Rural CMR female	97.41*	2002–2015	2.23 <sup>^</sup>				
13. GDP per capita (constant 2010 US\$)	4088	2002–2010	10.74 <sup>^</sup>	2010–2015	7.18 <sup>^</sup>		
14. Urban income per capita (¥)	12,791	2002–2006	9.74 <sup>^</sup>	2006–2015	12.72 <sup>^</sup>		
15. Rural income per capita (¥)	4041	2002–2006	3.94 <sup>^</sup>	2006–2015	13.03 <sup>^</sup>		
16. Urban–rural income ratio	3.13	2002–2006	4.97 <sup>^</sup>	2006–2012	0.54	2012–2015	– 2.55 <sup>^</sup>
17. GHG emissions total (kiloton of CO <sub>2</sub> equivalent)	8,283,479	2002–2004	8.24 <sup>^</sup>	2004–2009	11.42 <sup>^</sup>	2009–2015	6.55 <sup>^</sup>
18. CO <sub>2</sub> emissions per capita (metric ton)	5.02	2002–2004	9.02 <sup>^</sup>	2004–2007	15.41 <sup>^</sup>	2007–2015	7.08 <sup>^</sup>
19. CO <sub>2</sub> emissions total (kiloton)	6,639,545	2002–2004	5.9	2004–2007	16.16 <sup>^</sup>	2007–2015	7.61 <sup>^</sup>
20. CO <sub>2</sub> emissions from solid fuel (kiloton)	4,867,665	2002–2008	13.25 <sup>^</sup>	2008–2015	7.73 <sup>^</sup>		
21. PM <sub>2.5</sub> mean annual exposure (µg/m <sup>3</sup> )	46.05	2002–2004	8.51 <sup>^</sup>	2004–2008	5.16 <sup>^</sup>	2008–2015	– 0.88 <sup>^</sup>

APC annual percent change; CMR cancer mortality rate; GDP gross domestic product

\*Paired samples *t* test indicates that the rural–urban means of death and cancer mortality rates are significantly different from each other at the alpha = 0.05 level

<sup>^</sup>Indicates that the annual percent change (APC) is significantly different from 0 at the alpha = 0.05 level

<sup>a</sup>Variables 1–12 are based on National Health and Family Planning Commission of China (NHFPC 2003–2016). Variables 13, 17–20 are based on World Bank (2017). Variables 14–16 are based on National Bureau of Statistics of China (NSB 2017). Variable 21 is based on Yale University (2017), µg/m<sup>3</sup> micrograms per cubic meter

increasing trends, all of which indicate an alarming situation, despite the slight decrease in PM<sub>2.5</sub> from 2008 to 2015.

An examination in age-specific death rates and CMRs revealed additional information on rural–urban health inequities. Death rates were higher in rural areas than in urban areas for all age-groups (Table 2). Rural population aged 15–39 appeared to be the most disadvantaged. Rural 15–24-year-olds were over 40% more likely to die than their urban counterparts. Rural men 20–24 years old were 48% more likely to die than urban men. For rural women aged 15–19 years old, the inequities were 42%. CMRs were lower in rural areas than in urban areas for the population below 15 and above 69 years old (or 64 years old for women), but the pattern was reversed in the other age-groups (Table 3). The largest rural–urban inequity was 34% for men aged 35–39 years and 28% for women aged 15–19 years.

Further examination of rural–urban inequities focused on rural population aged 15–39 years as they appeared to experience unusually high inequities (Tables 2, 3). Table 4 shows the comparison of rural–urban death rate differences between the averages of the earliest (2002–2004) and latest 3 years (2013–2015). Urban rates declined in all cohorts except for men aged 25–29 years. Rural rates, regardless of

increase or decrease, changed slower than urban rates. The result is that rural–urban inequities increased by at least 34 percent from 2002–2004 to 2013–2015 for all genders, with the largest change by as much as 106% in the 25–29-year-old age-group. For men, inequities increased by at least 54% from 2002–2004 to 2013–2015, with the highest inequities of 183% in the 25–29-year-old age-group. There is also a shift in the age-group with the highest inequities. From 2002 to 2004 the age-group with the highest inequities was the 20–24 age-group; however, from 2013 to 2015 this trend shifted to the 30–34 age-group. For women, the shift seems to have been from an older age-group (35–39 years old) in 2002–2004 to a younger age-group (15–19 years old) in 2013–2015.

For CMRs, urban rates declined faster than rural rates. In fact, rural rates actually increased for men aged 15–19 and 25–29 years (Table 4). Increases in inequities were most striking for the 15–19-year-old age-group. For all genders, inequities increased by almost 45 times, from 0.86% (no inequity) in 2002–2004 to 39.67% in 2013–2015. For men, the increase was over 99 times, from 0.36% (no inequity) in 2002–2004 to 35.76% in 2013–2015. For women, the increase was 2.38 times, from 13.13 to 44.4%. Regarding all genders, the largest inequities in 2002–2004 were in the 30–35 age-group; however,

**Table 2** Age-specific average urban and rural all-cause death rates (per 100,000 population) and percent rural–urban change, China, 2002–2015. *Source:* calculated from National Health and Family Planning Commission of China (NHFPC 2003–2016)

Age-group	1. Urban all genders	2. Rural all genders	3. 1–2 change (%)	4. Urban male	5. Rural male	6. 4–5 change (%)	7. Urban female	8. Rural female	9. 7–8 change (%)
Below 1	571	606	4	621	643	13	514	578	6
1–4	48	65	36	53	74	39	42	55	30
5–9	20	25	27	24	31	29	16	19	22
10–14	20	23	14	25	29	15	14	16	12
15–19	27	38	41	35	49	40	17	25	42
20–24	34	48	42	44	65	48	23	31	34
25–29	43	57	33	56	76	35	29	38	30
30–34	65	84	29	85	112	31	44	57	28
35–39	101	135	34	135	179	33	66	90	36
40–44	167	213	28	225	283	26	106	139	32
45–49	251	284	13	338	367	8	161	190	18
50–54	407	489	20	543	631	16	263	338	28
55–59	573	738	29	756	950	26	383	511	34
60–64	943	1166	24	1214	1480	22	667	828	24
65–69	1617	1857	15	2040	2364	16	1203	1337	11
70–74	2875	3260	13	3568	4092	15	2231	2454	10
75–79	4899	5356	9	5927	6688	13	4016	4232	5
80–84	8609	9481	10	10,188	11,688	15	7413	7940	7
85+	16,640	18,912	14	17,160	21,577	26	15,536	17,543	13

**Table 3** Age-specific average urban and rural cancer mortality rates (per 100,000 population) and percent rural–urban change, China, 2002–2015. *Source:* calculated from National Health and Family Planning Commission of China (NHFPC 2003–2016)

Age-group	1. Urban all genders	2. Rural all genders	3. 1–2 change (%)	4. Urban male	5. Rural male	6. 4–5 change (%)	7. Urban female	8. Rural female	9. 7–8 change (%)
Below 1	7.37	6.77	– 13	8.03	6.97	– 11	6.61	5.88	– 8
1–4	4.84	4.31	– 11	5.32	4.51	– 15	4.31	4.17	– 3
5–9	3.22	2.90	– 10	3.51	3.34	– 5	2.90	2.35	– 19
10–14	3.53	3.10	– 12	3.95	3.54	– 10	3.09	2.72	– 12
15–19	4.31	5.05	17	5.27	5.86	11	3.29	4.20	28
20–24	5.08	6.39	26	5.91	7.72	31	4.20	5.13	22
25–29	7.77	9.09	17	8.80	10.53	20	6.71	7.60	13
30–34	15.36	18.20	18	17.41	22.15	27	13.22	14.72	11
35–39	29.85	37.57	26	35.05	46.99	34	24.47	28.63	17
40–44	56.99	71.19	25	68.97	90.21	31	44.49	51.71	16
45–49	98	106	8	123	138	12	71.86	74.56	4
50–54	169	190	13	219	251	14	116	128	10
55–59	243	294	21	323	390	21	162	189	16
60–64	373	427	14	498	572	15	247	267	8
65–69	567	591	4	740	805	9	378	368	– 3
70–74	836	822	– 2	1125	1138	1	569	527	– 7
75–79	1147	1042	– 9	1542	1477	– 4	808	690	– 15
80–84	1451	1197	– 18	1985	1749	– 12	1045	834	– 20
85+	1616	1271	– 21	2295	1883	– 18	1205	959	– 20

in 2013–2015 this shifted to the 15–19 age-group. The highest inequities in female CMRs also shifted from the 35–39 age-group in 2002–2004 to the 15–19 age-group in 2013–2015.

Figure 1 illustrates the increases in inequities between rural and urban young men from 2002 to 2015. Dramatic increases in death rate inequities occurred between 2012 and 2015 for men aged 25–29 and 30–34 years (a). CMRs also experienced a large increase in inequities between 2012 and 2015 for men aged 25–29 years (b).

All-age death rates are positively associated with all economic variables (Table 5), leading to an increasing trend in general (Table 1). This does not mean that income growth leads to higher mortality. However, it does suggest that the expected health benefits from economic growth might have been offset by negative impacts on health as a result of other factors associated with economic growth. These factors may include rural–urban income inequality and air pollution. Air pollution variables are positively correlated to all-age mortality rates in both rural and urban areas, as expected (Table 5).

PM2.5 exposure and cancer mortality rates are significantly correlated. However, the associations between the other four air pollution variables and CMRs tended to be insignificant. This is possibly because air pollution affects

some cancers such as lung cancer, but not other cancers (Turner et al. 2017). It should also be noted that it may take many years for the impact of air pollution on cancer deaths to fully reveal itself. Due to this delayed effect, the 2002–2015 CMRs could be related to air pollution before 2002 and may not be a reflection of air pollution levels during the same time period. Yet, air pollution variables, especially PM2.5 exposure, should be considered important factors in understanding health outcomes. It is not surprising that PM2.5 exposure appears to impact urban mortality rates more than rural rates, as reflected by the higher values of correlation coefficients.

## Discussion

### Contributions to the literature

The paper contributes to knowledge about rural–urban health inequities in the following six aspects.

First, the paper demonstrates that rural–urban health inequities are widening in China, as reported for some other countries (Singh and Siahpush 2014; Zhao et al. 2016).

**Table 4** Urban and rural death rates and cancer mortality rates (CMRs) (per 100,000 population) and percent rural–urban change, population aged 15–39 years, China, comparing the 2002–2004 and 2013–2015 means. *Source:* calculated from National Health and Family Planning Commission of China (NHFPC 2003–2016)

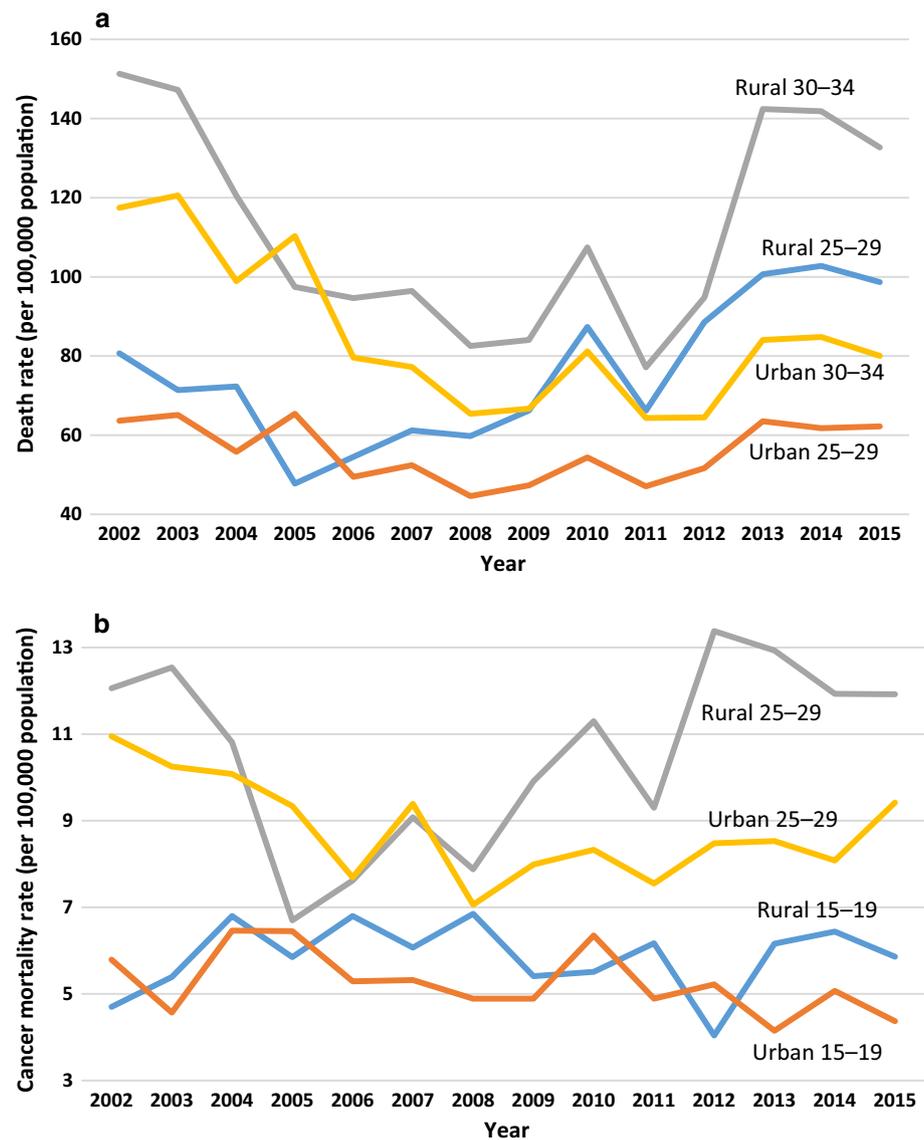
Age-group	2002–2004			2013–2015			7. 3–6 Change (%)
	1. Urban	2. Rural	3. 1–2 Change (%)	4. Urban	5. Rural	6. 4–5 Change (%)	
<i>Death rate all genders</i>							
15–19	26.74	34.58	29.32	26.46	40.09	51.51	75.69
20–24	36.21	47.67	31.65	27.83	41.58	49.41	56.12
25–29	49.47	63.1	27.55	45.05	70.68	56.89	106.48
30–34	87.54	112.8	28.86	61.47	95.65	55.6	92.69
35–39	130.6	176.61	35.23	77.48	114.18	47.37	34.46
<i>Death rate male</i>							
15–19	34.06	43.33	27.22	36.52	55.29	51.4	88.85
20–24	43.84	59.26	35.17	38.77	59.79	54.22	54.15
25–29	61.53	74.8	21.57	62.51	100.71	61.11	183.35
30–34	112.32	139.68	24.36	82.97	138.98	67.51	177.15
35–39	170.28	219.61	28.97	108.53	162.21	49.46	70.73
<i>Death rate female</i>							
15–19	19.06	25.28	32.63	15.66	22.98	46.74	43.23
20–24	27.74	35.73	28.80	16.51	23.07	39.73	37.94
25–29	36.6	50.83	38.88	27.98	39.61	41.57	6.92
30–34	61.61	84.45	37.07	39.06	54.33	39.09	5.44
35–39	89	130.69	46.84	45.78	64.38	40.63	–13.26
<i>CMR all genders</i>							
15–19	4.63	4.67	0.86	3.68	5.14	39.67	4491.8
20–24	5.16	5.8	12.40	4.16	5.14	23.56	89.95
25–29	8.94	10.55	18.01	7.66	10.41	35.9	99.35
30–34	19.44	23.13	18.98	14.56	19.06	30.91	62.84
35–39	39.25	50.42	28.46	21.72	28.32	30.39	6.79
<i>CMR male</i>							
15–19	5.61	5.63	0.36	4.53	6.15	35.76	9930.7
20–24	6.25	7.57	21.12	5.04	6.29	24.8	17.42
25–29	10.43	11.8	13.14	8.68	12.26	41.24	213.97
30–34	23.32	29.47	26.37	15.83	22.79	43.97	66.73
35–39	47.4	63.85	34.70	24.79	34.75	40.18	15.78
<i>CMR female</i>							
15–19	3.58	4.05	13.13	2.77	4	44.4	238.2
20–24	3.97	4.48	12.85	3.24	3.99	23.15	80.21
25–29	7.36	9.3	26.36	6.66	8.5	27.63	4.82
30–34	15.37	19.07	24.07	13.22	15.26	15.43	– 35.9
35–39	30.71	40.31	31.26	18.6	21.64	16.34	– 47.73

Second, the paper confirms reports that urban death rates and CMRs may have stopped increasing (e.g., Chen et al. 2016).

Third, the paper reveals that rurality still matters in China in terms of high death rates and rising CMRs. It confirms rural–urban inequities in CMRs for the young and

middle-aged population and the likelihood that rising rural CMRs will surpass urban CMRs. This paper, however, differs from reports that total CMRs had already been higher in rural than urban areas in China (Chen et al. 2016), which was based on unpublished data, but would have indicated even worse rural–urban CMR inequities.

**Fig. 1** Rural and urban male death rates at ages 25–29 and 30–34 years (a) and cancer mortality rates at ages 15–19 and 25–29 years (b), China, 2002–2015. *Source:* calculated from National Health and Family Planning Commission of China (NHFPC 2003–2016)



Fourth, the paper finds indications that rural–urban income inequality and air pollution, rather than income levels, may be important drivers of health. This is possibly because the health benefits that income growth is supposed to bring are outweighed by the negative health impact from environmental damage.

Fifth, the paper demonstrates the usefulness of using age–gender-specific analyses to help discover health inequities that would otherwise be hidden when only all-age mortality rates are examined. Using age-specific data may also be helpful when examining possible causes of rural–urban health inequalities because population aging, which is a major factor in all-age mortality studies, does not affect age-specific mortality rates.

Finally, this paper supports the literature that PM<sub>2.5</sub> exposure negatively affects population health in China

(Landrigan et al. 2017; Ebenstein et al. 2017; Chen et al. 2013). The three trends for PM<sub>2.5</sub> exposure data appear to support reports that PM<sub>2.5</sub> exposure in China may have stopped increasing or even declined (Landrigan et al. 2017). However, it must be noted that it is uncertain whether the small decrease in recent years suggests a change in trend. PM<sub>2.5</sub> in 2015 was still 47.2  $\mu\text{g}/\text{m}^3$ , nearly five times as high as the recommended 10  $\mu\text{g}/\text{m}^3$  level set by the WHO. According to the World Health Organization (2016), “small particulate pollution have health impacts even at very low concentrations—indeed no threshold has been identified below which no damage to health is observed.” Furthermore, the World Bank (2017) data show worsening air pollution with the annual mean PM<sub>2.5</sub> increasing from 58.22  $\mu\text{g}/\text{m}^3$  in 2010 to 58.38  $\mu\text{g}/\text{m}^3$  in 2015.

**Table 5** Bivariate correlation coefficients, health, income, income inequality, and pollution variables, China, 2002–2015

	GDP per capita	Urban income per capita	Rural income per capita	Urban–rural income ratio	GHG emissions total	CO <sub>2</sub> emissions total	CO <sub>2</sub> emissions solid	CO <sub>2</sub> emissions per capita	PM <sub>2.5</sub> exposure
Urban death rate all genders	0.726**	0.624*	0.566*	0.820**	0.729**	0.728**	0.732**	0.735**	0.897**
Urban death rate male	0.761**	0.665**	0.609*	0.825**	0.761**	0.762**	0.766**	0.768**	0.896**
Urban death rate female	0.655*	0.546*	0.488	0.793**	0.662**	0.658*	0.661*	0.665**	0.882**
Rural death rate all genders	0.752**	0.672**	0.631*	0.684**	0.759**	0.746**	0.745**	0.750**	0.828**
Rural death rate male	0.734**	0.649*	0.605*	0.692**	0.743**	0.730**	0.730**	0.734**	0.829**
Rural death rate female	0.769**	0.703**	0.670**	0.633*	0.773**	0.760**	0.757**	0.762**	0.795**
Urban CMR all genders	0.522	0.42	0.362	0.757**	0.523	0.532	0.535*	0.540*	0.785**
Urban CMR male	0.45	0.353	0.291	0.713**	0.45	0.464	0.471	0.471	0.690**
Urban CMR female	0.629*	0.521	0.459	0.842**	0.626*	0.635*	0.637*	0.643*	0.891**
Rural CMR all genders	0.294	0.194	0.146	0.628*	0.287	0.312	0.312	0.319	0.690**
Rural CMR male	0.147	0.049	0.002	0.552*	0.142	0.167	0.168	0.175	0.599*
Rural CMR female	0.467	0.378	0.334	0.659*	0.461	0.481	0.482	0.488	0.746**

$n = 14$

CMR cancer mortality rate, GDP gross domestic product, GHG greenhouse gas, CO<sub>2</sub> carbon dioxide, PM<sub>2.5</sub> particulate matter (PM) with a diameter of less than 2.5 micrometers

\*\*Correlation is significant at the 0.01 level (two-tailed)

\*Correlation is significant at the 0.05 level (two-tailed)

## Limitations

Ultimately, of course, there are limitations to the research that must be noted. Even though the reliability of the data has been supported by several publications (Liu et al. 2016), the comparability of the historical data is challenging due to an increase in sample size. Thus, the data quality and the resulting estimates of the trends might have been affected. Besides, the research was based on all causes of deaths and all cancers. It should be noted that different causes of deaths and different types of cancer may have different patterns and trends. It should also be noted that the interpretation of the impact of economic and environmental variables on death rates, particularly CMRs, is complicated by the delayed effect of these variables and many other known and unknown factors may affect death

rates and CMRs such as lifestyle (WHO 2017b) and population aging (Liu and Liu 2016).

## Further research

The widening of rural–urban health inequities for young population was shocking. Rural young men were found to have alarmingly high death rates and fastest rising CMRs. It is the first time such findings have been reported, which demands further research. Economic growth in the past decades has not been accompanied with an improvement in health for the rural youth in China, possibly due to increased environmental and occupational risks. Further research should seek additional data to verify the findings with new information and data. Further research also needs to examine how rural–urban health inequities could be reduced with innovative environmental and health policies.

Hopefully, this article can provide some basis for further research and stimulate debates over rural–urban health inequities.

## Conclusions

Rural–urban inequities in mortality and cancer mortality have widened in China. Rural young men suffered from the greatest inequities, while urban death rates and CMRs appeared to have plateaued. Rural–urban income inequality and air pollution appeared to be affecting health inequities. The health benefits that income growth was supposed to bring might have been offset by the health impact of air pollution, PM<sub>2.5</sub> exposure in particular. Further research should examine the causes of such inequities. In particular, environmental and occupational risk factors should be looked into in order to better understand the increasing death and cancer mortality rates among rural young men.

## Compliance with ethical standards

**Conflict of interest** The author confirms that this research involved no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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