Regional disparities in the burden of disease attributable to unsafe water and poor sanitation in China

Elizabeth J Carlton, Song Liang, Julia Z McDowell, Huazhong Li, Wei Luo & Justin V Remais

Objective To estimate the disease burden attributable to unsafe water and poor sanitation and hygiene in China, to identify high-burden groups and to inform improvement measures.

Methods The disease burden attributable to unsafe water and poor sanitation and hygiene in China was estimated for diseases resulting from exposure to biologically contaminated soil and water (diarrhoeal disease, helminthiases and schistosomiasis) and vector transmission resulting from inadequate management of water resources (malaria, dengue and Japanese encephalitis). The data were obtained from China’s national infectious disease reporting system, national helminthiasis surveys and national water and sanitation surveys. The fraction of each health condition attributable to unsafe water and poor sanitation and hygiene in China was estimated from data in the Chinese and international literature.

Findings In 2008, 327 million people in China lacked access to piped drinking water and 535 million lacked access to improved sanitation. The same year, unsafe water and poor sanitation and hygiene accounted for 2.81 million disability-adjusted life years (DALYs) and 62,800 deaths in the country, and 83% of the attributable burden was found in children less than 5 years old. Per capita DALYs increased along an east–west gradient, with the highest burden in inland provinces having the lowest income per capita.

Conclusion Despite remarkable progress, China still needs to conduct infrastructural improvement projects targeting provinces that have experienced slower economic development. Improved monitoring, increased regulatory oversight and more government transparency are needed to better estimate the effects of microbiologically and chemically contaminated water and poor sanitation and hygiene on human health.

Abstract: on العربية, Français, Русский and Español at the end of each article.

Introduction

China’s rapid economic growth has brought about a shift in health priorities as infectious diseases associated with poverty are gradually displaced by chronic illnesses. Yet the traditional causes of illness, including infections resulting from unsafe water and poor sanitation and hygiene, still exist and are unevenly distributed across China’s diverse cultural and geographic landscape as a result of regional differences in urbanization, economic development and environmental factors. Country-wide measures of important infectious diseases conceal important regional and socioeconomic disparities that, although widely recognized in China, have been poorly documented, particularly for diseases resulting from environmental pollution. In light of China’s large, diverse population and the government’s recent commitment to invest heavily in water infrastructure, estimates of the burden of disease attributable to unsafe water and poor sanitation and hygiene are needed at a resolution capable of capturing regional disparities. Such estimates can inform policies for targeting vulnerable populations through investments in health care and in infrastructural development.

Globally, unsafe water and poor sanitation and hygiene account for approximately 1.9 million annual deaths and 4.2% of the global burden of disease. Where water and sanitation facilities are inadequate, faecal contamination of drinking water and soil permits transmission of diarrhoeal pathogens and, according to prior estimates, diarrhoea accounts for the largest fraction (>90%) of the global burden of disease attributable to unsafe water and poor sanitation. In addition, unsafe disposal of human waste can promote the transmission of water- and soil-transmitted helminthic infections. Poorly managed surface water resources can facilitate vector breeding and promote the transmission of vector-borne diseases such as malaria and dengue. The burden of diseases attributable to unsafe water and poor sanitation and hygiene is largely borne by the poorer members of society and the resulting health effects, including impaired child growth and reduced work capacity, are substantial and poverty-reinforcing.

Over the past two decades, the water and sanitation infrastructure has improved dramatically in China. However, access to safe water and good sanitation varies markedly throughout the country, which suggests that some population groups bear a greater risk of disease than others. Rural residents, who represent 60% of China’s population, may be particularly vulnerable. In urban areas, piped water coverage rose from 48% in 1990 to nearly 94% in 2007. Access to sanitation facilities and piped water in rural areas has more than tripled since the initiation of a national campaign in the 1980s, yet in 2006 only 55% of 60,000 rural households surveyed across China had access to a centralized public water supply. Furthermore, 44% of rural water supplies did not meet minimum drinking water quality standards, largely on account of contamination from untreated sewage. To inform policy to further im-
prove water and sanitation in China, we estimated the burden of eight diseases attributable to unsafe water and poor sanitation and hygiene and examined the distribution of disease burden by age, province and level of economic development.

Methods

Unsafe water and poor sanitation and hygiene can cause illness through various pathways. Drinking water can be contaminated with biological or chemical agents, soil, water or foodstuffs can be contaminated with faeces, and, if water resources are poorly managed, they can become vector habitats. We used the comparative risk assessment (CRA) framework to estimate the amount of ill health in China that could be prevented by improving unclean water and sanitation facilities, promoting access to pathogen-free water supplies and reducing vector habitats. Our approach integrated exposure and disease surveillance data with a review of evidence of the impact of interventions to reduce hazardous exposures on population health. For each health outcome, we estimated the attributable fraction or proportion of disease that could be prevented through interventions to improve sanitation and water, based on a review of the literature. To ensure the suitability of our estimates for the local context, we used studies specific to China whenever possible. For example, in China, drinking hot tea may reduce the risk of diarrhoea among people exposed to unimproved drinking water sources, but tea drinking may not be accounted for in studies conducted in other regions.

We considered only interventions that were feasible, ethical and environmentally sound and sustainable, such as providing piped or treated water, installing sanitary toilets and covering or eliminating water containers around the home. No interventions that could harm ecosystems, such as destroying wetlands to reduce mosquito populations, were feasible, ethical and environmentally sound. No interventions that could harm ecosystems, such as destroying wetlands to reduce mosquito populations, were feasible, ethical and environmentally sound.

Selection of health outcomes

We limited our analysis to diseases for which (i) data describing disease prevalence or incidence or population exposure at the provincial level were available from Chinese national surveillance systems, and (ii) sufficient evidence linking improvements in water and sanitation to reductions in disease incidence was available. Our estimates do not include the health impacts of contamination of water supplies with industrial chemicals and municipal discharge, agricultural run-off and naturally-occurring metals such as arsenic. These sources of contamination are of great concern in China, yet efforts to estimate the burden of disease attributable to exposure to these contaminants have been hampered by limited data and important knowledge gaps that we discuss further in Box A1 in Appendix A (available at: http://www.sph.emory.edu/eh/remais/bwho). We identified eight health outcomes that met the required criteria: diarrhoeal disease, dengue, malaria, Japanese encephalitis, schistosomiasis, ascariasis, trichuriasis and hookworm infection.

Diarrhoeal diseases

Poor sanitation and unsafe drinking water can cause diarrhoeal diseases by exposing humans to ingestion of food or water contaminated with faecal material from unclean hands and faeces. Due to difficulties in directly measuring the incidence of diarrhoeal diseases, particularly on a national scale, we used an exposure-based approach to estimate the diarrhoeal disease burden attributable to unsafe water and poor sanitation and hygiene.

We adapted exposure scenarios previously defined by Prüss et al. to estimate the global burden of diarrhoeal diseases to reflect China’s typical water and sanitation systems and associated pathogen loads in the environment (Table 1). We estimated the relative risk (RR) of diarrhoeal disease based on a systematic review of the Chinese literature (Table A1 in Appendix A). However, to estimate the RR associated with Scenario II (relative to Scenario I) we used estimates derived from a study conducted in the United States of America because of the small likelihood of observing Scenario I in China. The RR forScenario IV, 4.5, was estimated from an intervention trial conducted in Henan. This estimate falls between the realistic (RR: 6.9) and conservative (RR: 3.8) global estimates for Scenario IV. In the same study, the incidence of diarrhoea was reduced by 12.6% when partially improved drinking water was provided in areas with improved sanitation (Scenario Va to IV), but in a similar study the reduction in incidence was 75.7%. We selected the more conservative estimate for its consistency with multinational studies. The RR for Scenario Vb, derived from a case-control study, suggests that improved sanitation has a greater effect on diarrhoea incidence than improved drinking water. Seven studies examined the impact of providing access to improved water or sanitation facilities where neither existed before. We selected the median estimate (RR: 11.2) and conducted sensitivity analyses using the minimum (RR: 5.2) and maximum (RR: 16.9) estimates.

The population in each exposure scenario was estimated from the National Survey on Rural Water and Sanitation for 2006–2007 and the National health yearbook (2008). We assumed that all urban populations had access to improved sanitation and drinking water (Scenario II). We estimated the incidence of diarrhoea attributable to unsafe water and poor sanitation and hygiene (\(I_{\text{WSH}}\)) as the diarrhoea incidence in excess of the incidence expected under Scenario I (\(I_{\text{baseline}}\)) using the following equation:

\[
I_{\text{WSH}} = I_{\text{baseline}} \times \left(1 - \sum_{n=2}^{6} \left(1 - \frac{1}{\text{RR}_n}\right)\right) \tag{1}
\]

Where \(F_n\) is the fraction of the population exposed to Scenario \(n\) and \(\text{RR}_n\) is the relative risk of diarrhoea for Scenario \(n\) (relative to Scenario I). \(I_{\text{baseline}}\) was estimated from diarrhoea incidence rates in established market economies where exposure to water and sanitation is assumed to conform to Scenario I, divided by the RR of infection in exposure Scenario II (versus Scenario I). Deaths from diarrhoea attributable to unsafe water and poor sanitation and hygiene were estimated using China-specific case-fatality percentages and diarrhoea incidence and mortality rates derived from the Global Burden of Disease Project.

Schistosomiasis and soil-transmitted helminthiases

The helminths Schistosoma japonicum, Ascaris lumbricoides, Trichuris trichuria, Ancylostoma duodenale and Necator americanus are excreted by human hosts.
were used to estimate the prevalence of infection surveys, conducted in 2004, to the risk of human infection. Water, such as large dams, can provide impacted by water resource management. The mosquito vectors of malaria, dengue and Japanese encephalitis can reduce the risk of infection. On the basis of previous work, we estimated that 95% of the burden of dengue and Japanese encephalitis is attributable to unsafe water and sanitation. Death and incidence rates for malaria, dengue and Japanese encephalitis in 2008 were obtained for each province from the Chinese National Infectious Disease Reporting System (NIDR). The NIDR includes 28 reportable diseases and has operated since 2004 on a real-time basis using networked computers that link the national surveillance centre, regional centres for disease control and prevention, and almost all rural and urban hospitals.

Estimation of disease burden
DALYs and mortality rates were used to quantify the health impact of multiple diseases. While the comparability of DALYs across diseases is sensitive to the choice of disability weights and to disease duration, which poses a particular challenge for conditions of low severity and high prevalence, the integration of multiple disease outcomes into a single measure is appropriate for exposures, such as exposure to unsafe water and poor sanitation and hygiene, that can lead to different health endpoints. Age and sex-specific incidence and mortality rates (for diarrhea and vector-borne infections) or prevalence rates (for schistosomiasis and soil-transmitted helminthiasis) at the provincial level were used to calculate DALYs using established morbidity weights, disease duration, age-weighting and 3% annual discounting for delayed morbidity (Box A2 in Appendix A). Provincial population estimates for 2008 were obtained from the National Bureau of Statistics. Province-specific age distributions from the 2000 Chinese National Census were projected against the population of each province in 2008.

<table>
<thead>
<tr>
<th>Exposure scenario</th>
<th>Description</th>
<th>RR of diarrhea</th>
<th>Reference for RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No transmission of diarrhoeal disease from unsafe water or sanitation.</td>
<td>1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>–</td>
</tr>
<tr>
<td>II</td>
<td>Centralized, treated drinking water is piped to each residence AND improved sanitation facilities are appropriately installed.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.5</td>
<td>Mead et al.&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>III&lt;sup&gt;c&lt;/sup&gt;</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>IV</td>
<td>Drinking water is available from centralized piped systems, but treatment is incomplete or nonexistent (hence only partially improved) AND improved sanitation facilities are appropriately installed.&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.5</td>
<td>Cao&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Va</td>
<td>No improved or partially improved drinking water is available BUT improved sanitation facilities are appropriately installed.&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.2</td>
<td>Cao&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Vb</td>
<td>Partially improved drinking water is available BUT improved sanitation is not.&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.8</td>
<td>Xing et al.&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>VI</td>
<td>No improved or partially improved drinking water or improved sanitation is available.&lt;sup&gt;d&lt;/sup&gt;</td>
<td>11.2</td>
<td>Xing et al.,&lt;sup&gt;e&lt;/sup&gt; Cao &amp; Zhang,&lt;sup&gt;f&lt;/sup&gt; Yang et al.,&lt;sup&gt;f&lt;/sup&gt; Luo et al.,&lt;sup&gt;f&lt;/sup&gt; Gu et al.,&lt;sup&gt;f&lt;/sup&gt; Chen et al.,&lt;sup&gt;f&lt;/sup&gt; Chen et al.&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> For comparability, we have numbered our scenarios to indicate similarities with previous work.<sup>11</sup> 
<sup>b</sup> Reference group 
<sup>c</sup> Improved sanitation includes a sewer connection (typically seen in urban areas), a triple compartment septic tank, an anaerobic biogas digester, a double barrel funnel type septic tank, and a urine-separating toilet with a septic tank. The latter four designs, found in rural areas, reduce pathogen loads through extended residence times as well as physical and chemical inactivation of pathogens, depending on soil and weather conditions.<sup>20</sup> Unimproved sanitation includes unprotected stool pits and the absence of any sanitation system. 
<sup>d</sup> Improved drinking water is defined as water that comes from centralized piped water systems that are treated regularly. Partially improved drinking water also comes from centralized piped water systems, but treatment is irregular or nonexistent. Untreated wells and surface water sources were classified as unimproved. 
<sup>e</sup> In light of typical Chinese access to safe water and sanitation facilities, we have omitted Scenario III as previously defined by Prüss et al. (i.e. access to water and sanitation facilities with improved drinking water quality through piped water systems or point-of-use treatment or improved personal hygiene). Improved sanitation and piped water access are included in China-specific Scenarios IV and II, and the widespread practice of consuming hot water or tea leads to point-of-use drinking water treatment in most households.

Table 1. China-specific scenarios of exposure to water and sanitation facilities and associated relative risk (RR) of diarrhoea

Proximate human hosts and vectors, and hence vector habitats, are required for the diseases such as malaria and dengue to be transmitted. Both factors can be impacted by water resource management. Stagnant water around the home and development projects involving water, such as large dams, can provide vector breeding grounds and increase the risk of human infection.

The mosquito vectors of malaria, dengue and Japanese encephalitis can breed in standing water near households. Based on previous work, we estimated that 42% of all cases of malaria could be prevented through interventions designed to improve water resource management.<sup>39,40</sup> Although some authors attribute a greater proportion of the burden of malaria to environmental factors (up to 88%), we did not adopt these estimates because they include interventions that can harm ecosystems, such as the draining of wetlands. Dengue can be prevented almost entirely by covering or eliminating containers holding stagnant water in or around the home.<sup>42</sup> Eliminating vector breeding sites reduces vector density, a predictor of dengue infection risk.<sup>43</sup> In the case of Japanese encephalitis, the proximity of livestock reservoirs to irrigated areas can increase the risk of human infection.<sup>44</sup> Intermittent irrigation of rice paddy habitats and isolation of pig rearing from such areas can reduce the risk of infection.<sup>45</sup> On the basis of previous work, we estimated that 95% of the burden of dengue and of Japanese encephalitis is attributable to unsafe water and sanitation.<sup>46</sup>

Death and incidence rates for malaria, dengue and Japanese encephalitis in 2008 were obtained for each province from the Chinese National Infectious Disease Reporting system (NIDR). The NIDR includes 28 reportable diseases and has operated since 2004 on a real-time basis using networked computers that link the national surveillance centre, regional centres for disease control and prevention, and almost all rural and urban hospitals. 

## Estimation of disease burden

DALYs and mortality rates were used to quantify the health impact of multiple diseases. While the comparability of DALYs across diseases is sensitive to the choice of disability weights and to disease duration, which poses a particular challenge for conditions of low severity and high prevalence, the integration of multiple disease outcomes into a single measure is appropriate for exposures, such as exposure to unsafe water and poor sanitation and hygiene, that can lead to different health endpoints. Age and sex-specific incidence and mortality rates (for diarrhea and vector-borne infections) or prevalence rates (for schistosomiasis and soil-transmitted helminthiasis) at the provincial level were used to calculate DALYs using established morbidity weights, disease duration, age-weighting and 3% annual discounting for delayed morbidity (Box A2 in Appendix A). Provincial population estimates for 2008 were obtained from the National Bureau of Statistics. Province-specific age distributions from the 2000 Chinese National Census were projected against the population of each province in 2008.
### Table 2. Deaths and disability-adjusted life years (DALYs) attributable to unsafe water and poor sanitation and hygiene, by disease and age group, China, 2008

<table>
<thead>
<tr>
<th>Disease</th>
<th>Cases</th>
<th>No. (%) of deaths</th>
<th>No. (%) of DALYs*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhoeal disease</td>
<td>487,305,914</td>
<td>62,655 (99.7)</td>
<td>2,750,874 (98.0)</td>
</tr>
<tr>
<td>Ascariasis</td>
<td>158,587,041</td>
<td>0 (0)</td>
<td>19,762 (0.7)</td>
</tr>
<tr>
<td>Japanese encephalitis</td>
<td>3,296</td>
<td>158 (0.3)</td>
<td>19,743 (0.7)</td>
</tr>
<tr>
<td>Hookworm infection</td>
<td>73,127,379</td>
<td>0 (0)</td>
<td>8,182 (0.3)</td>
</tr>
<tr>
<td>Schistosomiasis</td>
<td>67,494</td>
<td>0 (0)</td>
<td>5,195 (0.2)</td>
</tr>
<tr>
<td>Trichuriasis</td>
<td>55,109,540</td>
<td>0 (0)</td>
<td>1,844 (0.1)</td>
</tr>
<tr>
<td>Malaria</td>
<td>10,364</td>
<td>9 (0)</td>
<td>232 (0)</td>
</tr>
<tr>
<td>Dengue</td>
<td>207</td>
<td>0 (0)</td>
<td>4 (0)</td>
</tr>
</tbody>
</table>

* DALYs are age-weighted and include 3% annual discounting.

Note: The estimates are based on data from the Chinese National Infectious Disease Reporting system, China’s National Ascariasis Surveillance System, the National Survey on Rural Water and Sanitation, and the National Burden of Disease Study. Estimates of the fraction of each disease attributable to unsafe water and poor sanitation are based on a detailed review of the Chinese and international literature.

### Results

In 2008, 712 million people in China (54% of the population) had access to improved drinking water, 269 million (21%) had access to partially improved drinking water and 327 million (25%) had no improved drinking water source at all. Approximately 773 million people had access to improved sanitation (59%), whereas 535 million people did not. Drinking water and sanitation access varied markedly by province, from a high of 99% coverage in Shanghai to a low of 23% in Tibet (Fig. A1 and Table A2, both in Appendix A).

Unsafe water and poor sanitation and hygiene accounted for 62,800 deaths and 2,81 million DALYs in China in 2008 (Table 2). Most (83%) of the attributable disease burden and most (97%) of the deaths occurred in young children. Diarrhoeal disease accounted for 98% of the attributable DALYs. If all provinces attained universal coverage with improved drinking water and sanitation (Scenario II), an estimated 1.84 million DALYs and 42,000 deaths from diarrhoea alone could be prevented annually. Sensitivity analyses conducted using high and low RR estimates for Scenario VI yielded estimates of 1.85 and 3.63 million DALYs attributable to diarrhoea, respectively. When DALYs were calculated without age-weighting or without discounting future health effects, disease burden estimates nearly doubled. However, the overwhelming contribution of diarrhoea to DALYs attributable to unsafe water and poor sanitation and hygiene did not change (Table A3 in Appendix A).

Collectively, soil-transmitted helminthiases were the second leading cause of attributable DALYs: an estimated 287 million such infections occurred in China in 2008, and they accounted for 29,800 DALYs. Vector-borne diseases were less common than diarrhoeal diseases and soil-transmitted helminthiases. However, the disease burden attributable to Japanese encephalitis is high because of the high case-fatality rate and the long-term sequelae of the infection.

The distributions of total and disease-specific DALYs attributable to unsafe water and poor sanitation and hygiene showed substantial geographical and socioeconomic disparities (Table A4 and Table A5, both in Appendix A; Fig. 1). DALYs by province ranged from 46 to 522 per 100,000 people (in Shanghai and Tibet, respectively) and were highest in provinces with the lowest per capita GDP (Table 3, and Fig. A2 in Appendix A). The burden of diarrhoeal disease attributable to unsafe water and poor sanitation increased from east to west, generally following the gradient of economic development and infrastructural investment in China. Vector-borne infections were more focally distributed. They were found primarily in southwestern provinces and, to a lesser extent, in the southeastern and central regions. DALYs caused by helminthiases were concentrated in southwestern and central China and on the southern island of Hainan. The disease burden from vector-borne and helminthic infections was lowest in the northern provinces.

### Discussion

The deaths and DALYs reported in this paper are the first estimates of the health impacts of unsafe water and poor sanitation and hygiene in China to capture within-country heterogeneity in disease burden. We found unsafe water and poor sanitation and hygiene to be particularly detrimental to the health of young children, as they account for 61% of deaths and 2.33 million DALYs in children under five, predominantly attributable to diarrhoeal diseases. Geographically, the disease burden attributable to unsafe water and poor sanitation and hygiene is concentrated in China’s poorest, inland provinces.

While the burden of diarrhoeal diseases attributable to unsafe water and poor sanitation increased along an east–west gradient, the burden of helminthiases was clustered in Guizhou and Sichuan in the south-west, Hubei and Hunan in central China, and Hainan in the south. The transmission of schistosomiasis and soil-transmitted helminthiases is facilitated by the temperature and ecological conditions that prevail in these warm, low-lying provinces. The greatest per capita burden of soil-transmitted helminthiasis occurred in Hainan, where 59.4% of residents and 73.4% of school children were found to be infected with at least one soil-transmitted helminth in 2004. Vector-borne infections composed a relatively small fraction of the total DALYs attributable to unsafe water and poor sanitation and hygiene, but Japanese encephalitis was the third leading source of such DALYs. Notably, Japanese encephalitis is a vaccine-preventable disease. Widespread vaccination began in China in the 1980s and over 300 million people have been immunized since 1990. This has resulted in steady...
The distribution of disability-adjusted life years (DALYs) attributable to unsafe water and poor sanitation and hygiene, by province, China, 2008

Note: Vector-borne infections include dengue, malaria and Japanese encephalitis. Helminthiases include ascariasis, hookworm infection, trichuriasis and schistosomiasis.

Declines in the annual incidence of Japanese encephalitis, from a high of 20.92 cases per 100,000 during the epidemic of 1970 to less than one case per 100,000 since 1996. Before 2006, vaccination was not equally accessible across regions; poor regions offered fee-for-service vaccination, and wealthier regions provided it free. As a result, children in poorer regions had the lowest vaccination coverage, and these regions show the highest incidence of Japanese encephalitis in our analysis. China is now integrating vaccination against Japanese encephalitis into the country’s free, routine immunization programme to improve coverage in rural and underdeveloped areas. Coupled with improved management of water resources, this policy change could substantially reduce the burden of Japanese encephalitis in China.

Access to improved water and sanitation has been a national priority within China’s rural development projects since the 1980s. During each five-year planning phase, the Ministry of Health, the Ministry of Construction, the Bureau of Environmental Protection and the Ministry of Agriculture convene a steering meeting to set goals and strategies for improving water and sanitation over the ensuing five-year period. Most recently, China’s 12th five-year plan emphasized the importance of safe water and good sanitation and hygiene in promoting rural modernization, and the Ministry of Health has set a goal to achieve 68% coverage for both water and sanitation by 2011 in rural areas. To help achieve these targets, China will expand its nationwide surveillance (e.g. water quality testing and human health monitoring) and step up enforcement of drinking water safety in both urban and rural areas. As of 2011, the national drinking water surveillance system included more than 20,000 surveillance points, and these are expected to increase substantially under the twelfth five-year plan. What is more, the plan includes an investment of 27 billion United States dollars (US$) in improving drinking water access in rural areas as part of the National Project for Rural Drinking Water Safety. This reflects a nearly US$ 16 billion increase relative to the previous five-year plan. Central and western parts of the country have been identified as priority areas where these investments should be accompanied by expanded sanitation coverage as well (e.g. improved sanitation facilities at the household level). Technical support and evaluation of these efforts are available from China’s National Centre for Rural Water Supply Technical Guidance, which has helped to establish a national rural water quality and human health monitoring network as well as a sanitation evaluation programme. These efforts to ensure effective implementation of water and sanitation improvement programmes and to monitor drinking water quality should make it possible to achieve China’s most recent targets and could yield significant reductions in diseases attributable to unsafe water and poor sanitation and hygiene. Our estimates of the burden of such diseases offer a baseline against which to assess the impact of future improvements.

We caution that the true toll of unsafe water and poor sanitation and hygiene in China extends beyond the human health impacts presented here. Biological and chemical pollution of water resources can lead to ecological degradation and, in the water-scarce north, pollution can exacerbate the
Table 3. The distribution of deaths and disability-adjusted life years (DALYs) attributable to unsafe water and poor sanitation and hygiene among Chinese provinces, 2008

<table>
<thead>
<tr>
<th>Province</th>
<th>Population (10^6)</th>
<th>Provincial GDP (US$10^9)</th>
<th>Total Deaths</th>
<th>Diarrhoeal diseases</th>
<th>Vector-borne infections</th>
<th>Helminthiasesa</th>
<th>Deathsb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibet</td>
<td>2870.000</td>
<td>37,927,300</td>
<td>13,824</td>
<td>12.70</td>
<td>522</td>
<td>0.03</td>
<td>1.49</td>
</tr>
<tr>
<td>Guizhou</td>
<td>34,927,300</td>
<td>46,177,690</td>
<td>19,609</td>
<td>8.73</td>
<td>416</td>
<td>0.09</td>
<td>7.99</td>
</tr>
<tr>
<td>Ningxia</td>
<td>12,570,000</td>
<td>15,023,000</td>
<td>12,110</td>
<td>8.60</td>
<td>365</td>
<td>0.05</td>
<td>5.07</td>
</tr>
<tr>
<td>Yunnan</td>
<td>26,431,000</td>
<td>31,712,000</td>
<td>7,177</td>
<td>8.55</td>
<td>313</td>
<td>0.01</td>
<td>1.05</td>
</tr>
<tr>
<td>Gansu</td>
<td>40,500,000</td>
<td>44,000,000</td>
<td>2,986</td>
<td>6.79</td>
<td>698</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Jangxi</td>
<td>33,841,000</td>
<td>38,199,000</td>
<td>15,900</td>
<td>6.80</td>
<td>298</td>
<td>0.01</td>
<td>0.05</td>
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<tr>
<td>Qinghai</td>
<td>26,281,000</td>
<td>31,521,000</td>
<td>12,211</td>
<td>6.79</td>
<td>295</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Henan</td>
<td>29,500,000</td>
<td>34,420,000</td>
<td>14,630</td>
<td>6.98</td>
<td>298</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Anhui</td>
<td>24,109,000</td>
<td>28,318,000</td>
<td>11,820</td>
<td>6.49</td>
<td>250</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Shandong</td>
<td>26,940,000</td>
<td>32,740,000</td>
<td>12,930</td>
<td>6.79</td>
<td>292</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Shandong</td>
<td>27,140,000</td>
<td>33,230,000</td>
<td>13,200</td>
<td>6.98</td>
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Note: The estimates are based on data from the Chinese National Infectious Disease Reporting system, China's National Helminth Infection Survey, China's National Survey on Rural Water and Sanitation, the Chinese Census and the Global Burden of Disease Project. Estimates of the fraction of each disease attributable to unsafe water and poor sanitation are based on a detailed review of the Chinese and international literature.

GDP, gross domestic product.

a Vector-borne infections include dengue, malaria and Japanese encephalitis.

b The helminthiases include ascariasis, hookworm infection, trichuriasis and schistosomiasis.

c Per 100,000 population.

d DALYs are age-weighted and include 3% annual discounting.

Research
China's disease burden from unsafe water and sanitation
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health impacts of water shortages by forcing populations to rely on contaminated supplies. Chemical contamination of drinking water can lead to malignancies and other sequelae not accounted for in this analysis, and many such health endpoints attributable to unsafe water and poor sanitation and hygiene are associated with substantial economic costs from lost productivity, impaired cognitive development and other effects. Diarrhoeal diseases attributable to unsafe water and poor sanitation and hygiene can trigger a cascade of ill health which can in turn lead to malnutrition and make young children vulnerable to major childhood diseases, including measles and pneumonia. As much as 29% of the global burden of disease attributable to unsafe water and poor sanitation and hygiene is probably due to the secondary health effects of diarrhoea. Finally, unsafe water and poor sanitation can facilitate transmission of other parasitic infections whose distributions have not been well documented. For example, the foodborne trematode Clonorchis sinensis, which causes cholangiocarcinoma and infects an estimated 15 million people in China, is transmitted through unsafe human waste disposal.

The number of people without access to safe drinking water in China, and the associated disease burden, may exceed our estimates, as we have assumed that urban piped water systems are regularly treated. A 2006 survey of several thousand urban water suppliers revealed that 28% of municipal plants and 53% of private plants were not complying with water quality monitoring requirements. Over 15% of water samples did not meet drinking water standards, most often on account of microbial parameters. Transparent monitoring of municipal water systems is needed to ensure compliance with water quality standards and identify areas in need of long-term remediation and short-term public health advisories.

Globally, efforts to increase access to safe water and sanitation facilities have been frustratingly slow. In contrast, China has dramatically increased access to safe water and sanitation facilities over the past two decades. Our findings indicate the need for further work to increase access to improved water and sanitation and reduce disparities in the disease burden attributable to poor sanitation and unsafe water supplies. Investment in water and sanitation infrastructure is needed most urgently in western Chinese provinces with a high disease burden. Future improvements to water and sanitation should be accompanied by periodic estimates of the burden of disease attributable to unsafe water and poor sanitation to track progress in reducing these preventable diseases and identify populations that remain at risk of death and disability from unsafe water and poor sanitation and hygiene.

The disease burden estimates provided in this paper can guide the allocation of resources for improving water and sanitation facilities as well as provide a basis for establishing milestones for incremental infrastructural improvements.

**Acknowledgements**

When this study was conducted, SL was affiliated with the College of Public Health of Ohio State University.

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**Competing interests:** None declared.
Disparités régionales dans la charge de morbidité attributable à une eau insalubre et un assainissement déficient en Chine

Objectif Estimer la charge de morbidité imputable à l’eau insalubre ainsi qu’à un niveau sanitaire et hygiénique défectueux en Chine afin d’identifier les groupes à impact élevé et de proposer des mesures d’amélioration.

Méthodes La charge de morbidité attributable à l’eau insalubre et à un système d’assainissement et d’hygiène défectueux en Chine a été estimée pour les maladies résultant de l’exposition aux eaux et eaux biologiquement contaminées (diarrhées, helminthiases et schistosomiase), ainsi que pour la transmission vectorielle résultant d’une gestion inadéquate des ressources en eau (paludisme, dengue et encéphalite japonaise). Les données ont été obtenues grâce au registre national chinois de déclaration des maladies infectieuses, aux études nationales sur l’eau et la santé et aux études nationales sur l’eau et l’assainissement. Le pourcentage de chaque affection imputable aux eaux insalubres et aux carences en assainissement et hygiène en Chine a été estimé sur la base des données de publications scientifiques chinoises et internationales.

Résultats En 2008, 327 millions de personnes en Chine n’avaient pas accès à une eau courante potable, et 535 millions de personnes ne disposaient pas de sanitaires performants. La même année, l’eau insalubre et les conditions sanitaires et hygiéniques médiocres représentaient 2,81 millions d’années de vie de maladie (DALY) et 62 800 décès dans le pays, 83% des cas concernant des enfants âgés de moins de 5 ans. Le «DALY» par habitant était croissant selon un axe est-ouest, la charge de morbidité la plus importante étant marquée dans les provinces intérieures avec le plus faible taux de revenu par habitant. Une amélioration du suivi, l’augmentation de la surveillance obligatoire et une plus grande transparence du gouvernement sont nécessaires pour mieux estimer les effets des contaminations microbiologiques et chimiques des eaux ainsi que des mauvaises conditions sanitaires et hygiéniques sur la santé humaine.

Conclusion Malgré les progrès remarquables, la Chine a encore besoin de mener des projets d’amélioration de son infrastructure, ciblant les provinces qui ont connu un développement économique plus lent. Une amélioration du suivi, l’augmentation de la surveillance obligatoire et une plus grande transparence du gouvernement sont nécessaires pour mieux estimer les effets des contaminations microbiologiques et chimiques des eaux ainsi que des mauvaises conditions sanitaires et hygiéniques sur la santé humaine.

Resumen

Disparidades regionales en la carga de morbilidad atribuible a una agua insalubre y un saneamiento deficiente en China

Objetivo Estimar la carga de morbilidad atribuible a la agua insalubre y a un sistema de saneamiento y condiciones sanitarias insuficientes en China, para identificar a los grupos más afectados y proponer medidas de mejora.

Métodos La carga de morbilidad atribuible a la agua insalubre y a un sistema de saneamiento y condiciones sanitarias insuficientes en China ha sido estimada para las enfermedades causadas por la exposición a las aguas y aguas biológicamente contaminadas (diarreas, helminthiasis y schistosomiase), así como para las enfermedades vectoriales resultantes de la mala gestión de los recursos hídricos (malaria, dengue y encefalitis japonesa). Los datos se obtuvieron a través del registro nacional chino de declaración de enfermedades infecciosas, estudios nacionales de agua y salud y estudios nacionales de agua y saneamiento. Se estimó el porcentaje de cada enfermedad atribuible a las aguas insalubres y a las carencias en saneamiento y higiene en China sobre la base de los datos de publicaciones científicas chinas e internacionales.

Resultados En 2008, 327 millones de personas en China no tenían acceso a agua corriente potable, y 535 millones de personas no tenían sanitarios funcionales. En la misma año, la agua insalubre y las condiciones sanitarias y higiénicas medias representaron 2,81 millones de años de vida de enfermedad (DALY) y 62 800 fallecimientos en el país, 83% de los casos afectados a niños menores de 5 años. El «DALY» por habitante aumentaba según un eje este-oeste, la carga de morbilidad más importante se encontraba en las provincias interiores con el menor ingreso por habitante. Se necesitaba un mejor seguimiento, la aumento de la vigilancia obligatoria y una mayor transparencia del gobierno para poder mejorar las estimaciones de los efectos de las contaminaciones microbiológicas y químicas de las aguas, así como de las malas condiciones sanitarias y higiénicas sobre la salud humana.

Conclusion A pesar de los progresos significativos, China aún necesita mejorar la infraestructura de saneamiento, seleccionando a las provincias que presentaron un desarrollo económico más lento. Un mejor seguimiento, la aumento de la vigilancia obligatoria y una mayor transparencia del gobierno son necesarios para poder mejorar las estimaciones de los efectos de las contaminaciones microbiológicas y químicas de las aguas, así como de las malas condiciones sanitarias y higiénicas sobre la salud humana.
Resumen

Disparidades regionales en China en la carga de morbilidad atribuible a la insalubridad del agua y a las deficiencias en el saneamiento

Objetivo
Calcular la carga de morbilidad atribuible a la insalubridad del agua y a las deficiencias en el saneamiento e higiene en China con el fin de identificar los grupos de carga más elevada y de informar acerca de mediciones de mejora.

Métodos
Se calculó la carga de morbilidad atribuible a la insalubridad del agua y a las deficiencias en el saneamiento e higiene en China para aquellas enfermedades provocadas por la exposición a suelos y aguas biológicamente contaminados (diarrea, helmintiasis y esquistosomiasis) y a la transmisión vectorial ocasionada por una gestión inadecuada de los recursos hídricos (malaria, dengue y encefalitis japonesa). Los datos se recopilaron a partir del sistema de notificación nacional sobre enfermedades infecciosas de China, las encuestas nacionales sobre higiene y las encuestas nacionales sobre agua y saneamiento. A partir de los datos procedentes de la documentación china e internacional, se calculó la proporción de cada enfermedad atribuible a la insalubridad del agua y a las deficiencias en el saneamiento e higiene en China.

Resultados
En el año 2008, 327 millones de chinos no tenían acceso a agua potable canalizada y 535 millones no disponían de acceso a un saneamiento adecuado. En ese mismo año, la insalubridad del agua y las deficiencias en el saneamiento y la higiene se tradujeron en 2,81 millones de años de vida ajustados en función de la discapacidad (AVAD) y 62,800 muertes en el país. Además, el 83% de la carga atribuible se registró en niños con una edad inferior a los 5 años. Los AVAD per cápita fueron en aumento siguiendo un gradiente este-oeste y se observó la mayor carga en las provincias del interior, que contaban con los menores ingresos per cápita.

Conclusión
A pesar de los considerables esfuerzos realizados, China sigue necesitando iniciar proyectos de mejora de las infraestructuras, centrándose en aquellas provincias que han registrado un desarrollo económico más lento. Son necesarios un control mayor, un aumento de la supervisión normativa y una mayor transparencia gubernamental para calcular mejor los efectos que tienen en la salud humana las aguas contaminadas químicamente y microbiológicamente y las deficiencias en el saneamiento y la higiene.

Referencias
16. Lu H. Analysis on pollution factors and countermeasures of drinking water sources in rural areas. Beijing: China Environmental Protection Industry; 2009.
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