Essay



# Economic Burden, Health Burden and Predictive Analysis of Diarrhoea Attributed to Unsafe Water Sources, No Access to Handwashing Facilities, Unsafe Sanitation in Global from 1990 to 2030

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# Economic Burden, Health Burden and Predictive Analysis of Diarrhoea Attributed to Unsafe Water Sources, No Access to Handwashing Facilities, Unsafe Sanitation in Global from 1990 to 2030

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**Abstract**

**INTRODUCTION:** This study investigated the health and economic burden of global diarrhoea attributed to unsafe water sources, lack of access to handwashing facilities, and unsafe sanitation. **METHODS:** Data from the Global Burden 2019 study were used to collect age-standardized mortality rate (ASMR) and sociodemographic index (SDI) values from 21 regions. The relationship between ASMR or age-standardized disability-adjusted life years (ASDR) and SDI was analyzed with restricted cubic splines (RCS) and quantile regression. The trends of ASMR from 2020 to 2030 in global and five countries with different SDIs were predicted using a Bayesian age-period-cohort model. The economic burden of diarrhea was estimated for the 50 most populous countries, with direct costs assessed via a top-down approach and indirect costs via the human capital method. **RESULTS:** The global burden of diarrhea had decreased but remained significant. Major risk factors included unsafe water, sanitation, and lack of handwashing facilities. Children aged 1-5 had the highest incidence, and those over 90 had the highest mortality. Low and middle-low SDI areas had heavy health burden. The health burden is higher for men than for women. The RCS results showed that the burden of diarrhoeal diseases caused by these three factors declined as the SDI increased and remained essentially unchanged at an SDI of 0.7. By 2030, the ASMR of diarrhea was projected to decline globally, including in China, the US, Malaysia, Tanzania, and India, except for an increase in Malaysia attributed to unsafe sanitation. In 2019, the countries with heavier economic burdens were Nigeria, China, India, and America. **CONCLUSION:** The burden of diarrhea from unsafe water, lack of handwashing facilities, and unsafe sanitation is influenced by SDI, gender, and age. The populations of focus are children and the elderly; Older men and low SDI areas have a heavier health burden. Most of the heavier economic burdens occur in more populous countries with middle and middle-low SDI. Predictive studies provide country-specific recommendations for prevention and control.

**Keywords:** burden of diarrhoea; SDI; no handwashing facilities; unsafe water sources; sanitation facilities

## Introduction

Diarrhea is defined as over three bowel movements per day, exceeding 200 g/day, with stool water content above 85%. It significantly impacts human health, society, and the economy. In 2016, diarrhoea was the eighth leading cause of death among all ages (1,655,944 deaths) and the fifth leading cause of death among children under 5 years of age (446,000 deaths) [1]. Causes of diarrhea include infectious factors like rotavirus and salmonella, and non-infectious factors like drugs,

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chemicals, ischemic enteritis, allergies, and radiotherapy. The factors that promote the existence of diarrheal diseases among under-five children are complex, and many of them are related to poor socioeconomic circumstances. The association of poor implementation of water, sanitation, and hygiene (WASH),unsafe human waste disposal, limited access to healthcare education, poor diet, and housing conditions in a community are driving force to under-five diarrhea [2]. The main environmental factors that contribute to diarrhea included unsafe water, lack of handwashing facilities, and poor sanitation [1]. Despite progress in reducing diarrhea-related mortality and morbidity, it remains a leading cause of illness and death in low- and middle-income countries attributed to inadequate water, sanitation, and hygiene [3].

Diarrheal diseases cause one in nine child deaths globally, with 88 percent attributed to unsafe water, inadequate sanitation, and poor hygiene [4]. The problem of diarrhoea in developing countries is more serious, affected by economic and development factors [5,6]. Developing countries face a more severe challenge attributed to economic factors. Unsafe water sources, lack of handwashing facilities, and poor sanitation are leading causes of disability-adjusted life years (DALYs) and diarrheal deaths worldwide. Improved treatment, prevention, and access to safe water and sanitation have contributed to a decrease in DALYs associated with diarrhea [7,8].

Our study consist of four parts. Firstly, data on ASMRs, age-standardized DALY rates (ASDRs), and age-specific mortality rates for three risk factors were collected from 1990 to 2019 at different SDI quintiles. The analysis focuses on trends over a 30-year period, including differences between various SDI levels, gender, and age groups for each risk factor. Secondly, global SDI values were collected and divided into 21 regions according to the GBD 2019 classification. ASMR or ASDR data from 1990 to 2019 were examined, exploring the relationship between SDI and ASMR or ASDR using restricted cubic spline (RCS) and quantile regression analysis. Thirdly, a Bayesian age-period-cohort (BAPC) model predicted mortality trends from 2020 to 2030. Finally, the economic burden of diarrhea was analyzed in the top 50 countries by population. This study investigated the epidemiological and sociodemographic shifts in the health burden and economic burden of diarrhoea caused by three environmental risk factors in global.

## Methods

*Research Objective and Data Sources*

For this study, we used publicly available estimates from the GBD 2019 study. GBD led by the University of Washington's Institute for Health Metrics and Evaluation, involves over 7,000 researchers from 156 countries, which utilizes diverse data sources to comprehensively estimate global disease burden. The health burden comes from GBD2019. It offers tools to quantify health losses from hundreds of diseases, injuries, and risk factors, aiding informed decision-making and healthcare system improvement. Over the years, GBD has collected and analyzed data on premature death and disability for over 350 diseases and injuries across more than 200 countries since 1990 [9,10]. Economic burden data mainly came from GBD 2019, the World Bank database and the World Health Organization Global Health Expenditure database.

The GBD mortality database integrated vital registers, cause of death inferences, surveys, registrations, government, and surveillance data. Mortality estimates for each source were generated using the GBD cause ensemble model. To ensure coherence, an algorithm called CoDCorrect adjusts individual cause-specific mortality estimates to match all-cause mortality. The adjusted death estimate is then multiplied by the standard GBD life expectancy to calculate YLL. YLD is obtained by multiplying the number of illnesses by the disability weight. DALYs are derived by summing YLL and YLD for each age, sex, and location. ASMRS are computed using GBD 2019 global standard population data, and population attributable fractions (PAFs) are determined using a comparative risk assessment framework combining exposure dose and relative risk. By multiplying PAF by the corresponding disease burden indicator [9–11], the burden attributable to specific risk factors is calculated. For GBD 2019, exposure to unsafe water was defined based on: (1) reported primary water

 doi:10.20944/preprints202509.1982.v1



source used by the household, and (2) use of household water treatment (HWT) to improve the quality of drinking water before consumption. Exposure to unsafe sanitation was defined based on the primary toilet type used by households, and modelled three different categories of sanitation: unimproved, improved, and facilities with a sewer connection or septic tank. No access to handwashing facility was defined as lack of access to a handwashing station with available soap and water.

The SDI comprises lagging distributive income per capita, average educational attainment among those aged 15, and the total fertility rate of individuals under 25. Similar to the Human Development Index construction method, GBD 2015 employs the Socio-Demographic Index (SDI), a composite indicator ranging from 0 to 1 [12,13]. SDI categorizes 204 countries and regions into five quintiles: high (0.805129-1), high to medium (0.689504-0.805129), medium (0.607679-0.689504), low to medium (0.454743-0.607679), and low (0-0.454743) [14].

*Statistical Analysis Methods*

Restricted Cubic Splines (RCS)

RCS is commonly employed to analyze nonlinear relationships. It entails fitting piecewise polynomials, ensuring smoothness and second-order differentiability at each node. Spline regression involves linear functions within the data's range, with reference points at both ends. In RCS, the number and position of spline function nodes are specified. Typically, 3 to 5 nodes are recommended, but this study used only three nodes.

Quantile Regression

Quantile regression estimates conditional quantiles of the dependent variable on the independent variable, providing a model for all quantiles. It represents a class of models and utilizes weighted least squares based on minimum weighted absolute deviation.

$$\min\{w_t \mid y_t - \alpha|\} = -\sum_{i:y_i<\alpha}^{T} (1-\tau)(y_t - \alpha) + \sum_{i:y_i \geq \alpha}^{T} \tau(y_t - \alpha)$$

Quantile regression is more informative than traditional regression and is suitable for non-normally distributed data [15].

BAPC Model

The Bayesian Age-Period-Cohort (BAPC) model is an extension of the age, period, and cohort model. It predicts based on adjacent time points' effects within the same study population and period. The model employs a second-order random walk to smooth prior mortality for age, period, and cohort effects, approximating the marginal posterior distribution with the integrated nested Laplace approximation method [16]. Compared to traditional Bayesian methods, the BAPC model addresses convergence issues associated with Markov chain Monte Carlo sampling, enhancing robustness [4]. The Bayesian age-period-cohort model predicts the ASMR trend of diarrhea caused by unsafe water sources, lack of access to handwashing facilities, and unsafe sanitation from 2020 to 2030. It offers better coverage and accuracy compared to other prediction methods. The model includes the three most populous countries globally China (middle), India (low to middle) and United States (high), along with Malaysia (high to middle) and Tanzania (low) in Africa, representing diverse SDI levels.

Economic Burden

The economic burden of disease includes both direct and indirect economic burden. Direct economic burden refers to the economic resources directly consumed attributed to the prevention and treatment of disease; Indirect economic burden refers to the economic burden caused by the loss of time and labor caused by the illness, disability and premature death [17].

 doi:10.20944/preprints202509.1982.v1



Direct economic burden: disease costs per patient in the US were taken as the baseline (Table S1). The correction factor equal to total medical expenditure in a country in a certain year / total medical expenditure in the United States in the same year (Table S2). The direct economic burden attributable to exposure to a certain risk factor was measured using the top-down method, the specific formula is: direct economic burden = prevalent case * health-care costs per case of diarrhea in the US * the correction factor, where the PAF and the number of diseases was availabled from the GBD 2019 database.

Human capital method is to calculate the indirect economic burden according to the reduction of income caused by the loss of time [17]. At present, the more reasonable human capital method is calculated by using the per capital gross national product (GDP per capital) (Table S2). The specific formula is: indirect economic burden = GDP per capital * DALYs * productivity weight, where the GDP per capita was availabled from the World Health Organization Global Health Expenditure database; DALYs was availabled from the GDB 2019 database. In addition, considering the different productivity levels of different age groups, thus different weights are given. Productivity weight in 0-14 years was 0.15; 0.75 in 15-44 years,0.80 in 45-59years, and 0. 10 at over 69 years old [19]. Additionally, Yemen's GDP per capita data in 2019 was missing, which was replaced with its GDP per capita in 2018 in the World Bank database, and Yemen did not have total medical expenditure in 2019, we used its shares in the latest year (2015).

## Results

The temporal trends of diarrhea burden attributed to these three risk factors

The Table 1 displayed deaths, age-standardized mortality rate (ASMR), and temporal trends of diarrhoea from 1990 to 2019. Globally, deaths from unsafe water sources declined from 2,442,070 (95% UI: 1,764,954-3,147,028) in 1990 to 1,230,154 (95% UI: 817,816-1,788,898) in 2019, marking a 50% reduction. The trends of ASMR revealed a decreasing pattern across different SDI regions. Figure 1A depicted the global ASMR of diarrhoea attributed to water pollution. Over the period, global mortality decreased by 65.76% (from 49.09 to 16.81 per 100,000 people). Notably, the high SDI quintile saw the most significant drop of 76.92% (from 0.39 to 0.09 per 100,000 people).

Figure 1B displayed the global ASMR of diarrhoea from unsafe sanitation. Between 1990 and 2019, mortality plummeted by 99.86% (from 36.92 to 0.05 per 100,000 people), with the high SDI quintile least impacted. Conversely, the lowe SDI quintile saw a 66.77% decrease (from 160.61 to 53.36 per 100,000 people). Figure 1C illustrates the global ASMR of diarrhoea attributed to the lack of access to handwashing facilities. Over the same period, The ASMR decreased by 62.5% (from 0.08 to 0.03 per 100,000 people) in the high to middle quintile ,The 80.25% decrease in the middle SDI quintile was the most significant.

*The Differences of Diarrhea Burden Between Genders*

Globally, the ASMR for diarrhoea from these factors is higher in men than in women. In 2019, the ASMR attributed to unsafe water resources was 16.60 per 100,000 in men and 16.97 per 100,000 in women. Diarrhoea caused by the absence of handwashing facilities was 0.03 and 4.86 per 100,000 for men and women respectively, Diarrhea attributed to unsafe sanitation facilities unsafe sanitation facilities was 4.98 and 10.37 per 100,000 for men and women respectively (Figure 2A). Other different SDI quantiles also have a higher health burden for men than for women (Figure 2B-F).

In 2019, the ASMR for diarrhoea caused by unsafe water sources was highest in low SDI quantiles, reaching 79.40 per 100,000 male population; for women, it was also in low SDI regions, at 78.37 per 100,000 population (Figure 2B). Similarly, the highest ASMR of diarrhoea attributed to lack of handwashing facilities was in low SDI quintiles, with 26.45 cases per 100,000 people in men, while for women, it was 24.96 per 100,000 people. Furthermore, In 2019, men had a notably higher ASMR for diarrhea from unsafe sanitation facilities, reaching 54.37 cases per 100,000 people. In comparison, the ASMR for women, is implied to be lower.

 doi:10.20944/preprints202509.1982.v1



*The Differences of Diarrhea Burden Among Ages*

We analyzed age-specific mortality from diarrhoea attributed to three risk factors across five SDI quintiles globally. Figures 3, e-3, and e-4 present heatmap data. Age-specific mortality rates for each SDI quintiles declined annually from 1990-2019. The age-specific mortality rates peaked at ages 90-95. Predominantly, the highest age-specific mortality attributed to unsafe water sources was in the 90-95 age group particularly in low SDI areas. Low SDI individuals had higher age-specific mortality rates. High SDI quintiles had the lowest mortality (Figure 3). Age-specific death rates from diarrhoea due to unsafe sanitition and lack of hand-washing facilities have been decreasing year on year, with higher rates among patients aged 95 + ( (Figure 3S，4S).

The age-specific incidence of diarrhoea globally and in different SDI regions in 1990 and 2019 was shown in (Figure 6). Overall, the incidence of diarrhoea was highest in the low SDI region and the lowest in the high SDI area, with the incidence of diarrhoea in most age groups in 2019 being lower than in 1990, and the highest incidence in the age group of 1-5 years.

*The Relationship Between SDI and ASMR or ASDR of Diarrhoea*

The association between ASMR due to diarrhea caused by unsafe water and inaccessible handwashing facilities and SDI, for the 21 regions of the world from 1990 to 2019 is shown in Figures 4 and 5S. The colored lines represent the time trend for each specific region, and the dots represent the specific year for each region. The five quantiles regression lines run from top to bottom in order of P95, P75, P50, P25, and P5. According to the results of the Restricted cubic spline, the burden of diarrhoeal diseases caused by unsafe water declined as the SDI increased and remained essentially unchanged at an SDI of 0.7. The ASMR attributed to diarrhea caused by no access to handwashing facilities and unsafe sanitation is similar to that caused by unsafe water (Figure 4).

Projections of ASMR of diarrhoea in different SDI countries from 2020 to 2030

The trend of ASMR attributable to the three risk factors over the next 10 years is predicted in Figure 5,6S and 7S. Overall, in the next 10 years, the ASMR of diarrhea attributed to the three risk factors will decrease. According to the BAPC forecast, The ASMR attributable to unsafe water sources in 2020-2030 was declining globally, China, US, India, Malaysia, and Tasanian to 29.4%, 55.56%, 16.67%, 43.67%, 5.25% and 31. 42 by 2030, respectively, with China showing the largest decline of 55.56%, respectively. In contrast, the ASMR of diarrhea attributed to unsafe water sources for women in the US, Malaysia, and Tanzania was lower than the global level, with Tasanian women having the lowest level, and China and the US all higher, with Chinese women having the highest. According to the BAPC forecast, ASMR attributed to unsafe water sources between 2020-2030 was declining in women globally and in five countries, with Chinese women showing the largest decline of 62.5%. (Figure 5)

Overall, global ASMR of diarrhea attributed to unsafe sanitation for men and women are expected to show a downward trend to 36.51% and 39.94%, respectively. According to the BAPC forecast, ASMR attributed to unsafe health facilities between 2020-2030 decreased globally in men and women in five countries, with Malaysian women seeing the largest decline of 53.6% (Figure 6S). Overall, diarrhea attributable to no access to handwashing facility for men and women worldwide is expected to decline to 45.7% and 53.36%, respectively. According to BAPC prediction, ASMR of Chinese, Malaysian, and Indian women attributed to the lack of safe health facilities was decreased. The ASMR for diarrhea attributed to poor sanitation is expected to rise from 0.14 (95% CI,0.1-0.19) in 2020 to 0.16 (95% CI,-0.01-0.33) by 12.52% (Figure 7S).

*Economic Burden of Diarrhoea Attributed to These Three Risk Factors*

We collected per capita GDP and total medical expenditure in the top 50 countries of the global population in 2019 and estimated the economic burden of diarrhea due to unsafe water sources, no access to handwashing facilitiesand unsafe sanitation , respectively, as given in Tables S_S2.

 doi:10.20944/preprints202509.1982.v1



Our research results show that the top three countries with the highest economic losses due to diarrhea caused by unsafe water sources in 2019 were Nigeria, China, and India, with specific values of $3287.96 billion, $1795.31 billion, and $1321.68 billion respectively.The top three countries in economic losses of diarrhea by no access to handwashing facilityin 2019 are Nigeria, United States of America and India, the specific values are 1219.44billion, 380.28billion and 327.55billion. The top three countries in the economic loss of diarrhea by unsafe sanitation in 2019 are Nigeria, United States of America and China, specifically, 2209.51billion, 1447.81billion and 1021.93billion, respectively.

## Discussion

The diarrheal disease burden attributed to unsafe water sources is higher than No access to handwashing facility and unsafe sanitation. Age 1-5 years old is the group with high incidence, and age over 90 years old is the high death group. Countries with low SDI are the key areas for diarrhea prevention and control. The health burden is higher for men than for women. the ASMR of diarrhea was projected to decline globally, including in China, the US, Malaysia, Tanzania, and India, except for an increase in Malaysia attributed to unsafe sanitation. Countries with heavy economic burden are mainly those with middle or middle-low SDI.

This study showed that health burden of diarrhea attributed to these three risk factors decreased globally in 1990 and 2019 and the health burden of diarrhea attributed to unsafe water was higher than two other risk factors, which may, in some resource-poor areas, a disproportionate more population drinking water is at least occasionally contaminated by bacteria [18]. The diarrheal disease burden attributed to unsafe water sources is higher than no access to handwashing facility and unsafe sanitation，because billions of people do not use safe water, and hundreds of millions do not access basic WASH services. Unsafe WASH increases the risk of diarrhea [19]. In addition, diarrhea is attributed to the highest incidence of 1-5 years, which may be due to the combined effects of malnutrition and childhood infection, especially in low-and middle-income countries, with a higher incidence of diarrhea in children under 5 years [1]. The highest mortality rate is over 90 years old, which may be due to low immunity, the virus is more likely to invade, such as serious and persistent diarrhea caused by rotavirus, norovirus, leading to the death of the elderly [20,21]. The reason behind higher prevalence among males compared to that among females could be due to young males are more likely to wander off in unsanitary surroundings compared to young females. One study conducted at icddr,b hospital shows that males are admitted at a higher proportion than females to the ICU (64% vs 36%) with diarrhea [22].

We found that the burden of diarrhea attributed to the three risk factors gradually decreased with SDI increased. In low-income and middle-income countries (low-and middle-income countries), health awareness, sanitation equipment and safe water use are lacking [23]. Especially in the tropical climate areas, the rural agricultural communities are mainly involved. Therefore, improving living and working conditions and providing safe water intake will play an important role in the prevention of diarrheal diseases in the region. Currently, fresh produce continues to be the main source of diarrheal disease outbreaks, particularly in low- and middleincome countries where water stress results in the use of surface wastewater all year round for the irrigation of vegetables [24]. Moreover, untreated wastewater for irrigation is another major factor that results in the contamination of food products with pathogens [25]. Therefore, in order to safeguard public health and sustain livelihoods, there is a need to evaluate the microbial safety of wastewater-irrigated lettuce at locations in low- and middle-income countries. In addition, the lack of many health care facilities in low-resource settings affects the ability to provide safe care, with serious and health risks [26].

In general, the forecast suggests that diarrhea mortality attributed to the three risk factors will all decline over the next decade, which can be partially attributed to disease interventions to improve water quality, sanitation and hygiene [27]. However, this study found an increase in diarrhea mortality attributed to the absence of hand washing equipment in Malaysia. The possible reason for this is geographic location-related [28].

 doi:10.20944/preprints202509.1982.v1



Our research shown that the top three countries with the highest economic losses of diarrhea caused by unsafe water sources in 2019 were Nigeria, China, and India respectively. The results were similar to ours study, which is burden of diarrhea in the Eastern Mediterranean Region was significant differences found within the region, with low-and middle-income countries experiencing social unrest bearing the vast majority of the diarrhoea burden [29]. Different studies show that diarrhoea is commonly seen in low socio-economical groups [30].

The study presented several advantages. Firstly,The burden of diarrhea disease attributed to these three factors is a comprehensive study, encompassing both health and economic burdens. The global economic burden of the disease is relatively rare,For the first time, economic burden was studied,and this study may provide data to support future research. Secondly, We analyzed the sociodemographic and epidemiological changes in diarrhea attributable to these three factors. We use a range of statistical methods, including RCS and quantile regression, and BAPC. Thirdly, Predictive analytics offer insights into preventive measures. Additionally, we recommend interventions for women in specific countries (China, India, USA, and Malaysia) and highlight the need to address younger men's mortality burden. This study also has limitations. first, the lack of information on. disease-specific subtypes and other risk factors, and second, the selection of only five representative countries, with some unfairness.

## Conclusion

The disease burden of diarrheal attributed to unsafe water sources, no access to handwashing facilities and unsafe sanitation is linked to SDI, gender, and age. The populations of focus for diarrhea are children and the elderly; the regions of focus are countries with medium and low to middle SDI. Predictive studies provide country-specific recommendations for prevention and control.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

**CRediT authorship contribution statement:** Yan Liu:Writing–original draft,Writing–review & editing,Project administration,Conceptualization.Yajie Wang:Investigation,Software,Methodology,Resources. WenjingHuang: Investigation, Resources, Software. Xinyu An: Validation, Visualization Writing – review & editing. Jie Hu: Visualization, Writing – review &editing.Fei Yang: Funding acquisition, Supervision, Writing – review & editing,Project administration.

**Declaration of competing interest:** The authors declare that they have no known competing financial interestsor personal relationships that could have appeared to influence the work reported in this paper.

**Data availability:** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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