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■ RESEARCH ARTICLE

Variations in Predominant Risk Factors and Interventions for Diarrheal Diseases in Children Under Five Years of Age

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ABSTRACT: Diarrheal disease, the second highest cause of under-five deaths, is preventable through access to safe water, sanitation, and hygiene (WASH). Since the effectiveness of WASH interventions depends on local risk factors for diarrheal diseases, identifying these risks helps maximize the interventions' benefits. This study investigates the variations of diarrheal disease and the relationship between diarrheal-predominant risk factors and WASH interventions globally from 2000 to 2019. Disease outcomes and intervention data are from the Global Burden of Disease Study 2019 and the WHO/UNICEF Joint Monitoring Programme study, respectively. Changes in the percentage of mortality and Years Lived with Disability (YLD) and their risk factors were calculated to investigate their correlation and predominant risk factors. Globally, after 20 years, under-five diarrheal deaths decreased consistently by 60% from 1,238,822.57 to 500,663.83 deaths, while YLD decreased slowly at an inconsistent rate (3.5% from 1,836,681.85 to 1,771,591.63 YLD). Analysis of WASH intervention data shows that, on average, increasing basic drinking water coverage by 11.2% reduces 142 deaths and 39 YLD per 100,000 under-five children. In addition, a 14.4% increase in basic sanitation coverage reduces 139 fatalities and 38 YLD per 100,000 under-five children. In comparison, a 13% increase in basic hygiene coverage lessens 333 deaths and 90 YLD per 100,000 under-five children. Since interventions are less effective in lowering diarrheal YLD than mortality, more attention should be spent on identifying interventions effective at reducing diarrheal non-fatal health outcomes.

KEYWORDS: Biomedical and Health Sciences; Pathophysiology; Diarrheal Diseases; Mortality; Years Lived with Disability (YLD); Risk Factors; Water, Sanitation, and Hygiene (WASH).

■ Introduction

According to the World Health Organisation, diarrheal diseases are the second leading cause of death among children under five years of age (hereafter referred to as 'under-five'), killing approximately 500,000 children yearly.[1] Though diarrheal diseases are present globally across all countries and regions, the burden is disproportionately placed on areas with poor access to healthcare facilities, clean water, and sanitation.[2] About 90% of under-five diarrheal deaths occurred in Sub-Saharan Africa and South Asia, and 42% came from only two countries, India and Nigeria.[2] Hence, identifying the regions with the highest prevalence of diarrheal diseases allows focused interventions to reduce the disease burden effectively.

Since 1980, diarrhea mortality amongst under-five children has decreased thanks to numerous programs on interventions to prevent or treat acute diarrhea.[3] Diarrhea mortality per 100,000 under-five children globally decreased by 69.6% between 1990 and 2017, with the most significant absolute decline shown in Nigeria (1344.2 fewer deaths per 100,000 children from 1731.2 deaths per 100,000 children in 1990 to 387.8 deaths per 100,000 children in 2017).[4]

Generally, water, sanitation, and hygiene (WASH) interventions can improve water supply and quality, sanitation, and hygiene.[5] Improvements to water distribution at both public and household levels, such as establishing a hand pump or a household connection, were considered water supply interventions.[5] Water quality interventions focused on providing water treatment, such as chlorine tablets or solutions, on removing bacterial pathogens at the source or household level.[5,6] Interventions in sanitation include excreta disposal at either public or household levels.[5] Finally, hygiene improvements combine both education (promotion of handwashing) and facilities-based (provision of soap, access to handwashing facilities).[7] Therapeutic treatments such as oral rehydration therapy (ORT), zinc, and nutrition supplementation have improved infection recovery and effectively reduced mortality rates.[8]

However, prevention and protection interventions are less effective than treatment interventions, given that diarrhea incidence globally decreased by a modest 9.09% from 1990 to 2019 compared to a significant reduction in diarrhea deaths over the same period.[18] Survivors face both long-term and acute health burdens, including poor physical growth, pneumonia, and other health effects.[9,10] Diarrhea is a significant cause of malnutrition, and malnourished children are vulnerable to diarrheal diseases due to weaker immunity than normal children.[1] Therefore, the diarrheal burden should be addressed in terms of both mortality and morbidity.

The effectiveness of interventions for diarrhea varies considerably with different risk factors.[4] Environmental risks such as unsafe water sources and poor hygiene practices have been identified as the primary cause of diarrheal diseases.[11] In 2016, an estimated 829,000 deaths and 49.8 million years lived with disability (YLD) were caused by inadequate drinking water, sanitation, and hand hygiene, among which 297,000 under-five

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deaths occurred.[12] Accordingly, improving WASH interventions is crucial to reducing disease risk and burden.[5] Besides environmental risk factors, child and maternal malnutrition, including suboptimal breastfeeding, child growth failure, and vitamin A deficiency, are also risk factors for diarrhea.[13,14] Inadequate nutrition increases the susceptibility and severity of infectious diseases, including diarrhea.[15] Dietary management for diarrhea, such as promoting breastfeeding or micronutrient supplementation, is essential to control diarrheal diseases and their associated nutritional complications.[16] On the other hand, since WASH interventions are considered the primary approach to treating diarrheal diseases, it is important to understand any correlation between improvements in WASH and changes in exposure to both environmental and nutritional risk factors.

Motivated by the above context, this study aims to provide an up-to-date analysis of changes in diarrhea mortality and YLD from the latest Global Burden of Disease Study (GBD 2019).[18] Furthermore, by identifying the predominant risk factors of diarrheal diseases across all countries and territories and investigating any possible correlation between changing predominant risk factors to significant WASH interventions, this study helps to guide further research and interventions to target communities with different diarrheal risk factors better.

Methods

Data sources:

Data about mortality, YLD, and risk factors were obtained from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019 (GBD 2019) from the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. The study estimates prevalence, incidence, mortality, years of life lost (YLLs), years lived with disability (YLD), and disability-adjusted life-years (DALYs) due to 369 diseases and injuries for two sexes and for 204 countries and territories between 1990 and 2019. Data input sources include censuses, household surveys, civil registration and vital statistics, disease registries, health service use, air pollution monitors, satellite imaging, and disease notifications. Methods used to develop these data are described elsewhere.[17] In compliance with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) statement, data and code for the GBD 2019 are publicly available.[18]

This study also used data from the WHO/UNICEF Joint Monitoring Programme (JMP) to evaluate the changes in intervention data. The WHO/UNICEF JMP global database established in 1990 estimates improvements in household drinking water, sanitation, and hygiene since 2000. Estimates are derived from over 5,000 national data sources for over 200 countries and territories, including censuses, administrative reports, and nationally representative household surveys. Population-weighted averages for rural and urban areas of each region are calculated and assigned to countries lacking national data for the reference year. Data from JMP are publicly available.[19]

Variables

Disease outcome:

WHO defines diarrhea as "the passage of three or more loose or liquid stools per day (or more frequent passage than is normal for the individual)." The GBD uses cause-specific death rates and causes fractions, developed using the Cause of Death Ensemble model and spatiotemporal Gaussian process regression models. YLD data were estimated by multiplying prevalence estimates by disability weights for mutually exclusive sequelae of diseases and injuries. Data obtained were limited to the estimates of deaths and YLD caused by diarrheal diseases by age group (<5 years), sex (both male and female), as well as all WASH and child and maternal malnutrition risk factors available from 2000 to 2019. Classification of regions in this study followed that of WHO, which consists of the African Region, Region of the Americas, South-East Asian Region, European Region, Eastern Mediterranean Region, and Western Pacific Region.

Risk factors:

This study focused on diarrhea-associated risk factors, primarily environmental and nutritional-related risks. GBD 2019 estimates nine diarrhea-associated environmental and nutritional risk factors (unsafe water source, unsafe sanitation, no access to handwashing facility, suboptimal breastfeeding, child growth failure, low birth weight and short gestation, iron deficiency, vitamin A deficiency, zinc deficiency). The modeling framework for the risk factors has been described in other studies.[20,21] Generally, a comparative risk assessment framework was used in GBD to estimate levels and trends in exposure, attributable deaths, and attributable disability-adjusted life-years (DALYs) for multiple risks from 1990 to 2019. Relative risk and exposure estimates were derived from randomized controlled trials, cohorts, pooled cohorts, household surveys, census data, satellite data, and other sources. Some risk factors, most notably unsafe water, and sanitation, provided little to no data on deaths as the primary study outcome. Hence, diarrheal morbidity was considered the risk of diarrheal mortality for these risks.

Interventions:

Based on the data obtained from the JMP, interventions were categorized into three types: improvement in drinking water, sanitation, and hygiene. Definitions and detailed descriptions of service levels are mentioned in several reports from WHO/UNICEF.[22-24] Primary outcomes of this paper are estimates of the percentage of the population having at least basic drinking water, sanitation, and hygiene. Improvements in interventions were considered the increase in basic WASH services coverage between 2000 and 2019. No improvement can be noticed without the exact values from countries with >99% of the population with at least basic services between 2000 and 2019. It is important to note that some countries and territories did not have WASH data recorded. Therefore, these countries and territories were not considered to assess the improvements in basic WASH services coverage.

Data analysis

Disease outcome:

In the interest of this study, the primary outcomes were the number of deaths and YLD of under-five children due to diarrheal diseases between 2000 and 2019. The difference in the number of fatalities and YLD in 2000 and 2019 gave the val-

value for change in mortality and YLD. The percentage change in these numbers from 2000 to 2019 was also calculated. Changes in the number of deaths were plotted against those of YLD to assess both fatal and non-fatal outcomes of diarrheal diseases. In map representation, darker colors illustrate a greater magnitude of the values, such as a higher number of deaths and YLD or a greater change in the number of deaths and YLD over time. Where appropriate, diarrhea mortality and YLD rates per 100 000 under-five children were used to improve the comparability of results across locations with different populations.

Predominant risk factors:

The predominant risk factor in a particular year was the risk factor with the highest population-attributable fraction. If the predominant risk factor in 2019 is similar to that in 2000, changes in the prevalence of the predominant risk factor were calculated by the difference in percentages of its population-attributable fractions between 2000 and 2019. If the predominant risk factor changed between 2000 and 2019, the changes in the population attributable fractions of both initial and final risk factors were calculated.

Correlation between changing predominant risk factors to major WASH interventions:

Improvements in WASH intervention were considered in the increased national percentages of access to basic services from 2000 to 2019. These improvements were compared to the changes in the prevalence of risk factors through visual inspection of plots and calculation of correlation coefficients to deduce any possible relationships between WASH interventions and all diarrhea-associated risk factors, including both environmental and nutritional risks.

Results

Disease outcome:

In 2019, diarrheal diseases resulted in 500,663.8 deaths and 1,771,591.6 YLD among under-five children globally. This accounted for 9.92% and 6.5% of global under-five deaths and YLD in 2019, respectively. From 2000 to 2019, under-five diarrheal deaths decreased by 60% from 1,238,822.6 deaths, confirmed by a similar result documented by both UNICEF's Countdown to 2030 report and Jay S. *et al.* (2022).[25,26] However, under-five diarrheal YLD showed a smaller decrease (3.5% from 2,581,700.3 YLD). While the number of under-five diarrheal deaths continuously declined from 2000 to 2019, the number of YLD remained relatively constant, even though the overall trend was decreasing (Fig. 1).

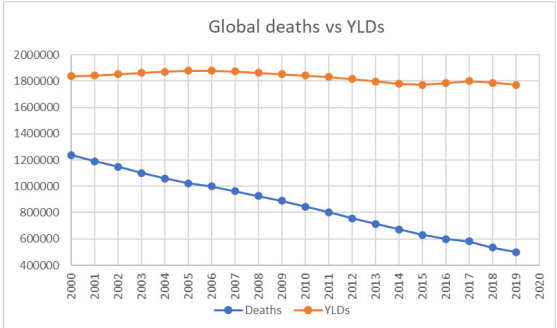
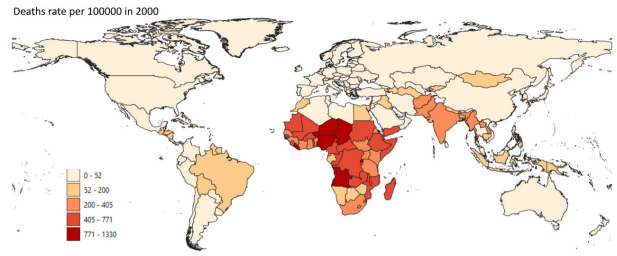


Figure 1: Number of under-five diarrheal deaths and YLD globally from 2000 to 2019.

There is substantial variation among countries in the global diarrheal mortality and YLD rate among children under five years of age (Fig. 2). In 2019: the global rate was 75.5 deaths per 100,000 under-five children (Fig. 2C), a 61.9% decrease (Fig. 2B) from 198.3 deaths per 100,000 under-five children in 2000 (Fig 2A). Finland had the lowest mortality rate (0.14 deaths per 100,000 under-five children), while Chad had the highest mortality rate (751.9 deaths per 100,000 under-five children). When comparing the 20-year change in mortality rate among countries, the most significant decline occurred in Liberia, which observed 884.3 fewer deaths per 100,000 under-five children (from 1099.2 deaths to 214.9 deaths per 100,000 under-five children).

Considering YLD, from 2000 to 2019 observed, a global decline in diarrheal YLD rate among 100,000 children under five years of age was 9.1% (Fig 2F), a shift from 294.0 YLD (Fig. 2D) to 267.3 YLD per 100,000 under-five children (Fig 2E). On the country scale, in 2019, Japan had the lowest YLD rate (7.2 YLD per 100,000 under-five children), while Sudan had the highest YLD rate (627.8 YLD per 100,000 under-five children). Equatorial Guinea saw the most significant decline in YLD with a rate of -231.8 YLD, shifting from 537.6 YLD in 2000 to 305.8 YLD per 100,000 under-five children in 2019.



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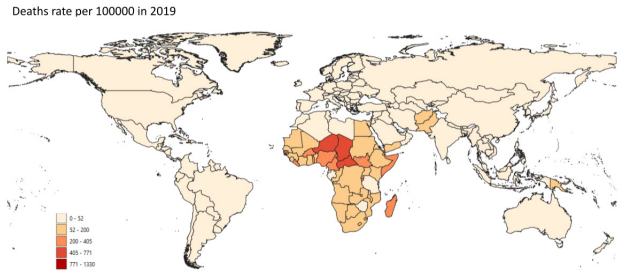

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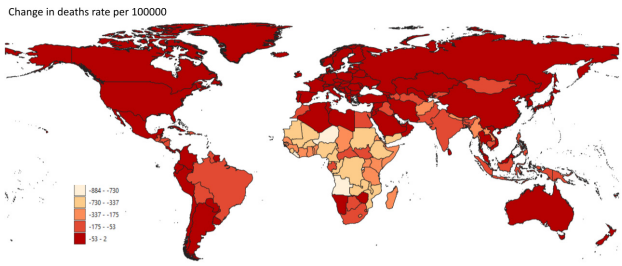

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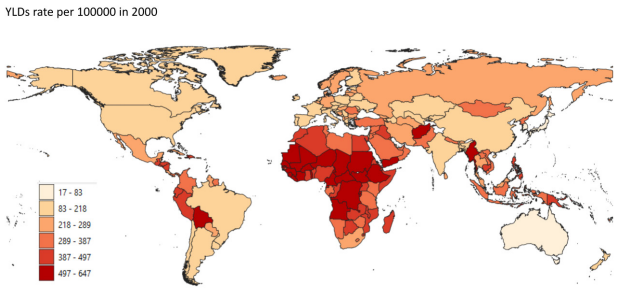

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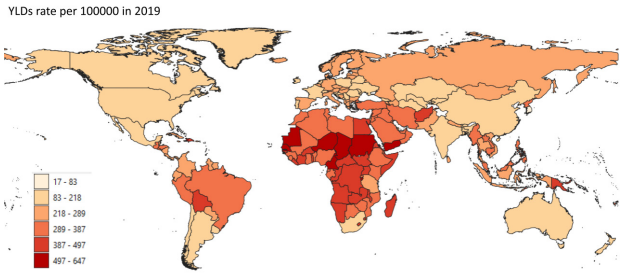

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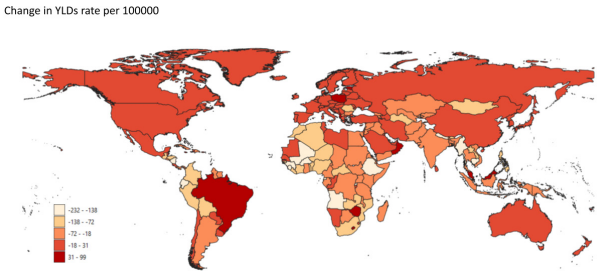
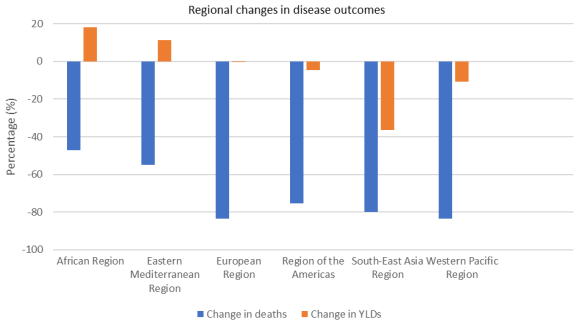
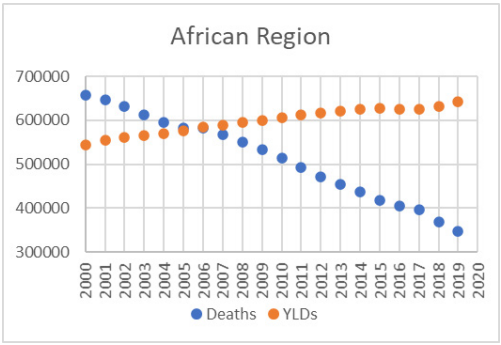


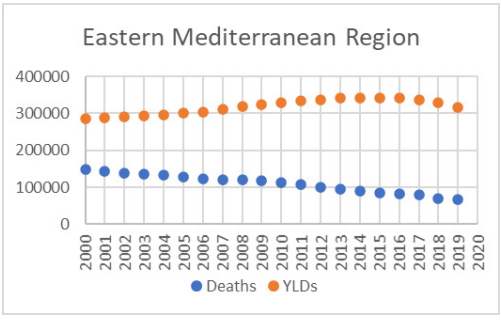
F.

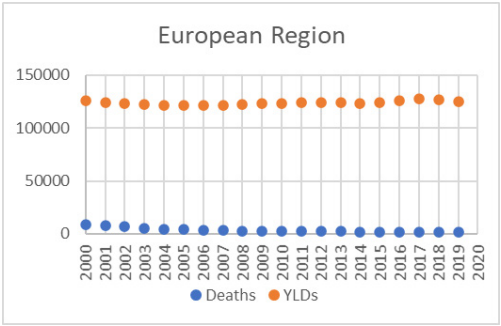
Figure 2: Maps of mortality and YLD rate between 2000-2019.

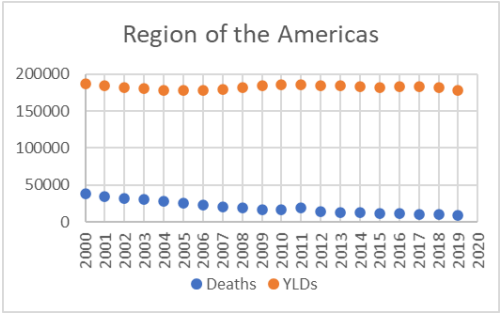
Between 2000 and 2019, the most significant regional decrease in diarrheal deaths of 83% occurred in both the European Region (from 9045.9 deaths to 1487.9 deaths) and Western Pacific Region (from 41045.6 deaths to 6791.0 deaths). Regional and temporal trends in fatalities and YLD are shown in Figure 3. Despite the highest percentage decrease in deaths, the European Region had less than a 1% change in YLD (0.56% from 125935.4 YLD to 125229.0 YLD). The South-East Asia Region observed the third most significant decline in the number of deaths (80% from 344158.2 deaths to 68863.9 deaths) and the highest percentage decrease in the YLD (36.5% from 435744.9 YLD to 276691.8 YLD). By contrast, the African Region had the most minor percentage decrease in the number of deaths (47.2% from 656626.8 deaths to 346770.7 deaths) and the highest increase in the number of YLD (18.1% from 544668.6 YLD to 643107.2 YLD). The African and Eastern Mediterranean regions were the only two regions with an increasing number of YLDs from 2000 to 2019. It is also important to note that percentage change may not be representative of absolute difference. For example, despite having the highest percentage decrease in diarrheal mortality, the European Region observed a smaller reduction in the number of deaths than the African Region (7558.0 deaths compared to 309856.1 deaths).











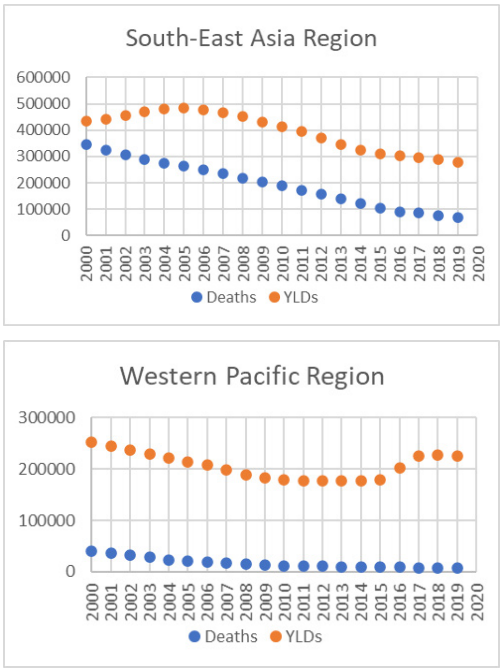


Figure 3: Regional changes in under-five diarrheal deaths and YLD from 2000 to 2019.

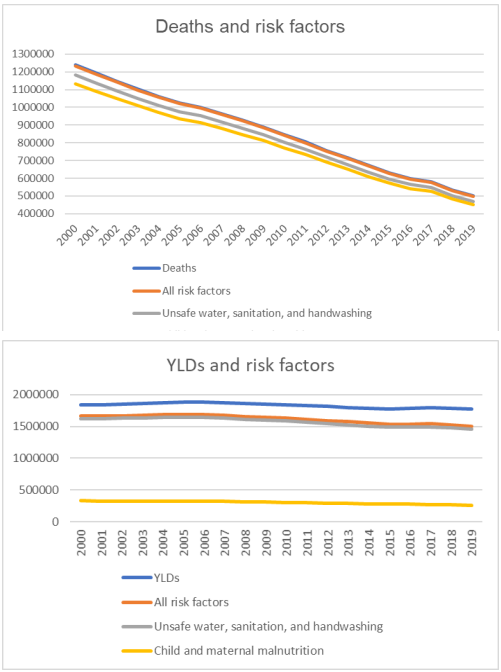


Figure 4: Changes in disease outcomes by categories of risk factors.

Risk factors:

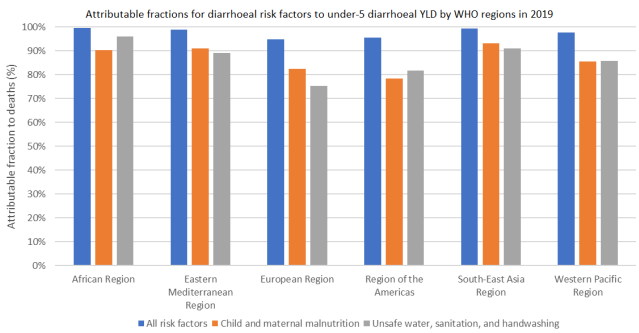
Since a single diarrheal case can be attributed to multiple risks, risk factors are calculated separately. Therefore, the sum of risk-factor attributable fractions is not equal to 100% in a given population.

Globally in 2019, unsafe water, sanitation, and handwashing (WASH) accounted for the most significant proportion of under-five diarrheal deaths at 94.0%, while risk factors related to child and maternal malnutrition, namely suboptimal breastfeeding, child growth failure, low birth weight, and short gestation, iron, vitamin A and zinc deficiencies are associated with 90.4% of deaths. Globally, between 2000 and 2019, a 60% decrease in deaths due to both WASH (from 1,181,128.9 deaths to 470,752.2 deaths) and child and maternal malnutrition risk factors (from 1,133,294.3 deaths to 452,453.5 deaths) resulted in a 59.5% decrease in under-five diarrheal deaths (from 1,238,822.6 to 500,663.8) (Fig. 4).

When considering YLD associated with diarrheal diseases, unsafe WASH was attributed to 82.2% of under-five diarrheal YLD worldwide in 2019. By contrast, poor child and maternal nutrition accounted for only 14.7% of diarrheal YLD. From 2000 to 2019, when YLD due to unsafe WASH decreased by 10.1% (from 1619413.5 YLD to 1455623.5 YLD), and child and maternal malnutrition decreased by 21.0% (from 327539.9 YLD to 258890.5 YLD), change in the global number of under-five diarrheal YLD only dropped by 3.5% (from 1836681.9 YLD to 1771591.6 YLD).

When considering regional trends in 2019, child and maternal malnutrition was the predominant risk factor in the Eastern Mediterranean Region, European Region, and South-East Asia Region, which accounted for 90.9%, 82.3%, and 93.1% of under-five diarrheal deaths, respectively (Fig. 5). Comparatively, unsafe WASH was the predominant risk factor in the African Region, Region of the Americas, and Western Pacific Region, associated with 96.1%, 81.7%, and 85.7% of under-five diarrheal deaths, respectively (Fig. 5). This marked an improvement from 2000 when unsafe WASH was the predominant risk factor for all regions.

Unsafe WASH was the leading risk factor for under-five diarrheal YLD, accounting for more than 75% of YLD in all regions except the European region. In the European Region, unsafe WASH was responsible for only 41% of diarrheal YLD. Unlike WASH risk factors, nutrition-related risk factors were not a significant risk of diarrheal YLD. Child and maternal malnutrition caused less than one-fifth of diarrheal YLD in all regions, with the highest fraction occurring in the European Region (18.9%).



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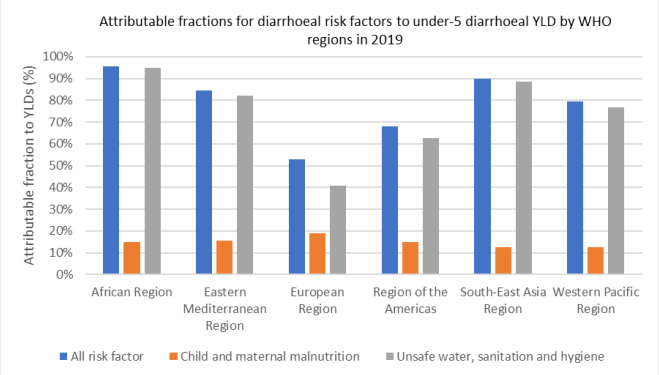

Figure 5: Attributable fractions for diarrheal risk factors to under-five diarrheal deaths (above) and YLD (below) by WHO regions in 2019

Additional nuance is observed when comparing predominant risk factors among countries. In 2000, there were only two predominant risk factors for under-five diarrheal deaths, unsafe water sources, and child growth failure across all countries and territories. Unsafe water sources contributed to the highest percentage of deaths in more countries and territories (108 countries and territories) than child growth failure (96 countries and territories). Comparatively, in 2019, there were three countries and territories with different predominant risk factors from unsafe water sources and child growth failure: Kyrgyzstan (unsafe sanitation), Bosnia and Herzegovina (suboptimal breastfeeding), and Switzerland (low birth weight and short gestation). Furthermore, child growth failure was the predominant risk factor in most countries (113 countries and territories compared to unsafe water sources in 88 countries and territories), over unsafe water sources which dominated in 2000. As a result, 26 countries and territories observed a change in their predominant risk factors for diarrheal deaths between 2000 and 2019. Twenty-two had the predominant risk factor changed from unsafe drinking water to child growth failure.

There were three predominant risk factors for under-five diarrheal YLD in 2000 and 2019: unsafe water source, suboptimal breastfeeding, and unsafe sanitation. There was no change in the status of these risk factors from 2000 to 2019, with unsafe water sources as the predominant factor (174 countries and territories in 2000 and 170 countries and territories in 2019), followed by suboptimal breastfeeding (28 countries and territories in 2000 and 31 countries and territories in 2019) and unsafe sanitation (2 countries and territories in 2000 and 3 countries and territories in 2019) (Fig. 6). However, nine countries' and territories' predominant risk factors for diarrheal YLD changed between 2000 and 2019. In four countries, the predominant risk factor changed from unsafe water and sanitation to suboptimal breastfeeding.

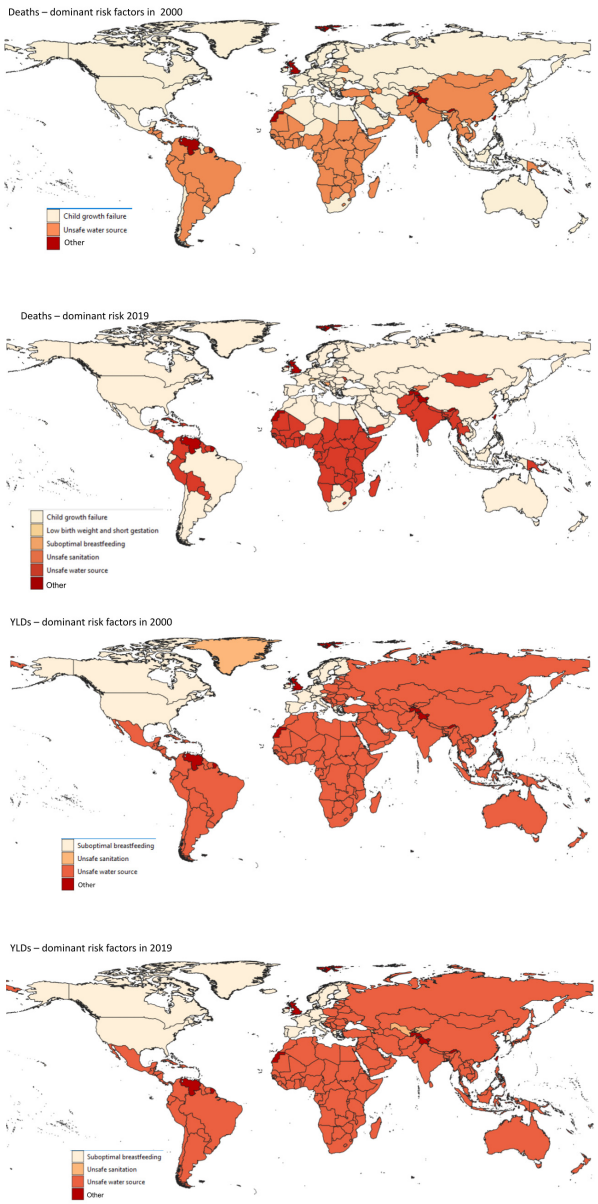

Figure 6: Map of predominant risk factors for under-five diarrheal deaths and YLD between 2000-2019.

Improvements in major WASH interventions:

Globally, between 2000 and 2019, the population with access to at least basic drinking water increased by 8.7% from 80.5% to 89.2%. In addition, the population with access to at least basic sanitation and hygiene increased by 22%, from 55% to 77%, and 11%, from 37% to 48%, respectively.

Generally, countries with high coverage of at least basic drinking water, sanitation, and hygiene had relatively lower mortality rates. Conversely, as the percentage of the population with at least basic drinking water decreased, the mortality rate increased (Fig. 7). However, there were considerable variations among countries. For example, Egypt had higher coverage of at least basic drinking water, more than 99% but a mortality rate of 71.4 deaths per 100,000 under-five children, higher than other countries with similar basic drinking water coverage. In comparison, in the United Republic of Tanzania, where

only 60% of the population had at least basic drinking water, a lower mortality rate of 35.5 deaths per 100,000 under-five children was reported. Similar trends were observed for sanitation and hygiene interventions.

In contrast, there was little or no clear relationship between the population percentage with improved WASH interventions and the diarrheal YLD rate (Fig. 8). Overall, there was an upward trend in the YLD rate as the WASH coverage went down. However, there were considerably more country-to-country variations compared to the mortality rate.

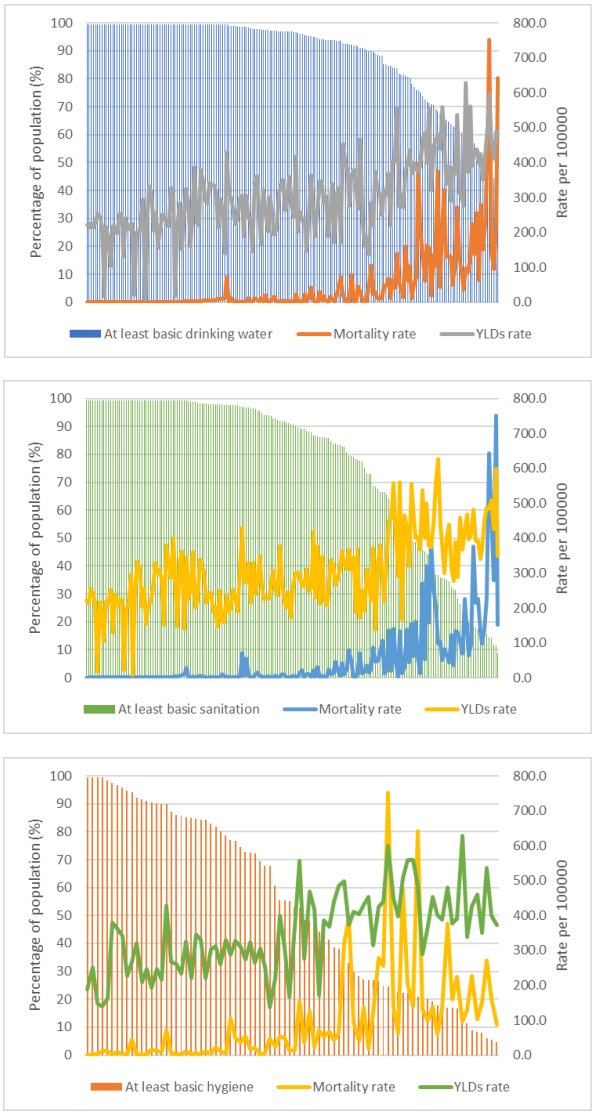

Figure 7: Graph of under-five diarrheal mortality and YLD rates (right y-axis) against the population percentage of countries (left y-axis) with at least basic drinking water (Fig. 7A), sanitation (Fig. 7B) and hygiene (Fig. 7C) across all countries and territories in 2019.

From 2000 to 2019, there were 127, 130, and nine countries and territories with improved drinking water, sanitation, and hygiene interventions, respectively. On average, an 11.2% increase in at least basic drinking water coverage reduces 142 deaths and 39 YLD per 100,000 under-five children. Likewise, at least basic sanitation coverage increased by 14.4% and was associated with 139 fewer deaths and 38 fewer YLD per 100,000 under-five children. Over the same period, access to at least basic hygiene increased by 13% and was associated with 333 fewer deaths and 90 fewer YLD per 100,000 under-five children.

Interestingly, despite the improvements in WASH interventions in many countries and territories, there were limited changes in the predominant risk factors for diarrheal deaths and YLD (Fig. 8). For example, out of 127 and 130 countries and territories with improved drinking water and sanitation, respectively, only 21 of those (17%) had different predominant risk factors for diarrheal deaths. Four countries and territories (3%) showed changes in predominant risk factors for diarrheal YLD between 2000 and 2019. Comparatively, out of nine countries and territories with improved hygiene, no country and territory have different predominant risk factors for diarrheal deaths. Still, one country (Armenia) has its predominant risk factor for diarrheal YLD changed from 2000 to 2019.

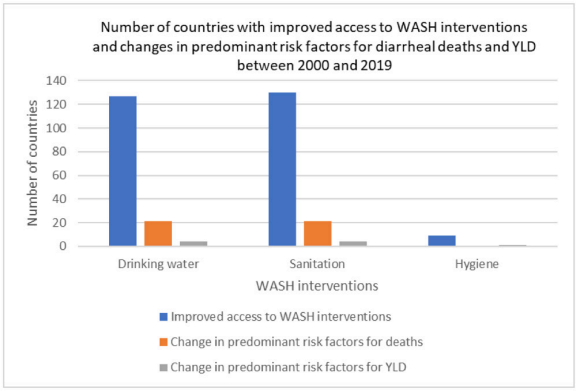

Figure 8: Graph of the number of countries with improved access to WASH interventions and changes in predominant risk factors for diarrheal deaths and YLD between 2000 and 2019.

Discussion

Improved access to safe water, sanitation, and hygiene (WASH) has the potential to prevent diarrheal disease, the second highest cause of under-five deaths globally. This study provides an up-to-date analysis of geographical and temporal variations in diarrheal diseases and their associated risk factors globally from 2000 to 2019 from the latest Global Burden of Disease Study (GBD 2019).[18] Intervention efforts have resulted in a greater decrease in under-five deaths from diarrheal diseases than the decrease in YLD. Regionally, the greatest diarrheal death reduction occurred in the European and Western Pacific regions, while YLD happened in the South-East Asia regions.

Predominant risk factors for diarrheal deaths and YLD are also estimated. When considering the regional trends, unsafe WASH was the predominant risk factor in the African Region, Region of the Americas, and Western Pacific Region in 2019, an improvement from 2000 when WASH risk factors were the predominant risk factor for all regions. This trend can also be spotted in national trends when WASH risk factors like unsafe water sources, which dominated in 2000, were no longer the predominant risk factor in most countries in 2019. Conversely, unsafe WASH was the leading risk factor for under-five diarrheal YLD, accounting for more than 75% of

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deaths in all regions except the European region. Unlike diarrheal deaths, the unsafe water source was the predominant contributor to YLD in most countries between 2000 and 2019.

As a result, additional efforts are needed to determine the interventions effective at reducing exposure to diarrheal disease pathogens, thereby reducing disease incidence.

Relationship between improvements in WASH interventions and changes in diarrheal deaths:

Globally, between 2000 and 2019, the number of under-five diarrheal deaths decreased continuously over the span of 20 years and dramatically by nearly 60%, which is a testament to serious global efforts to improve access to at least basic drinking water, sanitation, and hygiene, which increased by 8.7%, 22%, and 11%, respectively. However, the number of YLD declined at a slower rate than mortality (3.5% from 1,836,681.9 YLD to 1,771,591.6 YLD), and also the decline was not consistent throughout 20 years. Hence, to better address the impacts of diarrheal diseases, it is important to understand why the declines are unequal and what can be done to lower YLD.

Since the results show that unsafe WASH is associated with 94.0% of deaths, it is reasonable to suggest that improving access to WASH interventions is crucial to lowering diarrheal mortality. Indeed, results indicate a similar trend between the reduction in under-five diarrheal deaths and the attributable fraction of WASH risks to diarrheal mortality. With improved drinking water, even though there were only 21 countries seeing changes in predominant risk factors for under-five diarrheal deaths, 19 out of 21 countries had the predominant risk factor changed from unsafe water source to other risk factors. This is promising and indicates that drinking water treatment can significantly reduce the number of diarrheal deaths. Improving sanitation resulted in a similar reduction in diarrheal deaths due to unsafe water sources. Since sanitation systems reduce contamination of the environment with human waste, sanitation improvements minimize the transmission of pathogens that cause diarrhea into drinking water sources.[27] Furthermore, research from the American Journal of Epidemiology has reported that in locations with abysmal sanitation, improving drinking water quality would have little impact, while in places with better community sanitation, improved water treatment would result in a 40% reduction in diarrhea.[28]

Relationship between improvements in WASH interventions and changes in diarrheal YLD:

Some studies have suggested that mortality data can lead to misrepresentation or even underestimation of the total disease burden without considering the long-term health outcomes of diarrheal diseases, YLD.[29,30] These studies highlighted mortality and disability due to diarrheal disease.

Beyond acute infection, diarrheal diseases can have long-term impacts, including linear growth faltering, decreased cognitive function, and increased risk of subsequent infectious disease mortality.[31,32] To address the diarrheal burden, commonly used interventions such as the rotavirus vaccine seem to treat moderate-to-severe diarrheal cases better than non-severe ones.[33] Results of this paper show that WASH-related risk factors are highly associated with diarrheal YLD in all regions. Yet surprisingly, improvements in WASH interventions do not result in a proportional decrease in the YLD rate. This lack of correlation has been similarly reported in an analysis of the Global Enteric Multicenter Study (GEMS) reporting that there are difficulties in evaluating the effectiveness of WASH interventions in treating non-acute diarrheal cases as survey respondents may overstate water treatment of insufficiently conducted WASH interventions.[34] Another possible explanation for this lack of relationship is the exposure to diarrheal transmission on multiple pathways.[41]Hence, no single WASH intervention is enough to eliminate persistent diarrhea completely. In fact, overreliance on one WASH intervention may cause neglect of other transmission pathways, increasing the risk of diarrhea.

As a result, it is necessary to understand and consider the broad range of WASH interventions, from improvements in infrastructures, such as water storage systems, to changes in human behaviors, such as handwashing with soap. It has been found that safe water storage systems, household water treatment, and interventions to enhance water quality at the source can lower diarrhea incidence by as much as 47%.[35] In some studies, an estimated median reduction in diarrhea incidence of 36% has been linked to improved sanitation facilities.[36] Several studies also pointed out that handwashing with soap can diminish the risk of diarrhea by more than 40%.[37,38] Hence, to effectively reduce the diarrheal incidence and thus health outcomes like mortality or YLD, there should be a combination of different subcategories of WASH interventions. Beyond WASH interventions, several studies have documented that dietary management, especially with the addition of zinc supplementation, can significantly reduce the diarrheal incidence and thus reduce diarrheal YLD.[39,40]

Even though WASH risk factors were highly associated with under-five diarrheal YLD, a decrease in YLD due to unsafe WASH did not translate to the same level of decline in the overall YLD due to diarrheal disease. Because multiple risk factors can be attributed to one single diarrheal case, there is an urgent need to improve the current understanding of the factors driving the YLD rate and the effectiveness of interventions in addressing diarrheal YLD. The present analysis was limited by available data and depended on data obtained from two studies. Despite the best efforts to include matching data between the two sources, only some countries and territories were included in both datasets. Omitted countries include Cote d'Ivoire and Taiwan (China), potentially contributing to errors in global trends.

YLD is a relatively new area of study in diarrheal disease research compared to mortality. As a result, risk factors and other drivers of YLD rates have yet to be fully identified. Future work should include further investigation into the total burden of diarrheal diseases and practical solutions to address these non-fatal health outcomes. Moreover, since under-five diarrheal mortality and YLD rates vary from country to country, further evaluation of specific national trends and disease burden associated with subnational variation is needed, such as differences in facilities, different exposure to risk factors, or other ways to target intervention resources better. Finally, to make these studies comparable, authorities and organizations

should provide guidelines on uniform research methods to improve understanding of the results at different spatial scales.

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