Under-5 mortality in 2851 Chinese counties, 1996–2012: a subnational assessment of achieving MDG 4 goals in China

Yanping Wang, Xiaohong Li*, Maigeng Zhou*, Shusheng Luo*, Juan Liang, Chelsea A Liddell, Matthew M Coates, Yanqiu Gao, Linhong Wang, Chunhua He, Chuyun Kang, Shiwei Liu, Li Dai, Austin E Schumacher, Maya S Fraser, Timothy M Wolock, Amanda Pain, Carly E Levitz, Lavanya Singh, Megan Coggeshall, Margaret Lind, Yichong Li, Qi Li, Kui Deng, Yi Mu, Changfei Deng, Ling Yi, Zheng Liu, Xia Ma, Hongtian Li, Dezhi Mu, Jun Zhu†, Christopher J L Murray†, Haidong Wang*

Summary

Background In the past two decades, the under-5 mortality rate in China has fallen substantially, but progress with regards to the Millennium Development Goal (MDG) 4 at the subnational level has not been quantified. We aimed to estimate under-5 mortality rates in mainland China for the years 1970 to 2012.

Methods We estimated the under-5 mortality rate for 31 provinces in mainland China between 1970 and 2013 with data from censuses, surveys, surveillance sites, and disease surveillance points. We estimated under-5 mortality rates for 2851 counties in China from 1996 to 2012 with the reported child mortality numbers from the Annual Report System on Maternal and Child Health. We used a small area mortality estimation model, spatiotemporal smoothing, and Gaussian process regression to synthesise data and generate consistent provincial and county-level estimates. We compared progress at the county level with what was expected on the basis of income and educational attainment using an econometric model. We computed Gini coefficients to study the inequality of under-5 mortality rates across counties.

Findings In 2012, the lowest provincial level under-5 mortality rate in China was about five per 1000 livebirths, lower than in Canada, New Zealand, and the USA. The highest provincial level under-5 mortality rate in China was higher than that of Bangladesh. 29 provinces achieved a decrease in under-5 mortality rates twice as fast as the MDG 4 target rate; only two provinces will not achieve MDG 4 by 2015. Although some counties in China have under-5 mortality rates similar to those in the most developed nations in 2012, some have similar rates to those recorded in Burkina Faso and Cameroon. Despite wide differences, the inter-county Gini coefficient has been decreasing. Improvement in maternal education and the economic boom have contributed to the fall in child mortality; more than 60% of the counties in China had rates of decline in under-5 mortality rates significantly faster than expected. Fast reduction in under-5 mortality rates have been recorded not only in the Han population, the dominant ethnic majority in China, but also in the minority populations. All top ten minority groups in terms of population sizes have experienced annual reductions in under-5 mortality rates faster than the MDG 4 target at 4·4%.

Interpretation The reduction of under-5 mortality rates in China at the country, provincial, and county level is an extraordinary success story. Reductions of under-5 mortality rates faster than 8·8% (twice MDG 4 pace) are possible. Extremely rapid declines seem to be related to public policy in addition to socioeconomic progress. Lessons from successful counties should prove valuable for China to intensify efforts for those with unacceptably high under-5 mortality rates.

Funding National "Twelfth Five-Year" Plan for Science and Technology Support, National Health and Family Planning Commission of The People's Republic of China, Program for Changjiang Scholars and Innovative Research Team in University, the National Institute on Aging, and the Bill & Melinda Gates Foundation.

Introduction

China has made tremendous strides in reducing under-5 mortality rates in the past decades.[1–3] It achieved the Millennium Development Goal 4 (MDG 4) target of a two-thirds reduction in the under-5 mortality rate 7 years in advance of the target, in 2008.[1]

The under-5 mortality rate in 2013 reached 13·0 per 1000 livebirths (12·0–13·8) in China, a 78% reduction from 1990. The annualised rate of decline in this time period (6·6%) was the second highest in 188 countries analysed for the same period. Studies have linked China's national success in reducing child mortality to rapid economic growth, high and rising levels of female education and empowerment, reductions in fertility rates, and health policies such as antenatal care, in-facility birth, and immunisation.[4] Analysis of causes of child death have pointed to large reductions in diarrhoea and pneumonia deaths in particular.[2,5,6] China's experience in terms of lowering the burden of infectious disease among children has been identified as an example to be emulated by other low-income and middle-income countries.

China has made huge progress in reducing child mortality during a period of dramatic economic growth, with Gross Domestic Product (GDP) per person increasing 668% from 1990 to 2013. Economic

Published Online October 26, 2015 http://dx.doi.org/10.1016/S0140-6736(15)00554-1

See Online/Comment http://dx.doi.org/10.1016/S0140-6736(15)00555-3

*Joint first authors

† Joint corresponding author

National Office for Maternal and Child Health Surveillance of China, Department of Pediatrics, West China Second University Hospital, Sichuan University, Chengdu, Sichuan, China (Prof Y Wang, Prof J Liang, C He, L Dai, Q Li, K Deng, Y Mu, C Deng, L Yi, Z Liu, X Ma, Prof D Mu, Prof J Zhu); **Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA, USA** (C A Liddell, M M Coates, A E Schumacher, M S Fraser, T M Wolock, A Pain, C E Levitz, L Singh, M Coggeshall, M Lind, Prof C J L Murray, H Wang); **National Center for Birth Defect Surveillance of China, West China Second University Hospital, Sichuan University, Chengdu, Sichuan, China** (X Li, Prof J Zhu); **Key Laboratory of Birth Defects and Related Diseases of Women and Children (Sichuan University), Ministry of Education, Chengdu, Sichuan, China** (X Li); **National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing, China** (Prof M Zhou, Prof L Wang, S Liu, Y Li); **Office for National Maternal and Child Health Statistics of China, School of Public Health, Peking University Health Science Center, Beijing, China** (Prof S Luo, Y Gao, C Kang, H Li); **and Department of Child, Adolescent and Women's Health, School of Public Health, Peking University Health Science Center, Beijing, China** (Prof S Luo, Y Gao, C Kang)

Correspondence to:
Prof Jun Zhu, National Office for Maternal and Child Health Surveillance of China, West China Second University Hospital, Sichuan University, Chengdu 610041, China
zhujun028@163.com

or

Prof Christopher J L Murray, Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA, 98121, USA
cjlm@uw.edu

Research in context

Evidence before this study

China has made tremendous efforts in reducing child mortality in the past three decades and especially since the Declaration of the Millennium Development Goals (MDGs). Although China as a nation has achieved the MDG 4 goal by reducing the under-5 mortality rate by two-thirds from its 1990 level in 2008, much less is known about the country's performance at the subnational level. For our study, we have systematically searched published articles in both English and Chinese using PubMed and China National Knowledge Infrastructure (CNKI) using search terms including under-5 mortality, county, and China (only used in PubMed), with restrictions on year of publication. Of the 18 results we obtained from the two searches, none of them provided systematic analysis of county level under-5 mortality for China.

Added value of this study

In this analysis, we took advantage of a unique data source on under-5 mortality rates as collected by the National Health and Family Planning Commission from 1996 to 2012 for almost all counties in China and applied state-of-the-art small area mortality estimation methods and data synthesis models, a combination of spatiotemporal regression and Gaussian process regression, to generate under-5 mortality estimates for 2851 counties in China between 1996 and 2012. This study is the first of its kind to systematically document levels and trends of under-5 mortality rates at the county level in China. Additionally, using an econometric model, we were also able to identify counties with rates of change in under-5 mortality that diverged from what would be based on key socioeconomic variables and secular trends. We found fast progress made by most counties in China in reducing child mortality and a high level of heterogeneity in terms of both levels of and rate of change in under-5 mortality.

Implications of all the available evidence

The success stories or the opposite of it in China provides a great opportunity for researchers and policy makers worldwide to examine what effective interventions and policies are necessary to reduce child mortality. If counties in China can achieve rates of decline in under-5 mortality rates two times faster than the MDG 4 pace, studying and replicating such success in other developing countries are key in further reducing under-5 mortality worldwide.

transformation has been associated with rising income inequality and notable differences between the eastern provinces and the rest of China. Economic inequality has been and remains a major concern for China's leadership.[7] Policies to promote a Socialist Harmonious Society have included improving social equity and justice, and strengthening of environmental protection.[8] Health inequalities are also large[9] and data from several analyses suggest that they are growing.[10] Leadership concerns about inequalities in health and access to health care were a major impetus for the 2009 health system reforms in China; however, despite these reforms, health and health-care inequalities remain an issue of broad social concern.[11,12] For child mortality, results of numerous studies have shown large inequalities across regions and provinces,[6,10] across broad urban and rural designations,[13] and in local areas within selected provinces.[14] These studies have reported large and in some cases growing inequalities; many analyses highlight the link to economic inequality. Child mortality estimates across all the 2851 counties in China have never been published; based on local studies in some provinces inequality might be bigger across counties than across provinces.

A careful quantification of levels and trends in child mortality at the county level can provide important insights into whether child mortality and income inequality are following the same general trend and the success of national policies to address health inequalities. We aimed to quantify inter-county variations in under-5 mortality rate and its changes in the past two decades in China with a unique data source from the Chinese Government, the Annual Report System on Maternal and Child Health. Examining levels and trends in child mortality will help guide both the central and local governments to identify success stories within China such that better localised policy can be formed to improve child mortality in counties that are still lagging behind. Findings might also have implications for setting the next generation of health targets for China. Additionally, the success stories or the opposite stories at the county level in China have implications for policy makers outside of China. Study of the county level performance in improving child health might help form better public health strategies in other developing countries. We aimed to use several surveys, surveillance systems, censuses, and vital registration sources of data for child mortality to estimate for the first time the under-5 mortality rate from 1996 to 2012 for all Chinese counties.

Methods

Data

In 2014, Wang and colleagues[1] analysed several sources on child mortality at the national level to generate estimates for China for the period 1970 to 2013. In this study, we used the same modelling strategy as Wang and colleagues[1] to generate under-5 mortality at the provincial level. The most important sources analysed included child mortality data from censuses (1982, 1990, 2000, and 2010),[15] national surveys including the One per 1000 Survey on Fertility and

Birth Control (1982, 1987, 1988, and 1992),[16] the One per 1000 Annual Survey on Population Change (1986, 1994, 1996–99, 2001–04, and 2006–09),[17] the Intra-Census Surveys in 1995 and 2005,[18] the Maternal and Child Health Surveillance (MCHS, 1991–2013) system,[19] and the Disease Surveillance Point System (1996–2000, 2004–12).[20]

At the county level, we used the national Annual Report System on Maternal and Child Health (ARMCH). This routine reporting system was established in the early 1980s and was intended to cover the entire population in each county or district (part of a city that is equivalent to a county administratively). Individual records were available at the county or district level where the data were collected; aggregate birth and death numbers were reported to the provincial level Bureaus of Health and the National Commission for Health and Family Planning. We also collected other data including maternal mortality, management rate during pregnancy, visits for children younger than 7 years, pregnancy wellness checks, hospital deliveries, and newborn check-up rate.

In 2012, 2857 county level administrative units existed in China according to the National Bureau of Statistics. Of them, three counties were groups of islands in the South China Sea (the newly formed SanSha City) with a combined population of less than 2000 in 2013. Therefore, we excluded these counties from our analysis. Additionally, there were three Production and Construction Corps in Xinjiang Province (Elaer City, Tumushuke City, and Wujiaqu City) that have not reported any data to the ARMCH system and were thus excluded from our analysis. Because of changes in administrative boundaries during the study, we collapsed the remaining 2851 county level administrative units in 2012 into 2732 analytical county units for the study period.

Additionally, we used county-level GDP per person, which we converted to lag-distributed income based on international dollars using the method detailed by James and colleagues,[21] and maternal education level (which is the mean years of education received among mothers aged 15–49 years). We collected this information from the national, provincial, and city level statistics reports. Missing values in the covariates were imputed with standard multiple imputation methods.[22]

Estimation of county-level child mortality

Estimation of county child mortality involved three steps: correction for completeness of reported under-5 mortality rates; use of a validated small area estimation method combined with spatiotemporal regression and Gaussian process regression to deal with stochastic fluctuation in death numbers over time in counties; and addition of excess mortality due to natural disasters such as the 2008 Sichuan earthquake to without-shock under-5 mortality rates estimated using the first two steps. The appendix provides details about adding excess mortality.

Under-5 mortality rate completeness estimation

We computed the completeness of reported under-5 mortality rates in the ARMCH at the province level by comparing the under-5 mortality rates based on reported livebirths and deaths in the under-5 age group to the province level under-5 mortality rate estimates obtained using multiple sources and the method documented by Wang and colleagues.[1] We then explored the association between provincial under-5 mortality rate completeness and a set of covariates reflecting health-system infrastructure and availability of child and maternal health-related services including hospital delivery rate, neonatal check-up rate, management rate during pregnancy, visits for children under age 7 years, and pregnancy wellness check-up. Different model specifications were tested using an out-of-sample validation procedure in which we held out 20% of the data at the provincial level. We chose to use a hierarchical model that included fixed effects and provincial-level random effects on neonatal checkup rate, a fixed effect on time as a categorical variable, and provincial random effect as shown in equation 1 (appendix).

The purpose of modelling provincial-level death/under-5 mortality rate completeness in the ARMCH system was to predict completeness of under-5 mortality rates at the county level. We used the estimated coefficients from the aforementioned model and county-level covariates to make predictions of county-level completeness of under-5 mortality rates. We then adjusted the raw under-5 mortality rate at the county level from ARMCH using the predicted completeness. The adjusted data were used in the under-5 mortality rate estimation process including the small area model and the Gaussian process regression.

Small-area estimation model and Gaussian process regression for county-level under-5 mortality rate

The number of child deaths in smaller counties fluctuates from year to year because of chance and trends in the underlying rate. To generate consistent time series of under-5 mortality rate for each of the 2851 counties in China, we applied a small area estimation method that has been used in the USA in several studies.[23] Small area estimation methods stabilise estimates at the local level by borrowing strength over time, across space and from structured covariates. In our modelling process, a prior for the under-5 mortality rate was generated for each county-year using maternal education level (mean years of education in mothers aged 15–49 years), lag-distributed income, time, random effects (intercept and slope on time) at the province, city, and county level and a term for geospatial auto-correlation, which is the average of county-level random effects from neighbouring countries. This model, together with the spatiotemporal model, provides the prior that is used in Gaussian process regression, which updates the prior using the

See Online for appendix

	Province	County	Under-5 mortality rate (per 1000 livebirths)		Annualised rate of decline (%) 1996–2012
			1996	2012	
Top 20					
1	Shanghai	Huangpu Qu	12·1	3·3	8·2%
2	Shanghai	Changning Qu	11·2	3·3	7·7%
3	Zhejiang	Xiacheng Qu	15·0	3·5	9·0%
4	Guangdong	Yuexiu Qu	13·9	3·6	8·4%
5	Guangdong	Yantian Qu	17·2	3·8	9·4%
6	Guangdong	Baoan Qu	20·0	3·8	10·3%
7	Jiangsu	Jingkou Qu	16·0	3·9	8·8%
8	Jiangsu	Baixia Qu	17·8	3·9	9·4%
9	Zhejiang	Gongshu Qu	13·1	4·0	7·3%
10	Beijing	Xicheng Qu	10·6	4·2	5·8%
11	Guangdong	Potou Qu	12·8	4·2	6·9%
12	Jiangsu	Chong'an Qu	21·7	4·2	10·2%
12	Jiangsu	Xishan Qu	21·7	4·2	10·2%
12	Jiangsu	Binhu Qu	21·7	4·2	10·2%
12	Jiangsu	Beitang Qu	21·7	4·2	10·2%
12	Jiangsu	Nanchang Qu	21·7	4·2	10·2%
12	Jiangsu	Huishan Qu	21·7	4·2	10·2%
18	Guangdong	Leizhou Shi	45·2	4·2	14·8%
19	Jiangsu	Jianye Qu	17·3	4·2	8·8%
20	Zhejiang	Shangcheng Qu	14·3	4·3	7·5%
Bottom 20					
2832	Tibet	Baxoi Xian	91·7	67·0	2·0%
2833	Gansu	Maqu Xian	94·9	70·2	1·9%
2834	Tibet	Comai Xian	166·4	71·8	5·3%
2835	Gansu	Luqu Xian	104·4	72·6	2·3%
2836	Tibet	Geerzee Xian	203·4	73·2	6·4%
2837	Tibet	Gee'gyai Xian	190·2	73·4	6·0%
2838	Gansu	Jonee Xian	108·7	74·4	2·4%
2839	Tibet	Zhongba Xian	167·5	76·2	5·0%
2840	Tibet	Coqeen Xian	144·1	76·6	4·0%
2841	Xinjiang	Shule Xian	111·9	77·2	2·3%
2842	Tibet	Cona Xian	149·3	79·4	4·0%
2843	Tibet	Gyirong Xian	191·7	79·5	5·5%
2844	Tibet	Burang Xian	146·6	85·6	3·5%
2845	Tibet	Rutog Xian	160·8	85·6	3·9%
2846	Sichuan	Daocheng (Dabba) Xian	174·7	87·4	4·3%
2847	Tibet	Saga Xian	168·9	89·5	4·0%
2848	Tibet	Nyalam Xian	177·2	91·4	4·1%
2849	Tibet	Gamba Xian	165·9	100·3	3·3%
2850	Sichuan	Butuo Xian	345·1	104·0	7·5%
2851	Sichuan	Zamtang Xian	194·7	104·4	3·9%

Table 1: **Under-5 mortality rate, 1996 and 2012, and annualised rate of decline, 1996 to 2012, in the top and bottom performing counties**

data recorded in each county-year and the data variance for that measurement.

Details on the spatiotemporal regression and Gaussian process regression and their application in child mortality estimation have been extensively documented elsewhere[1,24] and are described further in the appendix.

After the predictions from Gaussian process regression were generated for each county, we rescaled the county-level under-5 mortality rate predictions to ensure that the aggregation of county estimates equaled the provincial estimates estimated separately.

To test the validity of our county level child mortality estimation process, we also compared our estimates with those from the National Maternal and Child Health Surveillance System. We used an ordinary least-squares regression model with estimates from our study as the dependent variable and those from the MCHS system as the independent variable. For the counties where we had overlapping data from the two systems, the coefficient of child mortality from MCHS was 1·3, which suggested that, at the county level, estimated child mortality rates from MCHS were lower than those provided by the current study. The appendix shows the scatter plots of estimated child mortality rates from the two aforementioned sources for counties covered by both the ARMCH and MCHS for the year 2012. Much of the discrepancy might come from the fact that in generating a child mortality rate at the national level, we included child mortality data from censuses, Annual Surveys on Population Change, One per 1000 fertility surveys, Disease Surveillance Points system, and other sources in addition to those from MCHS. More importantly, MCHS's national child mortality estimates were generated with specific adjustment to the surveillance site level child mortality data to account for regional heterogeneity and differences by rural or urban residency in under-5 mortality rate. At the national level, raw aggregated recorded births and deaths from all MCHS sites across the country seem to underestimate the level of child mortality compared with those generated with several sources by Wang and colleagues.[1] However, when we regressed the national under-5 mortality rate from Wang and colleagues on the national level under-5 mortality rate as published by MCHS, the coefficient was 0·987 suggesting that the MCHS's under-5 mortality rate estimates, after adjustment, were consistent with the national level under-5 mortality rate from Wang and colleagues,[1] which is what our current county-level under-5 mortality rate estimates sum to.

Comparisons to expected under-5 mortality rate

To assess the extent to which changes in the under-5 mortality rate in China could be attributed to rapid economic growth and expansion of educational attainment, we compared the estimated under-5 mortality rate with the under-5 mortality rate predicted on the basis of lag-distributed income per person, maternal educational attainment, secular trends at the global level, and country random effects. This model was similar to that published by Wang and collegues.[1] We estimated the coefficients for this model using the time series from 1970 to 2013 for 188 countries. The model is shown in the appendix.

This model accounted for 93·7% of the variance in under-5 mortality rates over time and across countries. We used this global regression model to estimate expected values of under-5 mortality rates for each county in China to provide a comparison to what the levels and trends in each county might be on the basis of the observed inter-country relationship between under-5 mortality rate, income, education, and time alone. We report ratios of the estimated under-5 mortality rate to the expected under-5 mortality rate from the inter-country global model.

Inequality measurement: Gini coefficient of under-5 mortality rate

To assess the inequality of both income and under-5 mortality rate across counties, we computed the population weighted inter-county Gini coefficient of the under-5 mortality rate (equation shown in appendix). As equation 3 shows, the Gini coefficient can be interpreted as the average relative differences between all pairs of counties.

Role of the funding source

The funders had no role in the study design, data analysis, data interpretation, or writing of the report. The corresponding authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Between 1996 and 2012, China's under-5 mortality rate decreased by 70%, from 46·0 per 1000 livebirths to 13·7 per 1000 livebirths. The country has achieved the MDG 4 target of a two-thirds reduction in child mortality from 1990 in 2008, the eighth country in the world to achieve the goal.

We noted high heterogeneity in terms of the under-5 mortality rates at the county level. In 2012, under-5 mortality rates ranged from 3·3 per 1000 livebirths in the Huangpu District in Shanghai to 104·4 per 1000 livebirths in Zamtang County in Sichuan. Table 1 provides the top and bottom 20 counties in terms of level of under-5 mortality rate in 2012 and the rate of decrease in under-5 mortality rates for these counties between 1996 and 2012. Zamtang County in Sichuan Province had the highest under-5 mortality rate in 2012, at 104·4 per 1000 livebirths, which is similar to Burkina Faso and Cameroon. The appendix and figure 1 show county-level under-5 mortality rates in 1996 and 2012. The maps highlight key areas with under-5 mortality rates lower than five

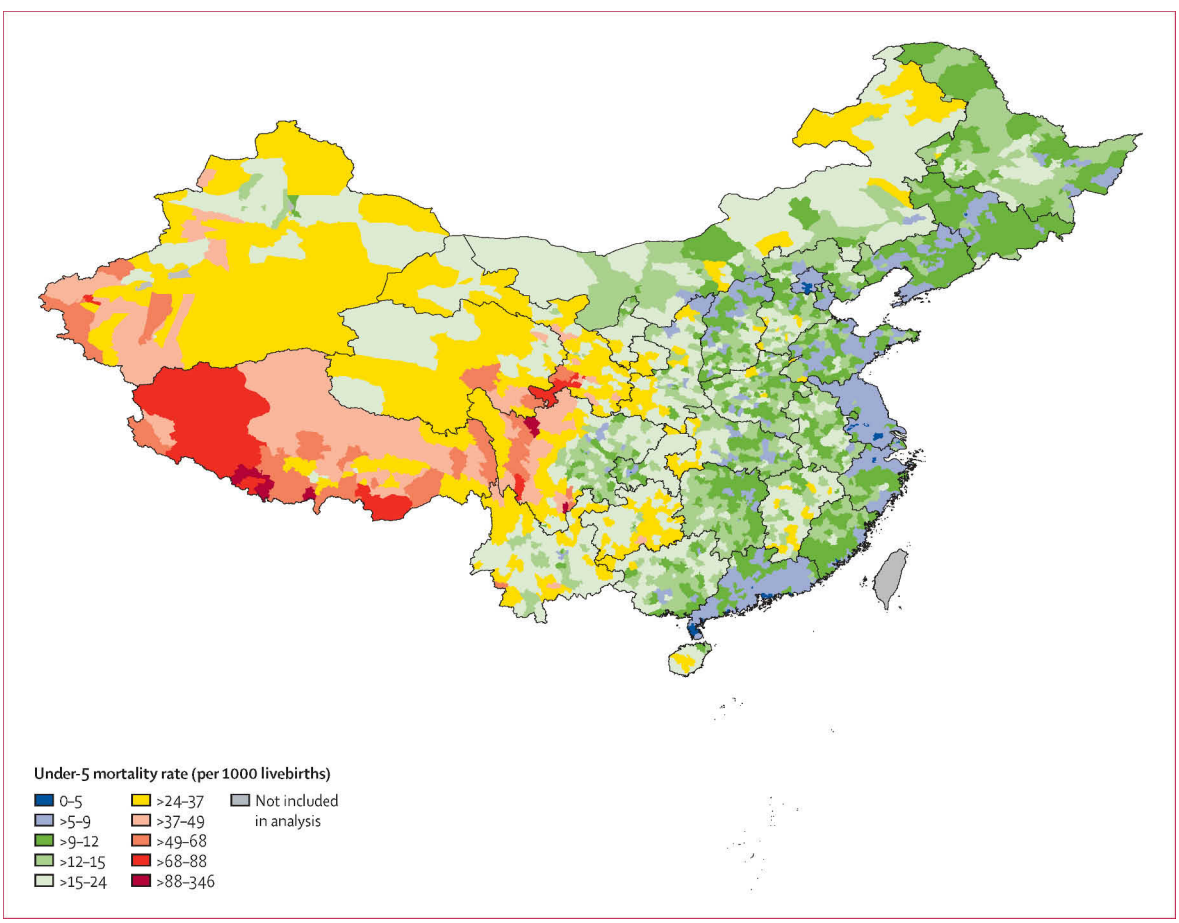

Figure 1: **Under-5 mortality rate by county, 2012**

per 1000; 31 countries in the world had achieved this level by 2012, all of which are high-income countries including Japan, Australia, Germany, Singapore, Norway, and Switzerland. These high achieving counties in China include ten of 123 counties in Guangdong, 13 of 102 counties in Jiangsu, six of 16 districts in Beijing, four of 17 districts in Shanghai, and four counties in Zhejiang. There are an additional three counties in three other provinces with levels lower than five per 1000 livebirths. By contrast, six provinces (Sichuan, Yunnan, Tibet, Gansu, Qinghai, and Xinjiang) have counties with under-5 mortality rates that were ten times higher than five per 1000 livebirths in 2012. The variation within provinces and across counties is large; the ratio of maximum to minimum under-5 mortality rate within a province ranges from 1·9 in Beijing to 14·6 in Sichuan Province. The appendix quantifies the width of the 95% uncertainty interval relative to the mean estimate for each county for 1996 and 2012, respectively. There were both provincial patterns with greater uncertainty in some western provinces and in Heilongjiang, and variation in the uncertainty intervals within provinces.

The appendix shows the inter-county Gini coefficient of under-5 mortality rates, which is also the average relative difference between pairs of counties. Inter-county inequality has decreased according to the population-weighted Gini coefficient. The appendix shows reductions in inequality; findings show that the number of counties with an under-5 mortality rate greater than 100 declined from 190 in 1996 to three in 2012, and at the same time, the number of counties with an under-5 mortality rate less than ten per 1000 livebirths increased from one to 791. The percentage reduction in under-5 mortality rates has on average been larger for counties with higher child mortality. The regression of the annualised rate of decline on the under-5 mortality rate in 1996 yielded a significant coefficient of 0·026 ($p<0·0001$). This figure can be interpreted as one point higher under-5 mortality rate than in 1996, which corresponds with 0·026 percentage point faster annualised rate of decline of under-5 mortality rates between 1996 and 2012. This is in sharp contrast to the consistent increase in inter-country Gini coefficient of under-5 mortality rates reported by Wang and collegues,[1] which shows the divergence of health in the under-5 age groups.

Annual estimates of under-5 mortality rates for 2851 counties (appendix) allowed us to compute the annualised rate of decline from 1996 to 2012 (figure 2).

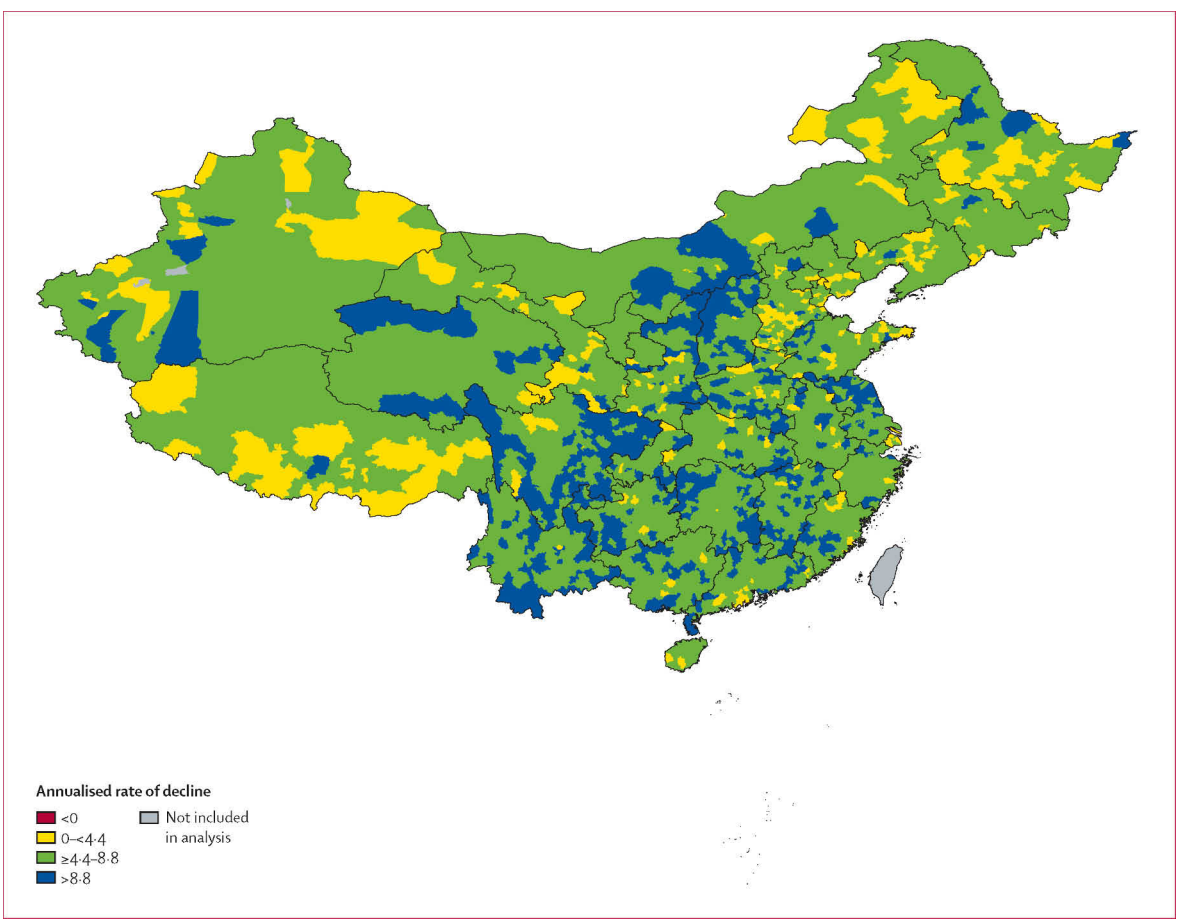

Figure 2: **Annualised rate of decline in under-5 mortality rate by county, 1996–2012**

543 counties have had annual rates of decline (ARDs) two times faster than the MDG 4 target pace of 4·4% per year. Another 1963 counties have ARDs that are between 4·4% and 8·8% per year. 345 counties have experienced rates of decline slower than the MDG 4 target pace.

In view of the large increases in GDP per person in China and the variability in percent change in county equivalent lag-distributed income per person, ranging from a 69·5% decrease to a 5680·2% increase between 1996 and 2012, and the increases in educational attainment for women, it is useful to explore how much of the under-5 mortality rate level and change cannot be accounted for by these transformations. The appendix shows the ratio of the estimated county under-5 mortality rate in 2012 to the expected value based on the global relationships between GDP per person, educational attainment, and the regional secular trend. In 2012, 2372 (83%) of 2851 counties achieved lower under-5 mortality rates than expected on the basis of income per person and maternal education (appendix). Counties with levels 70% lower than expected were concentrated in provinces such as Guangdong, Jiangsu, and Zhejiang. Counties in red (appendix) have higher levels than expected; many western provinces, as well as Inner Mongolia, western Shaanxi, Guizhou, Jiangxi, and Hainan stood out as underperforming. Some provinces show marked variation in performance such as Sichuan with most counties performing lower than expected, but 39 (22%) of 181 counties had better under-5 mortality rates than expected. Most counties (62%) had a significantly faster than expected decline in under-5 mortality rates between 1996 and 2012. Only 98 counties had significantly slower than expected decreases; these are distributed across 19 provinces with a notable cluster in Xinjiang, northeastern Inner Mongolia, Hebei, Henan, Gansu, and southern Shaanxi (figure 3). 998 (35%) of 2851 counties had reduced under-5 mortality at a rate that was not significantly different from the expected rate (figure 3). Although many counties in western China started with higher than expected under-5 mortality in 1996, rates of decline were higher than expected based on socioeconomic development (figure 3).

Of a population of 1·34 billion in mainland China, 8%, (113·8 million) are ethnic minorities. Table 2 shows the population-weighted average of under-5 mortality rates from all counties where any specific minority group accounted for at least 50% of the total population in the corresponding county. In 2012, six minority groups (Yi, Tibetan, Dongxiang, Kirgiz, Moinba, and Tajik) lived

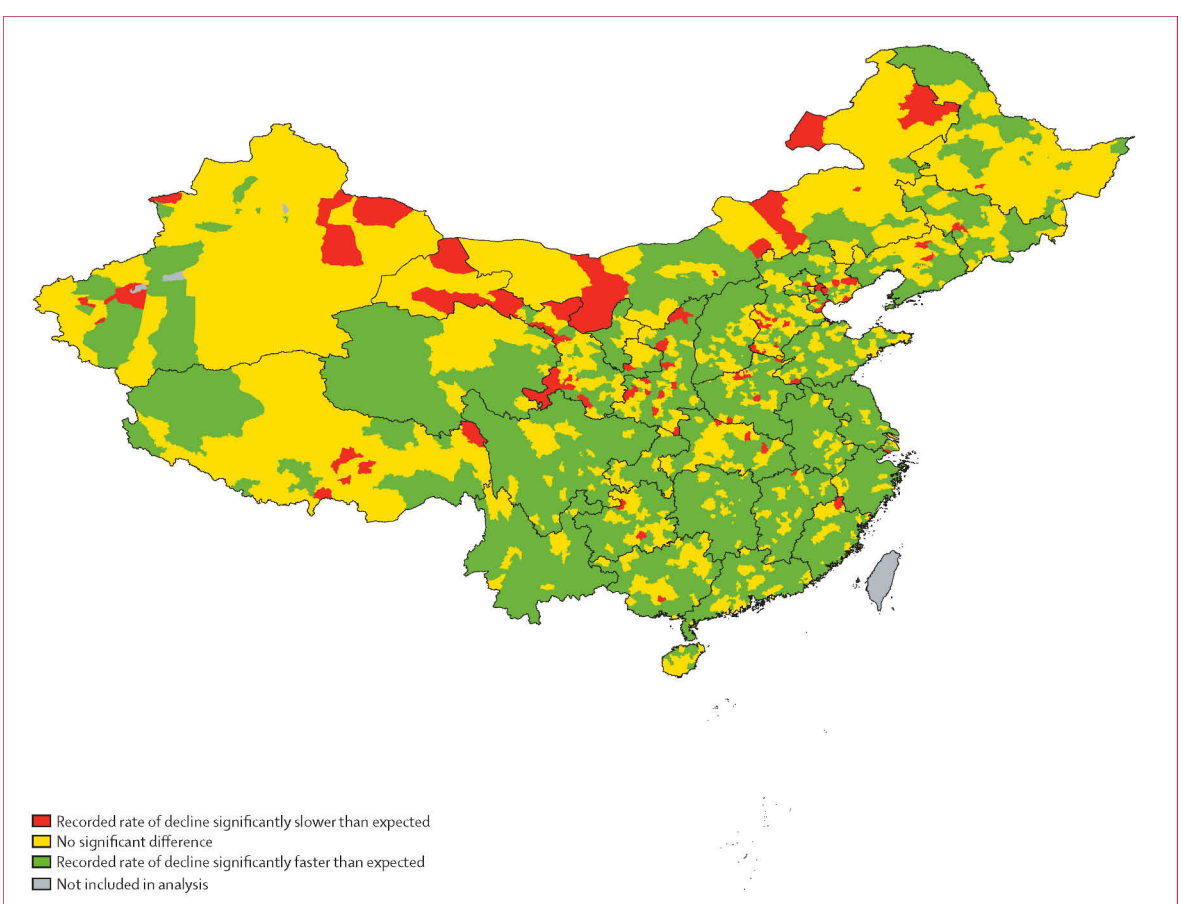

Figure 3: **Counties with statistically significant differences between the observed and expected rates of decline in under-5 mortality, 1996–2012**

	Under-5 mortality rate		Annualised rate of decline (%) 1996–2012	Ratio of estimated and expected rate of decline	Number of counties with ethnic group comprising 50% of the population	Total county population (thousands)
	1996	2012				
Korean	26·4	9·6	6·3%	1·57	4	1041·5
Manchu	30·2	12·0	5·7%	1·37	18	6816·3
Han	42·4	12·8	7·5%	1·67	2009	985765·0
Zhuang	52·4	14·1	8·2%	1·45	5	2070·8
Yao	53·1	14·6	8·0%	1·67	4	1078·8
Salar	63·7	15·6	8·8%	1·52	1	104·5
Tujia	68·1	18·3	8·2%	1·63	18	7288·5
Bai	64·4	18·5	7·8%	1·63	5	1448·1
Dong	88·1	18·9	9·6%	1·92	8	2101·6
Qiang	102·5	19·0	10·5%	2·15	2	263·9
Mongolian	47·1	19·9	5·4%	0·98	9	1573·0
Shui	88·1	20·0	9·3%	1·94	1	297·4
Miao	70·6	20·5	7·7%	1·48	11	2837·6
Hui	70·4	24·2	6·7%	1·32	7	1621·6
Lisu	106·0	29·3	8·0%	1·59	3	406·1
Kazak	89·5	30·1	6·8%	1·03	6	385·2
Bouyei	108·1	30·3	7·9%	1·45	5	1271·4
Hani	94·2	33·9	6·4%	1·49	3	831·8
Li	69·7	34·0	4·5%	0·93	2	265·3
Uygur	101·4	38·1	6·1%	1·19	34	7698·1
Tibetan	109·7	41·5	6·1%	2·30	125	5232·2
Dongxiang	83·5	41·8	4·3%	0·98	1	256·8
Yi	163·9	44·3	8·2%	1·99	11	1989·5
Kirgiz	112·6	52·6	4·8%	0·86	2	76·3
Tajik	149·0	54·3	6·3%	0·99	1	30·5
Moinba	106·8	54·3	4·2%	87·43	1	9·7

Table 2: **Population weighted average and annualised rate of decline in counties where at least 50% of the population consists of a specific ethnic group, 1996 and 2012**

For **online data visualisation of China under-5 mortality rates** see http://vizhub.healthdata.org/subnational/china

in counties with an under-5 mortality rate on average greater than 40 per 1000 livebirths. Between 1996 and 2012, under-5 mortality rates did not increase in any of the 25 minority groups (table 2). 23 (92%) groups had a rate of decline in under-5 mortality rates that was faster than the MDG 4 target pace of 4·4% (table 2). 12 (48%) of 25 minority groups experienced a faster rate of decline than the Han Chinese. Of note, nine minority groups (Yi, Lisu, Qiang, Zhuang, Yao, Tujia, Salar, Dong, and Shui) had rates of decline that were faster than 8% between 1996 and 2012. Three more minority groups, Bouyei, Bai, and Miao, had a rate of decline between 7·5% and 8% every year, faster than the 7·5% rate of decline for the ethnic Han.

The top ten minority groups with the largest population in the 2010 Census (Zhuang, Hui, Manchu, Uygur, Miao, Yi, Tujia, Tibetan, Mongolian, and Dong) have all made strides in reducing under-5 mortality rate faster than 4·4% per year. Table 2 shows the average ratio of estimated rate of decline in under-5 mortality rates from 1996 to 2012 to the expected rates of decline based on socioeconomic progress in the same period. 20 (80%) of 25 minority groups had faster estimated rates of decline in under-5 mortality than was expected based on the progress made in socioeconomic development and secular trends. Of those 20 minorities, three (Tibetan, Qiang, and Moinba) had a rate of decline that was at least twice as fast as the expected rate of decline (table 2). The minority groups that had slower estimated rates of decline than expected were Kirgiz (mainly in Xinjiang Province), Li, Dongxiang, Mongolian, and Tajik.

Detailed county level under-5 mortality rate estimates can be found online.

Discussion

The reduction of child mortality in China is an extraordinary success story. 2506 (88%) of 2851 counties have had decreases exceeding 4·4% per year between 1996 and 2012. Inequalities measured by the range from maximum to minimum and the Gini coefficient across counties have decreased. Explanations for trends in under-5 mortality often fall into two broad narratives: changes to underlying trends in distal social and economic factors and changes in coverage of specific lifesaving interventions such as vaccinations, breastfeeding, insecticide-treated bednets, and antibiotics for pneumonia. In 1984, Mosley and Chen[25] argued that these two perspectives were not in conflict with each other. Empirically there are very powerful associations between income per person and maternal education that account for much of the variation in under-5 mortality. Higher income per person and maternal education can lead to lower under-5 mortality through pathways of higher intervention coverage and through other risks and drivers of child mortality such as indoor air pollution, child malnutrition, and water and sanitation.[26]

Statistical models also show a strong global secular trend such that on average the under-5 mortality rate (controlling for income per person and maternal education) is decreasing nearly 2% per year.[1] Some of this secular trend might be the result of improved technologies for lowering child mortality that can be achieved at lower levels of income per person and other technical changes outside the health sector. All three factors taken together, income per person, educational attainment, and the secular trend, in addition to country random effects, account for more than 93% of variation in under-5 mortality rates worldwide. This strong statistical relationship does not suggest that coverage of life-saving interventions does not matter. Rather, an important component of the distal relationships is probably mediated through access to an ever improving set of life-saving technologies. Against this backdrop of global change in under-5 mortality rates, how should the very rapid declines in under-5 mortality rates in many counties of China be viewed?

By comparing progress in China at the country level with trends expected on the basis of the global relationship

between income per person, maternal education, and the global secular trend, our data suggest that many communities in China have made surprisingly rapid declines. Our descriptive analysis of trends does not provide any empirical assessment of the factors that might account for the more rapid progress than expected. However, existing studies provide some indication of these factors. The extensive scientific literature on the association between levels of fertility and child mortality suggests that the reduction in fertility rates might be an important factor. The national policy on family planning implemented since the late 1970s has been associated with decreases in the total fertility rate at the national level from 2·51 in 1990 to well below replacement level at 1·7 in 2012.[27] However, the global relationship between income per person, maternal education and under-5 mortality includes within it the component of fertility change that is associated with these two variables. Policies that have accelerated access to life-saving health interventions would be strong candidates for possible explanations. A wide range of health policies, such as the Program to Reduce Maternal Mortality and Eliminate Neonatal Tetanus,[28] the expanding Extended Program for Immunization,[29] and implementation of Integrated Management of Childhood Illness, in-facility delivery subsidy for all rural pregnant women, the national Reducing Child and Maternal Mortality Programme especially in less economically developed, and rural or inland, areas, and baby-friendly hospital[30] were implemented over this period. Furthermore, the introduction of the Law on Maternal and Infant Health Care in 1994 made improving maternal and child health a policy priority for local governments but with variability in local implementation.[31] Although it is important for central and provincial governments to promote certain public health interventions and programmes, how these programmes are implemented still varies at the county level. Some counties have gone further to improve child and maternal health by providing free or nearly free health care. The decision made by county governments to make health care fully free could improve access to key health interventions and reduce under-5 mortality rates. A comprehensive time series of under-5 mortality rates by county in China provides an opportunity for future research to assess whether there is a statistical relationship between the introduction and implementation of various policies at the local level and the pace of progress in reducing under-5 mortality rates.

The pace of decline in excess of the MDG 4 pace achieved in 2506 counties has implications for the current efforts to establish new targets for child mortality reduction in the post-MDG era. The USA, India, and Ethiopia have called for the end of preventable child mortality[32] by 2035, which has been interpreted as an under-5 mortality rate of 20 per 1000 livebirths. Various analyses have explored what it would take to achieve this, especially in the more disadvantaged countries in central and west Africa.[33,34] If the rate of decline faster than the MDG 4 pace in many Chinese counties, or even more importantly the pace of decline at more than 13·2% in 11 counties, can be replicated, the prospect for dramatic progress is much more plausible. The Partnership for Maternal, Newborn and Child Health (PMNCH) has been undertaking case studies of countries like China that have achieved MDG 4 pace declines. Similar case studies should be undertaken for counties such as Shenmu County in Shaanxi Province, which have achieved double or triple the MDG 4 pace of decline. Because these declines cannot be explained simply by high rates of economic growth, many potential policy lessons could emerge from a more in-depth quantitative and qualitative analysis of these communities. We believe that the accurately assessed level of and progress made in under-5 mortality rates at the county level in China reported here provides a unique opportunity to further understand how communities, especially those still with high levels of under-5 mortality rates and low rates of decline, can make progress in achieving MDG goals and post-MDG era global goals on child health. The call to study such progress in China by the China UK Global Health Support Programme, a collaboration between the Chinese government and the Department for International Development of the UK Government, is a welcome effort.

Despite the incredible success overall, 345 counties (12% of all Chinese counties) did not achieve the MDG 4 pace of decline from 1996 to 2012; these counties represent a population of 149·8 million and specifically 1·5 million livebirths per year in 2012. These findings highlight the importance of continued and reinvigorated efforts to address inequalities in these communities. Although China has been successful in reducing inter-county inequality in under-5 mortality rates, the range across counties in absolute terms is astounding. The mean under-5 mortality rate for sub-Saharan Africa in 2012 was 98·1 per 1000 livebirths,[1] and three counties in China were higher than this level. The mean under-5 mortality rate in south Asia was 55·0 per 1000 livebirths, and 37 counties in China were higher than this level. Researchers of a recent World Bank study argued that one key barrier to more rapid progress could be the largely decentralised financing of public services;[35] comparatively poor communities with the greatest needs still depend heavily on locally-raised revenue to support programmes. This problem has also been identified by many local public health officials in China as a key obstacle in further improving maternal and child health. Further analysis, qualitative and quantitative, is warranted to study such relationships and what are the best and most feasible mechanisms for local government to fully finance their public health programmes.

All major minority groups have made tremendous progress in reducing under-5 mortality rates despite most of them living in western or southwestern

provinces, where economic development has been lagging behind compared to the rest of the country. Nevertheless, 23 minority groups in a cluster of counties where they account for at least 50% of the population have made reductions in under-5 mortality rates that were faster than the MDG 4 pace, many of which even doubled the MDG 4 pace of 4·4%. Additionally, all major minority groups have made reductions in under-5 mortality that were much faster than expected. This development could perhaps be traced to national policies and programmes that were intended to lower child mortality and to improve maternal and child health, which have emphasised provinces in the west and provinces with lower per person income. Although the newly established New Cooperative Medical Scheme (NCMS) has yet to show its effect on child mortality,[36] NCMS could improve the use of inpatient services in the poor and in turn improve the health of the population in remote rural areas in the coming years. With increases in insurance financing and the expansion in the scope of reimbursement for childhood diseases since the introduction of the health-care reform in 2009,[37] further and timely assessment of the effect of NCMS on under-5 mortality rates is necessary.

This first-ever analysis of under-5 mortality rates at the county level in China has several limitations. First, the annual reporting system is incomplete and our results depend on the validity of the estimation of the equation estimating completeness in ARMCH reported under-5 mortality rate as a function of province, year, and the neonatal check-up rate. Equation 1 was developed based on testing a number of different specifications. However, the relationship recorded between completeness of the ARMCH at the province level might not hold true at the county level. Our comparison at the county level between the MCHS surveillance system and our ARMCH corrected under-5 mortality rate suggests that our estimates of completeness for some communities might be too low. Alternatively the MCHS surveillance system might be missing deaths in some communities. We have also ensured through raking that the sum of county estimates in each province equals the best estimates based on several sources for the province. A second limitation is that we have not used all data sources on child mortality at the county level. The censuses done in 1990, 2000, and 2010 included summary birth history questions. In future analyses, it would be interesting to analyse all sources available at the county level. However, because each county would need to be analysed separately, this would be a major undertaking. Additionally, the analysis by Wang and colleagues[1] suggested that census summary birth histories generally yielded under-estimates of under-5 mortality rates.

A third limitation is the substantial internal migration within China; a population estimated to be 122·1 million lives in urban areas without household registration status in these areas according to the 2010 census of China.[38] Births and deaths in this so-called floating population in principle are registered in the ARMCH. The MCHS system records the floating population who live in the surveillance areas for 1 year or more. However, concerns remain that the floating population was not fully recorded in the numerator or denominator of the ARMCH; this would tend to lower estimates for under-5 mortality rate in urban areas. Related to this limitation is the effect of internal migration on income. Remittance is an important income source for many less economically developed regions, and such quantity is not captured in the estimation of local GDP. Further analysis on the effect of migration on local income is warranted to accurately assess the effect of income on child health. A fourth limitation is that our small area model borrows strength over time and across neighbouring counties. Geospatial models like this might underestimate true variation across populations by smoothing variation across adjacent geographies. However, in other work, the small area mortality estimation model we used has been valid.[23] Alternative specifications such as the intrinsic conditional autoregressive (ICAR) model have been used for other outcomes; we have compared the performance of the ICAR model and other modelling strategies and have not found substantial differences in performance.[39] A fifth limitation is that our current analysis focuses on level and change in under-5 mortality rates at the county level in China. Although these are the primary metrics for measuring progress towards MDG 4 goals set by the international community, it is also important to study the composition of mortality by cause and by more detailed age group in the under-5 age group. Rigorous analysis on these fronts should be undertaken using several data sources from China that can better guide intervention efforts to reduce under-5 mortality rates in regions with less satisfactory progress made in the past two decades.

In view of the huge progress in reducing child mortality in China, the agenda of addressing the remaining communities with under-5 mortality rates in excess of 20 per 1000 livebirths (164·7 million population) will probably capture increasing attention. Regular surveillance of the under-5 mortality rate at the county level will be the only way to know if policies to counteract health inequalities are successful. The ARMCH is a useful system, but the quality of registration needs to be improved especially in counties falling behind MDG 4 pace. The addition of cause of death data for children in the Maternal and Child Health Information System would help policy makers identify what will be the most effective strategy to prevent further avoidable deaths in the more disadvantaged communities.

Contributors

JZ, CJLM, and HW conceived of the study and provided overall guidance. HW, XL, MMC, CAL, YW, JL, MZ, SL, MSF, and JZ did the analysis. CJLM, XL, HW, JZ, and YW reviewed each cycle of estimation in detail. CJLM, HW, YW, XL, MZ, SL, and JZ prepared the first draft. All other authors reviewed results, and reviewed the report.

Declaration of interests
We declare no competing interests.

Acknowledgments
This study was funded by the National "Twelfth Five-Year" Plan for Science and Technology Support (2014BAI06B01), National Health and Family Planning Commission of The People's Republic of China (grants QT2003-009 and 05wsb-02), University of Washington Center for Demography and Economics of Aging, Grant Number 1-P30-AG047845 from the National Institute on Aging, Program for Changjiang Scholars and Innovative Research Team in University (IRT0935), and the Bill & Melinda Gates Foundation. We thank the countless health workers who have contributed to data collection in the Chinese MCH information system; and acknowledge the extensive support from all staff members at National Office for Maternal and Child Health Surveillance of China and Jonathan Brown from the Institute for Health Metrics and Evaluation for facilitating research between IHME and MCHS.

Reference

1 Wang H, Liddell CA, Coates MM, et al. Global, regional, and national levels of neonatal, infant, and under-5 mortality during 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014; **384:** 957–79.
2 Rudan I, Chan KY, Zhang JSF, et al. Causes of deaths in children younger than 5 years in China in 2008. *Lancet* 2010; **375:** 1083–89.
3 UN Inter-agency Group for Child Mortality Estimation. Levels and trends in child mortality 2014. UNICEF; WHO; World Bank; UN-DESA Population Division, 2014. http://www.who.int/maternal_child_adolescent/documents/levels_trends_child_mortality_2014/en/ (accessed July 24, 2014).
4 Feng XL, Theodoratou E, Liu L, et al. Social, economic, political and health system and program determinants of child mortality reduction in China between 1990 and 2006: a systematic analysis. *J Glob Health* 2012; **2:** 010405.
5 Naghavi M, Wang H, Lozano R, et al. Global, regional, and national age–sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015; **385:** 117–71.
6 Wang YP, Miao L, Dai L, et al. Mortality rate for children under 5 years of age in China from 1996 to 2006. *Public Health* 2011; **125:** 301–07.
7 Knight J. Reform, growth, and inequality in China. *Asian Econ Policy Rev* 2008; **3:** 140–58.
8 The 17th National Congress of the Communist Party of China: Harmonious society. 2007. http://en.people.cn/90002/92169/92211/6274603.html (accessed July 24, 2014).
9 Zheng X, Song X, Chen G, et al. Health inequalities during 20 years of rapid economic development in China (1980–2000): a mortality analysis. *Biomed Environ Sci BES* 2011; **24:** 329–34.
10 Wang Y, Zhu J, He C, Li X, Miao L, Liang J. Geographical disparities of infant mortality in rural China. *Arch Dis Child Fetal Neonatal Ed* 2012; **97:** F285–90.
11 Meng Q, Xu L, Zhang Y, et al. Trends in access to health services and financial protection in China between 2003 and 2011: a cross-sectional study. *Lancet* 2012; **379:** 805–14.
12 Chen Y, Jin GZ. Does health insurance coverage lead to better health and educational outcomes? Evidence from rural China. *J Health Econ* 2012; **31:** 1–14.
13 Yanping W, Lei M, Li D, et al. A study on rural-urban differences in neonatal mortality rate in China, 1996–2006. *J Epidemiol Comm Health* 2010; **64:** 935–36.
14 Huo K, Zhao Y, Feng H, et al. Mortality rates of children aged under five in Henan province, China, 2004–2008. *Paediatr Perinat Epidemiol* 2010; **24:** 343–48.
15 National Bureau of Statistics of China. China Population and Housing Census 1982; 1990; 2000; 2010. China CDC.
16 National Bureau of Statistics of China. 1 per 1000 Survey on Fertility and Birth Control 1982; 1987–1988; 1992. State Family Planning Commission of China.
17 National Bureau of Statistics of China. China Sample Survey on Population Changes 1986; 1994; 1996–1999; 2001–2004; 2006–2009.
18 National Bureau of Statistics of China. China 1% National Population Sample Survey 1995; 2005. Ann Arbor, United States: China Data Center, University of Michigan.
19 China National Maternal and Child Health Surveillance System Under-5 Mortality 1992–2013. MCHS.
20 Chinese Center for Disease Control and Prevention (CCDC). China Disease Surveillance Points 1996–2000; 2004–2012. China CDC.
21 James SL, Gubbins P, Murray CJ, Gakidou E. Developing a comprehensive time series of GDP per capita for 210 countries from 1950 to 2015. *Popul Health Metr* 2012; **10:** 12.
22 Honaker J, King G. What to do About Missing Values in Time Series Cross-Section Data. *Am J Polit Sci* 2010; **54:** 561–81.
23 Wang H, Schumacher AE, Levitz CE, Mokdad AH, Murray CJ. Left behind: widening disparities for males and females in US county life expectancy, 1985–2010. *Popul Health Metr* 2013; **11:** 8.
24 Ng M, Freeman MK, Fleming TD, et al. Smoking prevalence and cigarette consumption in 187 countries, 1980–2012. *JAMA* 2014; **311:** 183–92.
25 Mosley WH, Chen LC. An analytical framework for the study of child survival in developing countries. 1984. *Bull World Health Organ* 2003; **81:** 140–45.
26 Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380:** 2224–60.
27 United Nations Department of Economics and Social Affairs Population Division. World population prospects: the 2012 revision. http://esa.un.org/unpd/wpp/Documentation/publications.htm (accessed July 24, 2014).
28 Liang J, Li X, Dai L, et al. The changes in maternal mortality in 1000 counties in mid-western China by a government-initiated intervention. *PLoS One* 2012; **7:** e37458.
29 Wu W-D, Liu D-W, Cao L. Study on the estimation of routine immunization coverage of China, 2005–2007. *Zhongguo Yi Miao He Mian Yi* 2009; **15:** 363–66 (in Chinese)
30 Chamberlain M. A baby-friendly hospital initiative in northern China. *Nurs Ethics* 1997; **4:** 511–18.
31 The Millennium Development Goal Report 2013. United Nations, 2013 http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf (accessed July 24, 2014).
32 UNICEF, WHO, World Bank, UN Population Division. Levels and trends in child mortality: report 2012. Estimates developed by the UN inter-agency group for child mortality estimation. http://www.who.int/maternal_child_adolescent/documents/levels_trends_child_mortality_2012.pdf?ua=1 (accessed July 24, 2014).
33 Hulton L, Matthews Z, Martin-Hilber A, et al. Using evidence to drive action: a 'revolution in accountability' to implement quality care for better maternal and newborn health in Africa. *Int J Gynecol Obstet* 2014; **127:** 96–101.
34 Lawn JE, Blencowe H, Oza S, et al. Every Newborn: progress, priorities, and potential beyond survival. *Lancet* 2014; **384:** 189–205.
35 Equity and public governance in health system reform: Challenges and opportunities for China. The World Bank, 2011. http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-5530 (accessed Feb 5, 2015).
36 Chen Y, Jin GZ. Does health insurance coverage lead to better health and educational outcomes? Evidence from rural China. *J Health Econ* 2012; **31:** 1–14.
37 Hou Z, Van de Poel E, Van Doorslaer E, Yu B, Meng Q. Effects of Ncms on Access to Care and Financial Protection in China. *Health Econ* 2014; **23:** 917–34.
38 National Bureau of Statistics of China. China Population and Housing Census 2010. China CDC.
39 Besag J, York J, Mollié A. Bayesian image restoration, with two applications in spatial statistics. *Ann Inst Stat Math* 1991; **43:** 1–20.