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Burden of Disease Attributable to Inadequate Drinking Water, Sanitation, and Hygiene in Korea

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ABSTRACT

Background: Diarrheal and intestinal infectious disease caused by inadequate drinking water, sanitation, and hygiene (WASH) is not only a great concern in developing countries but also a problem in low-income populations and rural areas in developed countries. In this study, we assessed the exposure to inadequate WASH in Korea and estimated the burden of disease attributable to inadequate WASH.

Methods: We used observational data on water supply, drinking water, sewage treatment rate, and hand washing to assess inadequate WASH conditions in Korea, and estimated the level of exposure in the entire population. The disease burden was estimated by applying the cause of death data from death registry and the morbidity data from the national health insurance to the population attributable fraction (PAF) for the disease caused by inappropriate WASH.

Results: In 2013, 1.4% of the population were exposed to inadequate drinking water, and 1.0% were living in areas where sewerage was not connected. The frequency of handwashing with soap after contact with excreta was 23.5%. The PAF due to inadequate WASH as a cluster of risk factors was 0.353 (95% confidence interval [CI], 0.275–0.417), among which over 90% were attributable to hand hygiene factors that were significantly worse than those in American and European high-income countries.

Conclusion: The level of hand hygiene in Korea has yet to be improved to the extent that it shows a significant difference compared to other high-income countries. Therefore, improving the current situation in Korea requires a continuous hand washing campaign and a program aimed at all people. In addition, continuous policy intervention for improvement of sewage treatment facilities in rural areas is required, and water quality control monitoring should be continuously carried out.

Keywords: Inadequate Drinking Water; Sanitation; Hygiene; Burden of Disease; Handwashing; Korea

INTRODUCTION

The United Nation's Sustainable Development Goals (SDGs), which inherited the Millennium Development Goals (MDGs), include "universal and equitable access to safe and affordable drinking water" and "adequate and equitable sanitation and hygiene."[1] These goals mean that

Author Contributions

Conceptualization: Cheong HK. Data curation: Kim JH, Jeon BH. Methodology: Kim JH, Jeon BH. Writing - original draft: Kim JH. Writing - review & editing: Cheong HK, Jeon BH.

a safe drinking water supply, adequate sanitation facilities, and good hygiene are essential to maintaining human health and socioeconomic development.[2,3] Intestinal infectious diseases with diarrhea caused by ingestion of unsafe drinking water are the major cause of death in children in low-income countries.[4] The level of sanitation associated with sewage treatment represents the national capacity for adequate waste management and supply of safe drinking water.[5] Handwashing for good hygiene after contact with feces acts as an important barrier to the spread of fecal-orally transmitted diseases and reduces the secondary transmission of pathogens.[6] Because of these advantages, handwashing with soap is an essential element for health care and disease control.

The World Health Organization (WHO) estimated that the population attributable fraction (PAF) of diarrheal disease due to risk factors such as inadequate drinking water, sanitation, and hygiene (WASH) is more than 25% in a report assessing the global environmental burden of disease.[7] In the global burden of disease (GBD) study conducted by the Institute for Health Metrics and Evaluation (IHME), the PAF of deaths caused by risk factors such as unsafe water, sanitation, and handwashing in the Republic of Korea (Korea) was estimated to be 21.7% (15.9%–27.1%) for diarrheal disease and 19.9% (15.4%–24.4%) for intestinal infectious diseases.[8] However, the WHO's estimates did not provide any results for subcategories of risk factors or for each country. In addition, the IHME estimates for Korea that the PAF of deaths due to risk factors such as unsafe water and sanitation is 0, and the PAF from not washing hands is presented using old data. The WHO did not calculate the value of the PAF of inadequate drinking water and sanitation facilities in high-income countries of all regions, and the IHME suggested a value of 0 in Korea based on its being a Western-Pacific high-income country.[8,9] The results of previous studies indicate that the PAF and burden of disease caused by inadequate WASH are mainly focused on low-income and middle-income countries.[4,9] However, even in high-income countries, low-income families living in harsh environments suffer from diseases caused by inadequate WASH. Some households in rural areas of Korea still have places where sewage facilities are not available.[10]

In studies involving countries around the world, there is a limitation in estimating the burden of disease from inadequate WASH due to a lack of representative data sources. In Korea, it is possible to present detailed research results because data such as the number of people consuming a specific type of drinking water, the results of drinking water quality inspection, the water supply and sewerage coverage area, and National Handwashing Survey results are readily available. In this study, we aimed to estimate the burden of disease due to inadequate WASH in Korea.

METHODS

The process of estimating the disease burden attributable to inadequate drinking WASH takes several steps. We have presented a flow chart (**Fig. 1**).

Exposed population and the relative risk

The relative risk (RR) of disease from inadequate WASH was determined by using IHME GBD study data that showed the results according to the level of each category of WASH after applying WHO methodology.[4,6,9,11,12] The proportion of the population using inadequate drinking water was estimated based on the proportion of the population using
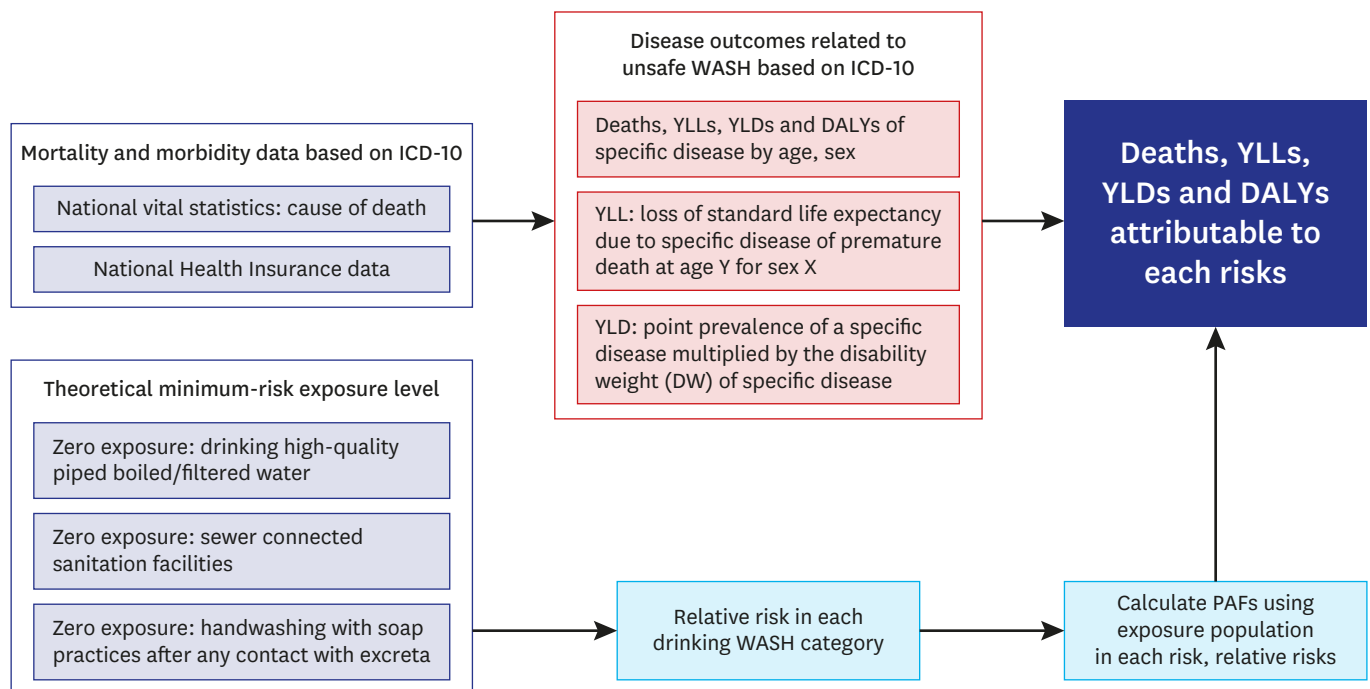
Fig. 1. Flow chart for estimating disease burden from inadequate drinking WASH in Korea.
WASH = water, sanitation, and hygiene, ICD-10 = International Classification of Diseases and Related Health Problems 10th Revision, YLL = years of life lost, YLD = years lived with disability, DALY = disability-adjusted life years, PAF = population attributable fraction.

a piped-water supply and the proportion of households depending on unsafe drinking water. The RR for inadequate drinking water was derived from studies that assessed the risk of disease according to drinking water treatment methods (**Supplementary Table 1**).[11] Sanitation was assessed by taking into account the proportion of the population living in areas where sewage treatment is not conducted. The RR for sanitation was derived from studies that estimated the risk of disease according to the type of sewage treatment method (**Supplementary Table 2**).[11] The hygiene level was assessed based on the percentage of the population who washed hands properly with soap and water after using the toilet and the RR associated with hand washing behavior was applied (**Supplementary Table 3**).[11] The RRs related with inappropriate WASH applied in this study can be found in the supplementary appendix of Reference.[11]

Theoretical minimum-risk exposure level

In GBD studies, theoretical minimum-risk exposure level (TMREL) is the risk exposure that is both minimizes risk in the exposed population and theoretically possible.[11] Therefore, TMREL is set differently depending on the risk factors. The TMREL for unsafe water is defined as the risk to health effects that may occur in household members who have access to high-quality piped water that has been boiled or filtered before drinking water. The TMREL for unsafe sanitation is defined as the risk to health effects that may occur in household members who have access to a sanitation facility with sewer connection. A sanitation facility with sewer connection included flush toilets and any toilet with connection to the sewer or septic tank. The TMREL for unsafe hygiene is defined as the risk to health effects that may occur in household members who engaging in handwashing with soap practices after any contact with excreta.

PAF

The PAF was estimated according to the following formula by applying the exposure ratio of each population to the RR for each exposure level of risk factor.

$$PAF = \frac{\sum_i^n p_i(RR_i - 1)}{\sum_i^n p_i(RR_i - 1) + 1}$$

Where Pi is the proportion of the exposure population at exposure level i, RRi is the RR at exposure level i, and n is the total number of exposure levels.

The following formula was used to calculate the PAF due to inadequate WASH as a cluster of the risk factors. The interval estimates for the total PAFs incorporating the three risk factors were calculated using Monte Carlo simulation.

$$PAF = 1 - \prod_{r=1}^{R} (1 - PAF_r)$$

Where r is the individual risk factor and R is the total number of risk factors considered in the cluster. Each risk factor in the formula is assumed to be independent and non-interacting.

Mortality and morbidity data

The range of diarrhea and intestinal infections due to inappropriate WASH, included in the calculation of disease burden in this study, was based on criteria classified according to the International Classification of Diseases and Related Health Problems 10th Revision (ICD-10). In 2013, the number of premature deaths was calculated from entries in the national death registry for which the cause of death was defined as intestinal infectious disease (A00–A09), acute hepatitis A and E (B15, B17.2), and helminthiases including schistosomiasis, hookworm diseases, ascariasis, and trichuriasis (B65, B76, B77, B79) (**Supplementary Table 4**). To calculate the burden of disease, national health insurance statistic were used to calculate the actual number of patients treated with the above-mentioned disease code in 2013.

Disability weights and severity distribution of diseases

WHO values were used for disability weights according to the health status of patients with intestinal infections caused by inadequate WASH in Korea.[13] Disease severity for diarrheal and intestinal infectious disease-related health status was classified as mild for outpatients and moderate for hospitalized patients. In the case of viral hepatitis A and E, the outpatient cases were classified as moderate and the hospitalized patients were classified as severe.

Burden of disease due to inadequate WASH

Disability-adjusted life years (DALY) is a single health indicator of disease burden consisting of the sum of years of life lost (YLL) and years lived with disability (YLD). The YLL for each disease was calculated by multiplying the number of cause-specific deaths by the loss of standard life expectancy due to premature death according to the sex and age of the individual at the time of death. The basic formula of YLL was the following for a given cause (c), sex (s), and age (a) in a particular time period (t). YLD is calculated by multiplying the disability weight corresponding to the number of prevalent morbidities according to the severity of the cause of disease in a particular time period (t). The basic formula of YLD is the following for a given cause (c) and health state (h):

$$DALY = YLL(c, s, a, t) + YLD(c, h, t)$$
$$YLL(c, s, a, t) = N(c, s, a, t) \times L(s, a)$$
$$YLD(c, h, t) = DW(c, h) \times P(c, h, t)$$

Where $N(c, s, a, t)$ is the number of deaths due to the cause c for the given age a and sex s in time t, $L(s, a)$ is the loss of standard life expectancy due to cause c of premature death at age a for sex s, $DW(c, h, t)$ is the disability weight for cause c in health states h, and $P(c, h, t)$ is the number of prevalent cases for cause c in health states h in a particular time period t.

The burden of disease attributable to each risk factor (AB) was calculated by multiplying the PAF by total DALY as the burden of diarrheal and intestinal infectious disease (B).

$$AB = PAF \times B$$

Ethics statement
This study protocol was approved by the Institutional Review Board (IRB) of Sungkyunkwan University School of Medicine (IRB No. 2014-06-008).

RESULTS

The Korean population distribution for inadequate WASH exposure, excess premature deaths, and burden of disease due to inadequate WASH-associated diarrheal and intestinal infectious diseases in Korea were estimated for the base year of 2013. However, in case of a lack of data sources for estimating the probability distribution, the data of adjacent years were used.

Exposure estimates of inadequate drinking water
From the 2010 census questionnaire on drinking water consumption, the percentage of the population consuming safe drinking water was estimated. Tap water and bottled water, which were previously treated or purified to the TMREL, accounted for 80.2% and 13.9%, respectively. The proportion of unqualified well water, groundwater, and unconfirmed water used as drinking water was 2.9%, 2.9%, and 0.1%, respectively (**Table 1**).[14] According to the quality survey for unqualified drinking water types, the inadequacy rate of groundwater was 11.6% and that of well water was 32.1% (**Table 2**).[15] As of 2013, inadequate consumption of drinking water accounted for 1.4% of the total population (713,342 people). Gangwon-do had the highest rate of 3.3% in its administrative area, and Jeju had the lowest rate of 0.1% (**Table 3**). In the metropolitan area, although the waterworks supply rate was almost 100%, some people still consumed inadequate drinking water. Local areas, including rural areas, had a slightly lower rate of waterworks supply than metropolitan areas and a higher proportion of inadequate drinking water populations.

Exposure estimates of inadequate sanitation
In Korea, no one lives in an unimproved sanitation area and 515,722 people, 1.0% of the total population, live in areas with improved sanitation facilities excluding sewer connections. In mega-cities, the sewage treatment rate was 100% and Gyeongsangbuk-do had the lowest rate of 93.8%. The sewage treatment rate in the metropolitan area has reached almost 100%. However, excluding Sejong and Jeju, local areas showed a slightly lower range of 93.8%– 99.5% (**Table 4**).

Table 1. Use of drinking water sources in population census in 2010 in Korea[a]

Administrative district	Tap water (%)	Bottled water (%)	Well water (%)	Groundwater (%)	Unconfirmed water (%)
Seoul	76.0	21.9	2.0	0.1	0.1
Busan	84.4	11.3	3.4	0.8	0.1
Daegu	85.3	12.0	2.4	0.3	0.0
Incheon	83.5	14.0	1.6	0.8	0.1
Gwangju	87.3	10.6	1.4	0.7	0.1
Daejeon	82.0	13.5	3.7	0.7	0.1
Ulsan	86.2	9.8	2.9	1.0	0.1
Gyeonggi-do	77.6	15.4	4.4	2.5	0.1
Gangwon-do	75.6	10.1	6.6	7.5	0.3
Chungcheongbuk-do	78.2	10.9	4.5	6.3	0.1
Chungcheongnam-do	72.8	10.9	1.6	14.5	0.2
Jeollabuk-do	87.3	6.4	1.2	5.0	0.1
Jeollanam-do	80.3	4.9	2.4	12.3	0.1
Gyeongsangbuk-do	84.4	9.5	2.0	4.1	0.1
Gyeongsangnam-do	85.7	8.4	2.9	2.9	0.1
Jeju	70.1	29.4	0.2	0.3	0.0
Sejong	72.8	10.9	1.6	14.5	0.2
Total	80.2	13.9	2.9	2.9	0.1

[a]Data source: usage of drinking water (Korean Statistical Information Service, http://kosis.kr/).

Table 2. Drinking water sources other than waterworks in Korea in 2014[a]

Sources	Investigated samples	Exceeding the standard	Proportion of exceeding the standard (%)
Groundwater	1,331	155	11.6
Well water	6,052	1,945	32.1

[a]Data source: soil and groundwater information system (National Institute for Environmental Research, http://sgis.nier.go.kr/sgis).

Table 3. Estimated population with insecure drinking water in Korea in 2013[a]

Administrative district	Total population	Waterworks supply rate (%)	Population with inadequate drinking water supply	Proportion of population with inadequate drinking water supply (%)
Seoul	10,388,055	100.0	78,367	0.8
Busan	3,563,578	100.0	45,812	1.3
Daegu	2,524,890	100.0	20,355	0.8
Incheon	2,930,164	100.0	20,717	0.7
Gwangju	1,488,467	99.7	9,395	0.6
Daejeon	1,547,609	100.0	21,208	1.4
Ulsan	1,178,907	99.2	13,535	1.1
Gyeonggi-do	12,549,345	98.3	226,410	1.8
Gangwon-do	1,555,672	94.5	51,201	3.3
Chungcheongbuk-do	1,600,213	97.1	36,438	2.3
Chungcheongnam-do	2,097,555	91.1	50,262	2.4
Jeollabuk-do	1,896,032	97.8	20,206	1.1
Jeollanam-do	1,931,716	93.4	44,394	2.3
Gyeongsangbuk-do	2,742,939	98.0	33,420	1.2
Gyeongsangnam-do	3,402,946	99.3	46,568	1.4
Jeju	604,670	100.0	599	0.1
Sejong	124,628	90.8	2,986	2.4
Total	52,127,386	98.5	713,342	1.4

[a]Data source: waterworks statistics (Korean Statistical Information Service, http://kosis.kr/).

Table 4. Sewage treatment status in Korea in 2013[a]

Administrative district	Total population	Population within sewage treatment area	Population within sewage untreated area	Sewage treatment rate (%)
Seoul	10,388,055	10,388,055	0	100.0
Busan	3,563,578	3,563,578	0	100.0
Daegu	2,524,890	2,497,249	27,641	98.9
Incheon	2,930,164	2,930,164	0	100.0
Gwangju	1,488,467	1,488,467	0	100.0
Daejeon	1,547,609	1,547,609	0	100.0
Ulsan	1,178,907	1,178,907	0	100.0
Gyeonggi-do	12,549,345	12,528,534	20,811	99.8
Gangwon-do	1,555,672	1,504,805	50,867	96.7
Chungcheongbuk-do	1,600,213	1,562,376	37,837	97.6
Chungcheongnam-do	2,097,555	2,086,480	11,075	99.5
Jeollabuk-do	1,896,032	1,838,731	57,301	97.0
Jeollanam-do	1,931,716	1,847,148	84,568	95.6
Gyeongsangbuk-do	2,742,939	2,574,110	168,829	93.8
Gyeongsangnam-do	3,402,946	3,346,153	56,793	98.3
Jeju	604,670	604,670	0	100.0
Sejong	124,628	124,628	0	100.0
Total	52,127,386	51,611,664	515,722	99.0

[a]Data source: sewage treatment statistics (Korean Statistical Information Service, http://kosis.kr/).

Exposure estimates of inadequate hygiene

The RR with respect to hygiene levels reflects the practice of proper handwashing, which reflects the observed prevalence of handwashing with soap and water after using the restroom or being in contact with excreta. Handwashing with soap after using a public restroom was observed in 23.5% of individuals in a Korean National Handwashing Survey in 2013.[16]

PAF and disease burden attributable to inadequate WASH in Korea in 2013

In Korea, the RRs of contaminated groundwater and inadequate drinking water as wells were applied at a RR (95% confidence interval [CI]) of 1.56 (1.43–1.70), which is one level above the theoretical minimum-risk exposure level. The PAF of diseases due to inadequate drinking water consumption was calculated as 0.008 (0.006–0.010), and the excess mortality was estimated to be 5.7 (4.4–7.1) persons in 2013. The disease burden was calculated as 65.7 (50.6–82.0) DALY for YLL and 5.0 (3.9–6.2) DALY for YLD. The RR for the sanitation-related improved category, which uses a septic tank or private sewage treatment plant for sewage treatment, was 2.71 (2.55–2.88). The PAF of diseases due to inadequate sanitation facilities was calculated as 0.017 (0.015–0.018), and the excess mortality was estimated to be 12.3 (11.2–13.5) persons in 2013. The disease burden was calculated as 142.1 (129.0–155.9) DALY for YLL and 10.8 (9.8–11.9) DALY for YLD. People who do not wash their hands with soap after contact with excreta in Korea accounted for 76.5% of the total population. The RR for the category of no handwashing with soap and water was 1.66 (1.46–1.87). The PAF of disease due to inadequate hand hygiene status was calculated as 0.336 (0.262–0.400), and the excess mortality was estimated to be 245.3 (190.3–292.1) persons in 2013. Disease burden was calculated as 2,835.3 (2,199.8–3,377.0) DALY for YLL and 216.1 (167.6–257.3) DALY for YLD (**Table 5**).

Table 5. PAF and disease burden attributable to inadequate water, sanitation, and hand hygiene in Korea in 2013

Variables	PAF (95% CI)	No. of deaths (95% CI)	YLL (95% CI)	YLD (95% CI)
Inadequate water	0.008 (0.006–0.010)	5.7 (4.4–7.1)	65.7 (50.6–82.0)	5.0 (3.9–6.2)
Inadequate sanitation	0.017 (0.015–0.018)	12.3 (11.2–13.5)	142.1 (129.0–155.9)	10.8 (9.8–11.9)
Inadequate hand hygiene	0.336 (0.260–0.400)	245.3 (190.3–292.1)	2,835.3 (2,199.8–3,377.0)	216.1 (167.6–257.3)
Inadequate WASH	0.353 (0.275–0.417)	257.7 (201.4–304.6)	2,979.1 (2,328.0–3,521.5)	227.0 (177.4–268.3)

PAF = population attributable fraction, YLL = years of life lost, YLD = years lived with disability, CI = confidence interval, WASH = water, sanitation, and hygiene.

DISCUSSION

This study estimated the burden of diarrheal and intestinal infectious diseases attributed to inadequate WASH by using the exposure level of risk factors of the Korean population. Exposure to inadequate drinking water is influenced by the number of people drinking water at a lower water quality than provided by waterworks, and an inadequate sanitation level is reflected in the number of inhabitants in areas where sewage treatment facilities are not available. Inadequate hand hygiene reflects the percentage of people who do not wash their hands with soap after contact with human excreta.

In the developed countries, the water supply rate is close to 100% in urban areas, but in rural areas, groundwater is often used as drinking water and there are a few people who use well water as drinking water according to individual preferences. The use of inadequate drinking water increases the likelihood of exposure to waterborne pathogens causing diarrhea and abdominal pain. In rural areas, water quality inspection is carried out periodically on groundwater and well water for the management of drinking water, but a certain level of inadequate water quality has been reported continuously. Inadequate water quality testing results have been reported in which the total colony counts and total coliform, used as indicators of human or animal fecal contamination, exceed the threshold.[17] In Korea, approximately 700,000 people use groundwater or well water that has been judged as inadequate drinking water in water quality tests. In particular, when contaminated drinking water was used for cooking in a restaurant or a group reception facility, several patients with water-borne diseases were diagnosed and epidemiological studies were conducted. The contamination of drinking water is closely related to the installation of sewage treatment facilities that provide an inadequate sanitation level. In areas where sewer is unconnected, septic tanks or private sewage treatment facilities can be inadequately treated due to technological inexperience and wrong usage of detention centers. In addition, livestock manure from livestock farming is recognized as a major source of water contamination.[18,19]

In 2013, the average sewage treatment rate in Korea was 99.0%. One percent of the total population is living in areas where individual improved sanitation facilities instead of sewer connections. However, the sewerage penetration rate in urban areas was almost 100%, but 98.3% in rural areas, which is different from urban areas. As a result, approximately 515,000 people live in rural areas where public sewage treatment facilities are not connected.[20] In Korea, there is a possibility of gastroenteritis due to contaminated groundwater intake, especially due to the low sewage treatment rate in rural areas and inadequately managed groundwater used as drinking water.[21] Studies suggesting that norovirus was detected in approximately 8.7% of the collected domestic groundwater supports this possibility.[21] Another study using geographic information systems showed that outbreaks due to norovirus infection occurred in areas with small, low-tech, self-operated sewage treatment plants and poorly treated sewage discharge.[22] The detection of hepatitis A RNA in approximately 13% of the pediatric and adolescent patients hospitalized for acute gastroenteritis in Seoul indicates that it has spread through contaminated water or food, resulting in illness in urban areas due to inadequate WASH.[23] In addition to acute gastroenteritis, some studies have suggested that contaminated water is a potential risk associated with the spread of aseptic meningitis and hand, foot, and mouth disease.[24-26]

In 2006, the frequency of handwashing with soap after using a public restroom was approximately 17% in the handwashing observational survey conducted in Korea.[16] In the survey conducted in 2013, it was 23.5%, which is still low compared with the North American

high-income countries (49%) and the European high-income countries (44%).[6,16] A low percentage of handwashing with soap in Korea has contributed to more than 90% of the total burden of diarrheal and intestinal infectious.

The risk of diarrheal and intestinal infectious disease due to inadequate drinking water provided by the WHO and IHME is mainly calculated from data for low- or middle-income countries. Therefore, in developed countries where the water supply rate is approaching 100%, there are limited categories that can be applied to populations using some groundwater or well water as drinking water. In this study, the RR of 1.56 (1.43–1.70), which is just above the TMREL, was applied to Korean population using inadequate drinking water (**Supplementary Table 1**). Although this RR may be overestimated in Korean context, the applied RR was considered acceptable when considering the result that 12.5% of the mean risk of acute gastroenteritis was attributed to drinking groundwater in a developed country environment.[27]

For the risk of inadequate sanitation related to the inadequate sewage treatment, the improved category in this study has a RR of 2.71 (2.55–2.88). However, in a meta-analysis that effects of sewerage on diarrhea and enteric infection, the risk with respect to diarrheal disease of the use of septic tank or other facility compare to the introduction of a sewage treatment facility was about 1.28–1.45.[28] This gap in RR is believed to be due to conceptual differences in defining improved sanitation facilities. It was due to the difference between the improved facility at the global context by WHO and researchers who judged the use of septic tanks as an improved facility at the Korean context. This shows that considering that Korea is a developed country, the RR applied in this study is likely to overestimate the PAF due to inadequate sanitation, and therefore, the burden of disease can be calculated to be larger than the actual impact.

The RR for no handwashing with soap and water in this study was 1.66 (1.46–1.87). Although the effects of handwashing according to national development level were all protective in preventing disease, the protective effects in developed countries (RR, 0.73; 95% CI, 0.58–0.92) were relatively less effective than those in non-developed countries (RR, 0.66; 95% CI, 0.53–0.82).[29] Health damage caused by poor WASH is not only a problem in developing countries but also in developed countries.[30,31] Intervention studies on handwashing with soap in the United States and Australia have shown a 50% reduction in diarrheal disease, consistent with the results of developing countries.[32-34] Therefore, although some preventive effects of handwashing with soap have been shown to be more effective in developing countries than in developed countries, the RR for no handwashing with soap and water presented by the WHO is considered to be applicable in developed countries.

Regarding the burden of disease due to inadequate WASH, unsafe drinking water and sanitation associated with sewage treatment are mainly due to the poor environment in rural areas. Environmental improvement in rural areas with a low population density will require policy intervention by the authorities, and therefore, policymakers will need to make a preliminary study of cost-effectiveness. In this regard, the cost-benefit ratio was estimated to be approximately 9.95 (3.36–20.65) for improving the drinking water supply environment in the rural areas in the developed countries of the western Pacific, including Korea. This means that even in developed countries, the health benefits are much greater than the cost of improving the drinking water supply environment.[35]

Based on the results of the present study, the magnitude of the burden of disease caused by inadequate WASH in Korea was found to be in the order of hand hygiene, sanitation, and

safe drinking water. Therefore, to reduce the burden of disease caused by the lack of these, it is necessary to raise awareness related to handwashing with soap and to form good habits through handwashing campaigns and various programs. Next, policy intervention by the authorities is required to improve the environment related to sewage treatment rates in rural areas. Finally, with regard to safe drinking water, it is advisable to use drinking water that is equivalent to the quality of water supplied by waterworks, and it is required to continuously monitor water quality and provide information for the population using groundwater and well water as drinking water.

ACKNOWLEDGMENTS

SUPPLEMENTARY MATERIALS

Supplementary Table 1
RR for inadequate drinking water[11]

Click here to view

Supplementary Table 2
RR for sanitation[11]

Click here to view

Supplementary Table 3
RR for not washing hands with soap[11]

Click here to view

Supplementary Table 4
Disease outcomes related to inadequate water, sanitation and hygiene in Korea

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REFERENCES

1. United Nations Development Programme. UNDP support to the implementation of the sustainable development goals. http://www.undp.org/content/undp/en/home/librarypage/sustainable-development-goals/undp-support-to-the-implementation-of-the-2030-agenda/. Updated 2016. Accessed April 4, 2017.

2. Hunter PR, MacDonald AM, Carter RC. Water supply and health. *PLoS Med* 2010;7(11):e1000361.
   PUBMED | CROSSREF

3. Mara D, Lane J, Scott B, Trouba D. Sanitation and health. *PLoS Med* 2010;7(11):e1000363.
   PUBMED | CROSSREF

4. Wolf J, Prüss-Ustün A, Cumming O, Bartram J, Bonjour S, Cairncross S, et al. Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. *Trop Med Int Health* 2014;19(8):928-42.
   PUBMED | CROSSREF

5. Hsu A, Zomer A. Environmental performance index. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118445112.stat03789.pub2. Updated 2016. Accessed April 4, 2017.

6. Freeman MC, Stocks ME, Cumming O, Jeandron A, Higgins JP, Wolf J, et al. Hygiene and health: systematic review of handwashing practices worldwide and update of health effects. *Trop Med Int Health* 2014;19(8):906-16.
   PUBMED | CROSSREF

7. World Health Organization. *Preventing Disease through Healthy Environments: a Global Assessment of the Burden of Disease from Environmental Risks*. Geneva: World Health Organization; 2016.

8. GBD compare. http://vizhub.healthdata.org/gbd-compare/. Updated 2016. Accessed March 29, 2017.

9. Prüss-Ustün A, Bartram J, Clasen T, Colford JM Jr, Cumming O, Curtis V, et al. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Trop Med Int Health* 2014;19(8):894-905.
   PUBMED | CROSSREF

10. Sewage treatment statistics. http://kosis.kr/statisticsList/statisticsList_01List.jsp?vwcd=MT_ZTITLE&parentId=E#SubCont. Updated 2016. Accessed April 5, 2017.

11. Forouzanfar MH, Alexander L, Anderson HR, Bachman VF, Biryukov S, Brauer M, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015;386(10010):2287-323.
    PUBMED | CROSSREF

12. Clasen T, Pruss-Ustun A, Mathers CD, Cumming O, Cairncross S, Colford JM Jr. Estimating the impact of unsafe water, sanitation and hygiene on the global burden of disease: evolving and alternative methods. *Trop Med Int Health* 2014;19(8):884-93.
    PUBMED | CROSSREF

13. World Health Organization. *WHO Methods and Data Sources for Global Burden of Disease Estimates 2000–2011*. Geneva: World Health Organization; 2013.

14. Usage of drinking water. http://kosis.kr/statisticsList/statisticsList_01List.jsp?vwcd=MT_ZTITLE&parentId=E#SubCont. Updated 2016. Accessed April 5, 2017.

15. Soil and groundwater information system. http://sgis.nier.go.kr/sgis. Updated 2016. Accessed April 5, 2017.

16. Lee MS, Hong SJ, Kim YT. Handwashing with soap and national handwashing projects in Korea: focus on the National Handwashing Survey, 2006–2014. *Epidemiol Health* 2015;37:e2015039.
    PUBMED | CROSSREF

17. Yu J, Wang C, Shin I, Kim D, Park K. Analysis of waterborne pathogenic bacteria among total coliform positive samples in the groundwater of Chungcheongnam-do province, Korea. *J Environ Health Sci* 2016;42(3):189-95.

18. Sahoo PK, Kim K, Powell M. Managing groundwater nitrate contamination from livestock farms: implication for nitrate management guidelines. *Curr Pollution Rep* 2016;2(3):178-87.
    CROSSREF

19. Wen Y, Schoups G, van de Giesen N. Organic pollution of rivers: combined threats of urbanization, livestock farming and global climate change. *Sci Rep* 2017;7(1):43289.
    PUBMED | CROSSREF

20. 2013 sewage statistics. http://www.me.go.kr/home/web/policy_data/read.do?menuId=10264&seq=6564#. Updated 2015. Accessed April 12, 2017.

21. Lee GC, Jheong WH, Jung GS, Oh SA, Kim MJ, Rhee OJ, et al. Detection and molecular characterization of human noroviruses in Korean groundwater between 2008 and 2010. *Food Environ Virol* 2012;4(3):115-23.
    PUBMED | CROSSREF

22. Kim JH, Lee DH, Joo Y, Zoh KD, Ko G, Kang JH. Identification of environmental determinants for spatio-temporal patterns of norovirus outbreaks in Korea using a geographic information system and binary response models. *Sci Total Environ* 2016;569-570:291-9.
    PUBMED | CROSSREF

23. Park SH, Kim EJ, Lee JH, Choi SS, Kim MS, Jung SS, et al. Molecular characterization of hepatitis A virus isolated from acute gastroenteritis patients in the Seoul region of Korea. *Eur J Clin Microbiol Infect Dis* 2009;28(10):1177-82.
    PUBMED | **CROSSREF**

24. Cheong HK, Park SK, Ki M, Lee K. Six year national trend of childhood aseptic meningitis incidence in Korea, 1996–2001. *Korean J Epidemiol* 2008;30(2):252-62.
    CROSSREF

25. Park SK, Cheong HK, Ki M, Son YM, Kim H. Assessment of the availability of health insurance data for epidemiologic study of childhood aseptic meningitis. *Korean J Prev Med* 2003;36(4):349-58.

26. Lee YA, Oh SH, Hong SJ, Kim YH, Moon HN, Hong CY. Hand, foot and mouth disease associated with the aseptic meningitis in Seoul, 1990. *J Korean Pediatr Soc* 1993;36(6):842-9.

27. Murphy HM, Pintar KD, McBean EA, Thomas MK. A systematic review of waterborne disease burden methodologies from developed countries. *J Water Health* 2014;12(4):634-55.
    PUBMED | **CROSSREF**

28. Norman G, Pedley S, Takkouche B. Effects of sewerage on diarrhoea and enteric infections: a systematic review and meta-analysis. *Lancet Infect Dis* 2010;10(8):536-44.
    PUBMED | **CROSSREF**

29. Aiello AE, Coulborn RM, Perez V, Larson EL. Effect of hand hygiene on infectious disease risk in the community setting: a meta-analysis. *Am J Public Health* 2008;98(8):1372-81.
    PUBMED | **CROSSREF**

30. Levy K, Klein M, Sarnat SE, Panwhar S, Huttinger A, Tolbert P, et al. Refined assessment of associations between drinking water residence time and emergency department visits for gastrointestinal illness in Metro Atlanta, Georgia. *J Water Health* 2016;14(4):672-81.
    PUBMED | **CROSSREF**

31. Tinker SC, Moe CL, Klein M, Flanders WD, Uber J, Amirtharajah A, et al. Drinking water residence time in distribution networks and emergency department visits for gastrointestinal illness in Metro Atlanta, Georgia. *J Water Health* 2009;7(2):332-43.
    PUBMED | **CROSSREF**

32. Curtis V, Cairncross S. Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. *Lancet Infect Dis* 2003;3(5):275-81.
    PUBMED | **CROSSREF**

33. Roberts L, Jorm L, Patel M, Smith W, Douglas RM, McGilchrist C. Effect of infection control measures on the frequency of diarrheal episodes in child care: a randomized, controlled trial. *Pediatrics* 2000;105(4 Pt 1):743-6.
    PUBMED | **CROSSREF**

34. Black RE, Dykes AC, Anderson KE, Wells JG, Sinclair SP, Gary GW Jr, et al. Handwashing to prevent diarrhea in day-care centers. *Am J Epidemiol* 1981;113(4):445-51.
    PUBMED | **CROSSREF**

35. Hunter PR, Pond K, Jagals P, Cameron J. An assessment of the costs and benefits of interventions aimed at improving rural community water supplies in developed countries. *Sci Total Environ* 2009;407(12):3681-5.
    PUBMED | **CROSSREF**