

Water and sanitation interventions to control diarrheal disease in rural China

Li Hongxing, Yao Wei, Dong Guoqing, Wang Li, Luo Qing, Wang Shan, Xiong Chuanlong and Zhang Qi

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

Li Hongxing
Yao Wei
Dong Guoqing
Wang Li
Luo Qing
Wang Shan
Xiong Chuanlong
Zhang Qi (corresponding author)
National Center for Rural Water Supply Technical
Guidance,
Chinese Center for Disease Control and
Prevention,
No.13 Zhengfu St, Changping District,
Beijing 102200,
China
E-mail: zhangqi@crwstc.org

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.* 2001). 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 2013). 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 water-borne 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 $Q > \chi_{k-1, 0.05}^2$, 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.

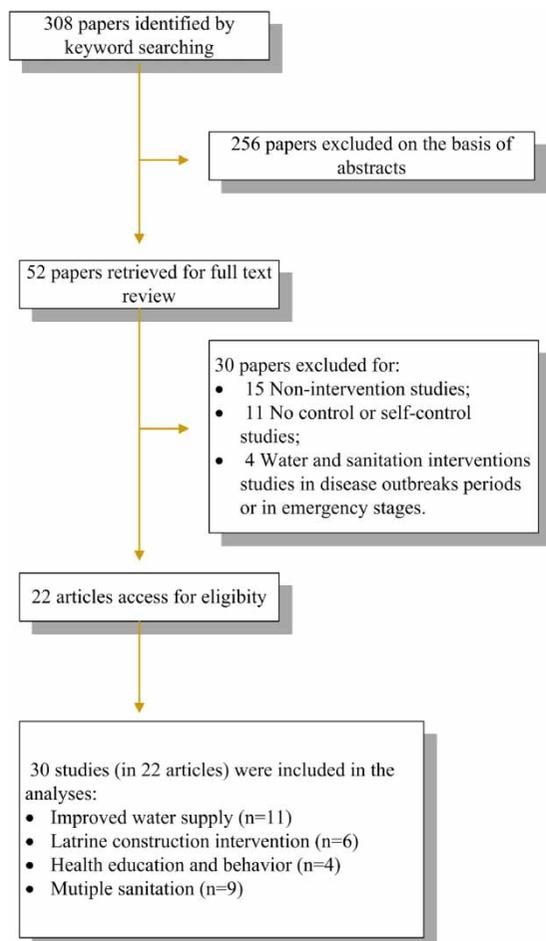


Figure 1 | Flowchart for the selection of studies on water and sanitation intervention in rural China.

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

Table 1 | Summary of included water improvement intervention studies

Authors and publishing year	Intervention group		Control group		Weight (%)	RR	95% CI
	No. of cases	Study population	No. of cases	Study population			
Zhang & Huo (1987)	4,057	29,328	5,596	19,312	12.3	0.48	0.46 ~ 0.49
Wang <i>et al.</i> (1989)	321	1,816	767	2,685	11.3	0.62	0.55 ~ 0.69
Lou <i>et al.</i> (1989)	608	2,154	392	842	11.6	0.61	0.55 ~ 0.67
Chen <i>et al.</i> (1999)	95	1,341	179	1,676	8.8	0.66	0.52 ~ 0.84
Zhu & Xia (1997)	129	1,733	320	1,739	9.7	0.40	0.33 ~ 0.49
Zhang <i>et al.</i> (2000)	331	1,172	867	1,864	11.5	0.61	0.55 ~ 0.67
Gu <i>et al.</i> (2000)	176	6,211	315	5,951	10.0	0.54	0.45 ~ 0.64
Chen (2006)	781	15,159	1,444	14,746	11.8	0.53	0.48 ~ 0.57
Wang (2011)	42	2,721	197	2,780	6.9	0.21	0.15 ~ 0.30
Tang <i>et al.</i> (2011)	3	2,839	26	1,024	1.1	0.04	0.01 ~ 0.14
Wang <i>et al.</i> (2014)	23	1389	104	1404	5.0	0.22	0.14 ~ 0.35

Table 2 | Summary of included sanitation intervention studies

Authors and publishing year	Intervention group		Control group		Weight (%)	RR	95% CI
	No. of cases	Study population	No. of cases	Study population			
Zhuang <i>et al.</i> (2005)	150	3,084	261	2,952	19.5	0.55	0.45 ~ 0.67
Zhengkui <i>et al.</i> (2005)	30	5,007	72	6,579	16.9	0.55	0.36 ~ 0.84
Liu <i>et al.</i> (2007)	19	1,028	5	1,075	9.9	3.97	1.49 ~ 10.6
Wang (2011)	57	2,800	197	2,780	18.6	0.29	0.21 ~ 0.38
Yun <i>et al.</i> (2013)	95	5,241	46	1,807	17.9	0.71	0.50 ~ 1.01
Wang <i>et al.</i> (2014)	29	1,406	104	1,404	17.2	0.28	0.19 ~ 0.42

Table 3 | Summary of included health education intervention studies

Authors and publishing year	Intervention group		Control group		Weight (%)	RR	95% CI
	No. of cases	Study population	No. of cases	Study population			
Rao (1997)	164	1,978	295	1,824	40.4	0.51	0.43 ~ 0.61
Gu <i>et al.</i> (2004)	33	4,756	52	4,619	6.9	0.62	0.40 ~ 0.95
Mo <i>et al.</i> (2008)	16	858	41	1,193	4.5	0.54	0.31 ~ 0.96
Gu <i>et al.</i> (2009)	177	5,014	355	4,720	48.1	0.47	0.39 ~ 0.56

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).

Table 4 | Summary of included multiple intervention studies

Authors and publishing year	Intervention group		Control group		Weight (%)	RR	95% CI
	No. of cases	Study population	No. of cases	Study population			
Lou <i>et al.</i> (1989)	272	2,455	309	850	18.0	0.30	0.26 ~ 0.35
Zhu & Xia (1997)	129	1,733	320	1,739	12.6	0.40	0.33 ~ 0.49
Xiao & Lin (1997)	684	2,469	1,716	2,341	69.4	0.38	0.35 ~ 0.40
Zhang <i>et al.</i> (2000)	29	1,172	83	1,864	18.0	0.56	0.37 ~ 0.84
Cao & Zhang (2007)	3	1,719	9	1,278	9.8	0.25	0.07 ~ 0.91
Jin <i>et al.</i> (2009)	48	6,872	67	5,173	18.4	0.54	0.37 ~ 0.78
Wang (2011)	37	2,902	197	2,780	18.6	0.18	0.13 ~ 0.25
Yun <i>et al.</i> (2013)	60	3,779	46	1,807	18.3	0.62	0.43 ~ 0.91
Wang <i>et al.</i> (2014)	14	1,460	104	1404	16.8	0.54	0.37 ~ 0.78

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

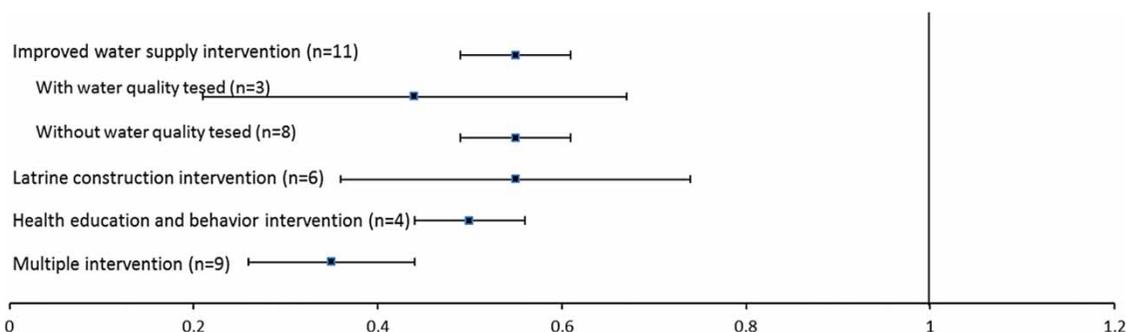
**Figure 2** | Summary of the meta-analysis.

Table 5 | Begg's test and Egger's test of the intervention groups

Group	Begg's test		Egger's test		
	Z value	P	T value	95% CI	P
Improved water supply	1.32	0.180	- 0.32	- 5.34 ~ 3.96	0.740
Latrine construction	0.00	1.000	- 0.02	- 22.99 ~ 22.74	0.984
Health education and behavior intervention	0.00	1.000	- 0.00	- 14.28 ~ 14.26	0.998
Multiple intervention	0.52	0.602	- 0.35	- 48.67 ~ 46.05	0.785

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 popularization 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 popularization 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.

ACKNOWLEDGEMENTS

This research was supported by the project Key Technology Study of Drinking Water Safety Testing, Monitoring, Risk Evaluation, Alarming and Forecasting (No. 201302004), a part of China's Non-profit Health Sector Scientific Research Program 2013. Author Yao Wei and the first author contributed equally to this work.

COMPETING INTERESTS

None declared.

REFERENCES

- Bartram, J. & Cairncross, S. 2010 Hygiene, sanitation, and water: forgotten foundations of health. *PLoS Med* 7, e1000367.
- Beckerman, W. 1992 Economic growth and the environment: whose growth? Whose environment? *World Development* 20, 481–496.
- Begg, C. B. & Mazumdar, M. 1994 Operating characteristics of a rank correlation test for publication bias. *Biometrics* 1088–1101.
- Cao, D. & Zhang, R. 2007 Investigation on rural water and sanitation intervention effect to control diarrhoea. *Chinese Rural Health Service Administration* 27 (6), 466–467.
- Carlton, E. J., Liang, S., McDowell, J. Z., Li, H., Luo, W. & Remais, J. V. 2012 Regional disparities in the burden of disease attributable to unsafe water and poor sanitation in China. *Bulletin of the World Health Organization* 90, 578–587.
- Chen, B. 2006 Study on rural water improvement and intestinal infectious affection in Yongshun county. *Practical Preventive Medicine* 13 (6), 1535–1535.
- Chen, X., Li, P., Chen, M., Lu, Y., Cai, Z., Zhou, M., Lv, Y., Yanng, P., Sun, M. & Lu, P. 1999 Study on the effect of the simple centralized water supply and the control effect for diarrhea in Huaibei area. *Jiangsu Health Care* (1), 16–19.
- China Daily 2014 The dissemination rate of the sanitation toilets in China is 74.1%. Available at: <http://health.people.com.cn/n/2014/1020/c14739-25865472.html> (accessed 26 October 2014).
- Cohen, A., Tao, Y., Luo, Q., Zhong, G., Romm, J., Colford, J. M. & Ray, I. 2015 Microbiological evaluation of household drinking water treatment in rural China shows benefits of electric kettles: a cross-sectional study. *PLoS One* 10, e0138451.
- Ding, G., Zhang, Y., Gao, L., Ma, W., Li, X., Liu, J., Liu, Q. & Jiang, B. 2013 Quantitative analysis of burden of infectious diarrhea associated with floods in northwest of Anhui Province, China: a mixed method evaluation. *PLoS One* 8, e65112.
- Egger, M., Smith, G. D. & Altman, D. 2008 *Systematic Reviews in Health Care: Meta-Analysis in Context*. John Wiley & Sons, London.
- Esrey, S. A., Potash, J. B., Roberts, L. & Shiff, C. 1991 Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the World Health Organization* 69 (5), 609.
- Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L. & Colford, J. M. 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet Infectious Diseases* 5, 42–52.
- Gu, B., Lin, Y. & Jin, H. 2004 Observation on the effect of behavioral meddle for control of diarrheal diseases among primary school students. *Sh J Prev Med* 16 (1), 3–4.
- Gu, B., Lin, Y., Jin, H. & Xiao, W. 2009 Effect of health education on control of diarrhea diseases in community population. *China Prev Med* (1).
- Gu, X., Zhao, H., Sun, X. & Zhang, Q. 2000 Relationships between improved drinking water supply and intestinal infectious diseases in rural areas of Kashi district of Xinjiang. *J Environment and Health* 17 (1), 34–35.
- Haidich, A. B. 2011 Meta-analysis in medical research. *Hippokratia* 14, 29–37.
- Hulton, G. 2012 Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage. Available at: http://apps.who.int/iris/bitstream/10665/75140/1/WHO_HSE_WSH_12.01_eng.pdf (accessed 26 October 2014). World Health Organisation, Geneva, Switzerland.
- Jin, L., Zhang, C., Yang, L., Zhang, Z., Sun, L., Zhu, H. & Cai, M. 2009 Water supply and latrine improvement and prevention of diarrheal diseases in rural areas in Sichuan province. *J Environ Health* 26 (1), 56–58.
- Li, H., Zhang, Q., Li, W., Luo, Q., Liu, K. & Tao, Y. 2015 Spatial analysis of rural drinking water supply in China. *Water Policy* 17, 441–453.
- Lin, X., Ran, L., Ma, L., Wang, Z. & Feng, Z. 2011 Analysis on the cases of infectious diarrhea (other than cholera, dysentery, typhoid and paratyphoid) reported in China 2010. *Chinese Journal of Food Hygiene* 23, 385–389.
- Liu, J., Yang, G. & Li, C. 2007 Analysis of the control effect of the intestinal disease and the worm disease in rural latrine-improved areas. *Practical Preventive Medicine* 14 (6), 1787–1788.
- Lopez, A. D., Mathers, C. D., Ezzati, M., Jamison, D. T. & Murray, C. J. L. 2001 Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. *The Lancet* 367, 1747–1757.
- Lou, H., Liu, M., Sun, S., Li, Q., Liu, A., Xu, G. & Fu, B. 1989 Effect evaluation and economic benefit analysis of rural environmental health improvement on control of diarrhea. *J Henan Preventive Medicine* 1 (1), 12–13.
- Mo, P., Cao, Z. & Yin, Y. 2008 Effect of health education in the prevention and treatment of diarrhea at school. *Occupation and Health* 24 (5), 477–478.
- MOH 2009 *China Health Year Book: A Comprehensive Collection of 1983–2009*. China Health Science and Technology Publishing House, Beijing, China.
- MOH 2010–2012 *China Health Year Book*. China Xie-he Medical University, Beijing, China.
- National Patriotic Health Campaign Committee 2015 Urban-Rural Environment Clean Action Plan (2015–2020). Urban-Rural Environment Clean Action. Available at: <http://www.nhfp.gov.cn/jkj/s5898/201503/9fb577a310084455b54ae3fbd87aa0e9.shtml> (accessed 20 May 2015).
- Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A. D., De France, J., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Johnston, R. B., Mathers, C., Mäusezahl, D., Medlicott, K., Neira, M., Stocks, M., Wolf, J. & Cairncross, S. 2014 Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Tropical Medicine & International Health* 19, 894–905.

- Rao, Y. 1997 Effect evaluation of health education in reducing diarrhoea disease in rural area. *China Health Education* **10**, 14–15.
- Shuchen, M., Yong, T. & Jiayi, L. 2004 *Rural Water Supply and Sanitation in China: Scaling Up Services for the Poor*. World Bank, Washington, DC.
- Tang, M., Liu, J., Peng, X., Tang, M. & Liang, S. 2011 Investigation on drinking water quality and its relationship with enteric infectious disease in elementary and secondary schools in a county of Hunan province. *J Hebei Medical University* **32** (2), 191–193.
- Tao, Y. 2009 National survey on rural drinking water and sanitation. *Journal of Environment and Health* **26**, 1–2.
- UN 2000 *United Nations Millennium Declaration*. United Nations, New York.
- Varley, R., Tarvid, J. & Chao, D. 1998 A reassessment of the cost-effectiveness of water and sanitation interventions in programmes for controlling childhood diarrhoea. *Bulletin of the World Health Organization* **76**, 617.
- Wang, S. 2011 Study on burden of diarrheal disease and cost benefit analysis due to water supply and sanitation facilities in typical rural areas. China CDC.
- Wang, S., Zhang, R. & Tao, Y. 2014 Burden of diarrheal in typical rural areas with water supply and latrines improvement. *J Environ Health* **31** (2), 159–162.
- Wang, Z., Shepard, D., Zhu, Y., Cash, R.A., Zhao, R., Zhu, Z. & Shen, F. 1989 Reduction of enteric infectious disease in rural China by providing deep-well tap water. *Bulletin of the World Health Organization* **67** (2), 171.
- Wei, C. 2004 The basic condition of intestinal infectious diseases in China and prevention countermeasure. *Chinese Journal of Public Health* **20**, 126–128.
- WHO 2013 Diarrhoeal disease fact sheets. Available at: <http://www.who.int/mediacentre/factsheets/fs330/en/.20> (accessed 26 October 2014). World Health Organisation, Geneva, Switzerland.
- WHO 2015 Global Health Observatory data repository. Available at: <http://apps.who.int/gho/data/view.main.CODWORLDV?lang=en,2015> (accessed 26 October 2014). World Health Organisation, Geneva, Switzerland.
- WHO, UNICEF & WSSCC 2014 *WHO/UNICEF Joint Monitoring Report 2014: Progress on Sanitation and Drinking Water*.
- WHO 2015 Global Health Observatory data repository. Available at: <http://apps.who.int/gho/data/view.main.CODWORLDV?lang=en,2015> (accessed 26 October 2014). World Health Organisation, Geneva, Switzerland.
- Wolf, J., Prüss-Ustün, A., Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., Clasen, T., Colford, J. M., Curtis, V., De France, J., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Jeandron, A., Johnston, R. B., Mäusezahl, D., Mathers, C., Neira, M. & Higgins, J. P. T. 2014 **Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression**. *Tropical Medicine & International Health* **19**, 928–942.
- Xiao, S. & Lin, C. 1997 Valuation of effectiveness of comprehensive control for diarrhea diseases in rural areas of east Fujian and analysis of its cost-benefit. *China J Prev Med* **31** (1), 40–41.
- Yun, L., Zhuming, S., Weiping, J. & Wanming, Z. 2013 Study on the effect of hygiene intervention measures on diarrheal diseases in the rural areas of Jiaying city. *Practical preventive medicine* **20** (011), 1343–1345.
- Zhang, W., Liu, M., Yin, W., Zhang, H., Li, G., Liu, L., Wang, G. & Zhang, Y. 2000 Long-term effect evaluation of rural water and sanitation improvement on control of diarrhea. *J Disease Control* **4** (1), 76–78.
- Zhang, Y. & Huo, E. 1987 Study on the control effect of water improvement in Jiangsu province. *J China primary health care* **7**, 009.
- Zhengkui, W., Yun, Y. & Chuanye, W. 2005 Economic and social benefit analysis of improvement of latrines in Countryside of Hunan Province, China. *J Environ Health* **22** (6), 445–447.
- Zhong, G. 2007 Benefit of water supply and latrine improvement in control of intestinal infectious diseases in rural areas of China. *J Environ. Health* **24**, 927–929.
- Zhu, X. & Xia, Q. 1997 Effect evaluation of environmental health interventions in rural schools. *Health Study* **26** (6), 378–380.
- Zhuang, H., Cai, H., Tu, J., Xue, W. & Yao, K. 2005 The relationship between the harmless treatment of rural household toilet and the incidence of intestinal infectious diseases in China rural. *Strait J Prev Med* **11** (6), 39–39.

First received 19 August 2015; accepted in revised form 20 April 2016. Available online 31 May 2016