Water and sanitation interventions to control diarrheal disease in rural China
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ABSTRACT
To evaluate diarrheal disease control effects of various water and sanitation interventions, a comprehensive search strategy was developed to identify all peer-reviewed papers relating to water and sanitation intervention studies in China. All published studies since 1980 on water and sanitation interventions to reduce diarrheal disease in China were analyzed using meta-analysis. Fixed-effects and random-effects models were used to calculate the summarized relative risk of all included studies. The results show that water and sanitation interventions can be classified into four types: improved water supply; latrine construction intervention; health education and behavior intervention; and multiple interventions. All of these intervention studies were found to reduce the risks of diarrhea illness. This study, which analyzed high control effects of water and sanitation intervention to prevent diarrheal disease, revealed that water improvements and sanitation interventions in China played an important role in reducing diarrhea illness. The diarrhea study concluded that the intervention of water and sanitation in China must involve the whole population as it aims to build a more comprehensive intervention system.

Key words | meta-analysis, rural China, sanitation, water

INTRODUCTION
Diarrheal disease has long been recognized as one of the leading causes of morbidity and mortality in developing countries. In 2010, the disease was cited as one of ten leading diseases contributing to the global disease burden (Lopez et al. 2003). According to the Global Health Observatory data (WHO 2015), there were approximately 1.5 million deaths in 2012 due to diarrheal disease.

Diarrhea is defined as the passage of three or more loose or liquid stools per day (WHO 2015). This disease typically lasts several days and often leaves the body without the water and salts that are necessary for survival. Exposure to infectious agents is the major risk factor for contracting diarrheal disease. Bacteria and viruses are often transmitted by the fecal–oral route; thus, approximately 58% of total diarrhea (842,000 deaths worldwide) has been attributed to inadequate water, sanitation, and hygiene (Prüss-Ustün et al. 2014). There is evidence that clean drinking water, improved health conditions, and implementation of health interventions can reduce 22% of the incidence and 21% of deaths related to diarrheal disease (Varley et al. 1998). To reduce the occurrence of diarrhea worldwide, it is essential to provide access to safe, adequate, and accessible drinking water as well as proper sanitation. This type of water supply not only reduces incidences of waterborne and water-related diseases, but is also effective in protecting water, soil, and living environments (Bartram & Cairncross 2010). Moreover, related studies showed sanitation facilities decreased diarrhea morbidity and mortality as well as the severity of hookworm infection (Esrey et al. 1991). Water supply and sanitation yield direct social, economic, and health benefits stemming from low incidence of diseases,
increased life expectancy, and overall quality of health and well being (Hulton 2012).

The global health community has long viewed access to water supply and sanitation as a fundamental human right. As such, the WHO and other governing bodies worldwide have focused upon and prioritized the need for working to secure safe water supply and sanitation. According to Millennium Development Goals, the world has pledged to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation (UN 2000). The Report on Global Water and Sanitation showed that in 2012, 89% of the global population used an improved source of drinking water, and 64% used an improved sanitation facility (WHO et al. 2014). Many studies focused on the effects of water and sanitation intervention, and meta-analysis demonstrated that implementing water quality interventions was found to be more efficient than utilizing multiple interventions (although most interventions had a similar degree of impact on diarrhea illness) (Fewtrell et al. 2005). However, other studies suggested that the total number of benefits of water, sanitation, and hygiene interventions are greater than the total number of health benefits alone, and thus can be valued more than the costs of the interventions (Bartram & Cairncross 2010). More recent reviews on the effects of water, sanitation, and hygiene intervention showed that there are notable differences in illness reduction according to the type of improved water and sanitation implemented (Wolf et al. 2014).

The People’s Republic of China (PRC) is a large, developing agricultural country. By the end of 2013, the total population living in rural areas was approximately 629 million people (including the population in rural townships), accounting for 46.27% of the overall population of nearly 1.3 billion people. Access to a safe drinking water supply and sanitation facilities in the poor rural regions has been a serious issue in the social and economic development of these areas. Due to the shortage of local water sources, the rural residents are accustomed to obtaining their drinking water supply directly from surface water sources, open wells, or distant sources. Latrines in these areas are particularly primitive. Poor drinking water and sanitation have resulted in high incidence rates of various water-related and epidemic diseases, which severely threaten the physical well being of the rural population. In China, poor water, sanitation and hygiene accounted for 62,800 deaths and 2.81 million Disability Adjusted of Life Years (DALY) a year; diarrheal disease accounted for 98% of the attributable DALYs (Carlton et al. 2012). There were 747,551 cases of infectious diarrhea reported in 2010 in China, with an annual morbidity of 55.93/105; children were the high-risk population, accounting for 53.57% of the total reported cases (Lin et al. 2011). Diarrheal disease was caused by a host of bacterial, viral, and parasitic organisms, most of which can be spread by contaminated water. It is more common when there is a shortage of clean water for drinking, cooking, and cleaning. Water was contaminated with human or animal feces if there was poor sanitation and no basic hygiene. It was especially obvious in the heavy flood periods; floods have significantly increased the risks of infectious diarrhea in China (Ding et al. 2013).

In an effort to respond, the Chinese government increased funding for the construction of water supply and sanitation. This construction included the building and implementation of centralized water plants as well as sanitation toilets. As a result, the country experienced a significant decline in the incidence and mortality rates of diarrhea, especially among children (Zhong 2007). Many studies have focused upon effect or benefit analysis of water and sanitation interventions in China, and the health and economic benefits of various interventions have been estimated using health economics methods. However, there is no systematic, comprehensive analysis of the data sourced from these studies, and the various water and sanitation interventions are not analyzed specifically for possible policy making. In this study, a comprehensive search strategy to identify all peer-reviewed papers relating to water and sanitation intervention studies in China was developed, and all data of these published studies were extracted and re-analyzed using meta-analysis. In this meta-analysis, the study attempts to determine which of these interventions may be most effective in controlling diarrhea illness: water supply intervention, sanitation intervention, or a combination of multiple measures.

### METHODS

#### Search strategy

PubMed, Google Scholar, Web of Science, and Elsevier Science Direct were searched in May 2015 to identify and
locate all peer-reviewed papers in English on water and sanitation intervention studies in China. CNKI (National Knowledge Infrastructure), Wafang Data, and VIP Journal Integration Platform were searched for papers published in the Chinese language. The search terms were as follows: ‘drinking water’, ‘sanitation’, ‘hygiene’, ‘diarrhea’ and ‘intervention.’ Reference lists of all the eligible studies and relevant reviews were manually searched for any additional trials.

**Study selection**

To be selected for inclusion in this study, the research studies satisfied the following criteria: (i) Study papers were published between January 1, 1980 and December 31, 2013; (ii) Studies detailed explicit water or sanitation intervention; (iii) The outcome index included the number of diarrhea cases and the diagnosis of diarrhea conforming to WHO standards; and (iv) The intervention studies were conducted in rural areas on mainland China. Studies were excluded if they met the following criteria: (i) Included non-intervention studies; (ii) Lacked control or self-control studies; and (iii) Detailed water and sanitation interventions studies in disease outbreak periods or in emergency stages.

**Data extraction**

Research data were extracted and sorted by two reviewers independently. Information such as the year of publication, intervention methods, study population, number of diarrhea cases in the intervention and control groups, and sample size of the intervention group and control group provided the basis for review and analysis. Following this sorting process, two reviewers checked the integrity and accuracy of extracted data and resolved differences by discussion. In case of disagreements, other researchers read the literature and decided whether or not to include the study in question. If the study provided incidence value of diarrhea, this study’s authors calculated the approximate number of diarrhea cases from the group size.

**Statistical analyses**

Revman v5.1 (Cochrane Collaboration) was applied to assess the relationship between intervention and diarrheal disease. Random-effects models and fixed-effects models (which both use a form of inverse variance weighting) were used for each analysis.

Random-effects models were used to summarize the relative risk (RR) estimates if the test of heterogeneity for a group of study results was significant. In the absence of heterogeneity, fixed-effects models were used. The Cochran Q test was used to test for heterogeneity between individual study results (Haidich 2011), and Q is distributed as a chi-squared statistic with a freedom of $k$ ($k$ is number of studies). If $Q > \chi^2_{k-1, 0.05}$, and the value of $P$ was lower than 0.05, the difference in each comparison of group was significant. Sensitivity analyses were conducted to ascertain if the results were stable, as well as to discover the source of heterogeneity, thereby deleting the included studies one by one in a certain order. In the meta-analysis, potential publication bias was examined by Begg’s test (Begg & Mazumdar 1994) and Egger’s test (Egger et al. 2008) using Stata SE12.0.

Water and sanitation related interventions were categorized into four different groups: improved water supply, latrine construction, health education and behavior intervention, and multiple interventions. Improved water supply was defined as all measures aiming to provide clean water such as the building of water plants and hand-pump wells, and rain collection. Water quality before and after interventions was not tested in all of the studies; therefore, the intervention was divided into two sub-groups: one with water quality tested and one without. Latrine construction interventions include measures that provided some means of public or household latrines, particularly sanitary latrines with non-hazardous feces treatments. Health education and behavior interventions refer to those measures designed to impact an individual’s actions with regard to the individual’s health, including actions such as sound hand washing and environmental and personal cleanliness. To promote latrine construction and use, knowledge about the importance of sanitary toilets, as well as the correct use of sanitary toilets, were also included in health educations. Multiple interventions are defined as those groups that introduced water, sanitation, and hygiene (or health education) elements to the study population, and the comprehensive intervention measures included provisions for safe drinking water, installation of convenient hand-washing facilities, and construction of toilets.
RESULTS

Overview of included studies

Through online database searches and cross-referencing of works cited in recent reviews, 308 potentially relevant publications were identified. Based on titles and abstracts, the researchers identified 52 studies for full-text review and excluded 30 studies in 22 published peer review journals due to the fact that these studies met one of the criteria for exclusion. The 22 selected intervention studies included 11 water improvement intervention studies, six latrine construction intervention studies, four health education and behavior intervention studies, and nine multiple intervention studies. Figure 1 details the literature search and screening process and the supplementary table (available in the online version of this paper) summarizes all the included studies.

Improved water supply intervention

There are 11 studies included in the water improvement intervention group, with dates of publication ranging from 1987 to 2014. The total study population observed was 119,936 (Table 1). Based on $\chi^2 = 114.36$ ($P < 0.01$), there emerged a low degree of inter-study heterogeneity, and a random-effects model should be used for combined RR. The overall pooled estimate indicates that water improvement interventions are effective in reducing diarrheal disease (random-effects model RR 0.48, 95% CI 0.42–0.54). In the sub-group with water sample tested ($n = 3$), the RR was 0.44 (0.28–0.67), while the RR was 0.55 (0.49–0.61) in the no water sample tested group ($n = 8$).

Latrine construction intervention

There are six studies included in the sanitation intervention group, with dates of publication ranging from 2005 to 2014, and a total study population of 35,163 was observed (Table 2). Based on $\chi^2 = 44.04$ ($P < 0.01$), a low degree of inter-study heterogeneity was determined, and a random-effects model should be used for combined RR. The overall pooled estimate indicates that sanitation interventions are effective in reducing diarrheal disease (RR with random-effects model is 0.55, 95% CI 0.36–0.85).

Health education and behavior intervention

There are 4 studies included in the health education intervention group, with dates of publication ranging from 1997 to 2009, and a total study population of 24,962 was observed (Table 3). Based on $\chi^2 = 1.54$ ($P = 0.67$), a high degree of inter-study heterogeneity was determined, and a fixed-effects model should be used for combined RR. The overall pooled estimate indicates that health education interventions are effective in reducing diarrheal disease (RR with fixed-effects model is 0.50, 95% CI 0.44–0.56).

Multiple interventions

There are nine studies included in the multiple intervention group, with dates of publication ranging from 1989 to 2014, and a total study population of 43,797 was...
observed (Table 4). Based on \( \chi^2 = 54.10 \) \((P < 0.01)\), a high degree of inter-study heterogeneity was concluded. The overall pooled estimate indicates that sanitation interventions are effective in reducing diarrheal disease (RR with random-effects model is 0.35, 95% CI 0.29–0.44).
Comparison between study groups

The four sub-groups of the intervention are summarized as Figure 2. From the figure, it can be concluded that most of the intervention groups have a similar degree of effect on the control of diarrhea, with a RR ranging from 0.33 to 0.55. The various intervention study groups have overlapping 95% CI, showing there was no statistical difference between groups ($P < 0.05$).

Publication bias

Publication bias was explored through the use of Begg’s test and Egger’s test, with a result of a $P$ value larger than 0.05, which demonstrated an acceptable publication bias (Table 5).

**DISCUSSION**

Diarrheal disease is one of many types of infectious diseases strongly linked to poverty. Poverty is characterized by those specific elements that would increase the risk of diarrheal disease. These include factors such as poor housing, overcrowding, and lack of access to clean and sufficient water as well as proper fecal waste disposal. Additionally, poverty includes malnutrition and overall poor health conditions, both of which lead to a high mortality rate of diarrheal disease. China is a developing country with a population of over 600 million people who live in rural areas. Historically, rural residents obtained their water directly from unimproved water supply sources such as rivers, streams, lakes, or ponds; some of them have to walk for kilometers to fetch water. In these rural areas, the use of unhygienic
Table 5 | Begg’s test and Egger’s test of the intervention groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Begg’s test</th>
<th>Egger’s test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved water supply</td>
<td>1.32</td>
<td>-0.32</td>
</tr>
<tr>
<td>Latrine construction</td>
<td>0.00</td>
<td>-0.02</td>
</tr>
<tr>
<td>Health education and behavior</td>
<td>0.00</td>
<td>-0.00</td>
</tr>
<tr>
<td>Multiple intervention</td>
<td>0.52</td>
<td>-0.35</td>
</tr>
</tbody>
</table>

open pit latrines for defecation practices is widespread. Further exacerbating the problem is the practice of residents using temporary stored human excreta from open pit latrines as fertilizers to enrich their farmlands (Shuchen et al. 2004). The incidence rates of diarrheal disease are very high in poor villages that do not have safe water supply, sanitation latrines, and effective hygiene practices. Since the establishment of the PRC in 1949, the Chinese government has sought to emphasize the need for continued governmental support in the development of improved rural water supply and sanitation. As the gap widens between rich and poor, as well as between urban and rural areas, water supply and sanitation in rural China has received increasing focus and attention (Li et al. 2015). As a result of efforts to improve water and sanitation, incidences of diarrheal disease have been dropping sharply (Wei 2004). The main water supply and sanitation interventions to control diarrheal disease in rural China could be summarized as follows: (1) Improving rural water supply. Rural water supply development works have been established as a governmental goal in each Five Year Plan. After the 7th Five Year Plan (1986–1990), 8th Five Year Plan (1991–1995), 9th Five Year Plan (1996–2000), 10th Five Year Plan (2001–2005), 11th Five Year Plan (2006–2010), and 12th Five Year Plan (2010–2015), more than 225,000 centralized water supply plants solved the drinking water problem for 21.2 million people. Additionally, the rural population rate of tap water rose from 82.9% in 1983 to 94.2% in 2011 (Li et al. 2015). (2) Building sanitary latrines. At the end of 2012, the rural population rate of hygienic and sanitary latrines rose from 7.5% in 1993 to 74.1% in 2012 (MOH 2009, 2010–2012), which resulted in a sharp drop in fecal–oral transmitted disease from 35.7/100,000 to 22.2/100,000 in sanitary latrine building program areas from 2009 to 2011 (China Daily 2014). (3) Multiple environmental interventions. A nationwide Urban-Rural Environment Clean Action was launched by the Chinese government in 2010 (NPHCC 2015). This action included multiple environmental measures, such as piped water supply, family sanitary latrine construction, waste and sewage water treatment, and clean living environments. Through goal setting and programming, the central government has dedicated significant attention to water and sanitation and has called upon all levels of government to invest in similar actions. (4) Health education and behavior intervention. The Chinese government has launched a series of nationwide health education activities to disseminate basic health knowledge to rural populations. The media was also used to promote healthy living and hygienic life styles. The rural population is now more aware of personal hygiene.

When the results were compared with meta-analyses conducted in other countries, the authors of this study found the results to have a higher RR rate in controlling diarrheal disease. Therefore, it is concluded that water and sanitation interventions may be more effective than those that have taken place in other countries. The reasons for this finding could be as follows: (1) The Chinese government attributes great importance to rural water supply and sanitation. The government has placed significant emphasis on water and sanitation development and has set progressive improvement targets related to investments in rural water supply, sanitation, and latrine improvement. The rural water supply and latrine construction has been integrated into national planning, and significant manpower, material resources, and funding allowed for this kind of implementation to take place. (2) The Chinese government has a strong executive record in the area of water and sanitation programs. (3) A series of reasonable intervention strategies were developed...
in China. These strategies included community participation, coordination between governmental departments and agencies, an emphasis on capacity building, and integration of sanitation and health education with regard to rural water supply. (4) The rapid development of China’s economy allowed for improved external conditions for rural water and sanitation progress. Many studies have proved the correlation between economic development and water and sanitation (Beckerman 1992). Increased economic development yields more demand on water and sanitation policy and programs as well as more overall investment in these areas.

In this meta-analysis, various water and sanitation intervention measures were compared, and there was an effort to induce more effective action and highly efficient government policy. The research revealed all types of water and sanitation could reduce diarrhea illness incidence, but they were different in degree. Single ‘hardware’ investments such as building water supplies or latrines, and single ‘software’ investments such as health education to cut the classic fecal-oral cycle, have a similar effect on diarrheal disease, with a close RR. The improvement of water quality and sanitation as the main intervention measures combined with the comprehensive improvement of rural environmental health initiatives (including residents’ health education and behavior intervention) can effectively reduce the incidence of diarrhea, as the group of multiple interventions was determined to have a higher RR. This study showed similar results to the related studies and suggested during the implementation of rural water supply and sanitation projects, the ‘3-in-1’ concept combining rural water improvement, health environment, sanitation and health education, which could result in greater social, economic, and health benefits. The results also revealed that the intervention of water and sanitation must involve the whole population in aiming to build a comprehensive intervention system at the community level.

There are several limitations to this study. First, the studies included spanned a long period of time. The earliest study selected took place in 1978, and the last one took place in 2014, resulting in a 30-year span for this research study. In this period of time, the incidence rate of diarrheal disease may have decreased as a result of improvements to China’s basic level of health. Second, some factors related to diarrheal disease were not considered such as the habitual practice of drinking hot water in China. A national survey showed 85% of the rural population heats or boils its drinking water (Tao 2009). Boiling is microbiologically effective (Cohen et al. 2015), and should be considered in assessment of controlling diarrheal disease. Last, the definition of the included water and sanitation interventions could not be confined to a certain intervention type for the association between the four types of water and sanitation intervention. A literature-based meta-analysis could not solve these limitations; therefore, a well-designed epidemiological intervention study is needed in the future.

CONCLUSION

Water improvements and sanitation interventions in China play an important role in reducing diarrhea illness. Improved water and sanitation intervention in China can be attributed to increasing and widespread concern, great investment, powerful executive ability and control, and sustainable and effective strategy. The rapid development of China’s economy allowed for the external conditions for the overall improvement of water and sanitation. The benefits of multiple interventions are far greater than ones that yield health benefits alone; therefore, the comprehensive water, sanitation, and hygiene (or health education) interventions proposed will allow for effective control effects of diarrheal disease. The intervention of water and sanitation must involve the entire population if the country aims to build a comprehensive intervention system based on the community level.

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COMPETING INTERESTS

None declared.
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