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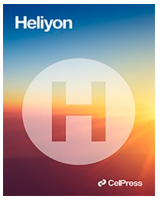

Research article

Effect of the lack of access to handwashing facilities on the global burden of lower respiratory infections, 1990–2019: A systematic analysis from the global burden of disease study 2019

Zhenyu Mao [a], Xiaoyan Zhu [a], Yuchen Huang [a], Pengdou Zheng [a], Lingling Wang [a], Fengqin Zhang [a], Huiguo Liu [a], Hai Li [b,c], Ling Zhou [a,*], Wei Liu [b,c,**]

[a] *Department of Respiratory and Critical Care Medicine, National Health Committee (NHC) Key Laboratory of Respiratory Disease, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China*
[b] *Department of Geriatrics, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, 430030, China*
[c] *Key Laboratory of Vascular Aging, Ministry of Education, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, 1095 Jiefang Avenue, Wuhan, 430030, China*

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ABSTRACT

A lack of access to handwashing facilities is a significant risk factor for lower respiratory infections(LRIs). However, no studies have reported epidemiologic changes in the burden of LRIs attributed to the lack of access to handwashing facilities. We conducted an integrated assessment of the burden of LRIs attributable to the lack of handwashing facilities from 1990 to 2019 using data from the Global Burden of Disease Study 2019. In 2019, 270,000 deaths were attributed to LRIs due to a lack of access to handwashing facilities, with DALYs reaching 14.02 million. The age-standardized mortality rate (ASMR) of LRIs caused by a lack of access to handwashing facilities was approximately 3.74, while the age-standardized DALY rate (ASDR) was reported to be 203.55 in 2019. Over the past 30 years, the burden of LRIs attributed to the lack of access to handwashing facilities has shown a global decline. In 2019, this burden was most pronounced in infants under 1 year of age and in those older than 95 years, reflecting the highest DALY (5591.83) and mortality rates (79.43), respectively. The burden of LRIs caused by the lack of access to handwashing facilities was found to be more severe in males and significantly more pronounced in regions with a low sociodemographic index (SDI), such as the Sahara African region. The development of targeted strategies to address the inadequate and unequal distribution of handwashing facilities holds important value in improving the disease burden of LRIs.

Abbreviations: GBD, Global Burden and Disease Study; LRIs, lower respiratory infections; EAPC, estimated annual percentage change; DALYs, disability-adjusted life years; YLL, Years of Life Lost; YLD, Years Lived with Disability; ASDR, age-standardized DALYs (disability-adjusted life years) rate; ASMR, age-standardized mortality rate; SDI, sociodemographic index; DW, disability weight; CODEm, Cause of Death Ensemble model; UI, uncertainty interval; IPC, Infection Prevention and Control; IHME, Institute for Health Metrics and Evaluation; ICD, International Classification of Diseases.

* Corresponding author. Department of Respiratory and Critical Care Medicine, National Health Committee (NHC) Key Laboratory of Respiratory Disease, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China.

** Corresponding author. Department of Geriatrics, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, 1095 Jiefang Avenue, Wuhan, China.

E-mail addresses: 471699217@tjh.tjmu.edu.cn (L. Zhou), 404793938@tjh.tjmu.edu.cn (W. Liu).

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1. Introduction

In 2019, lower respiratory infections (LRIs) were identified as the fourth most common cause of death worldwide, making them the most fatal infectious disease according to the World Health Organization. Furthermore, a recent Global Burden of Disease (GBD) study revealed that there were approximately 488.9 million incident cases of lower respiratory infections in 2019, with the death toll still reaching a staggering 2.4 million [1]. LRIs, a common type of respiratory disease, are caused by a variety of common microorganisms, such as *Streptococcus pneumoniae*, *Haemophilus influenzae*, influenza viruses, respiratory syncytial virus and various other prevalent pathogens [2]. The incidence of LRIs is negatively correlated with the level of economic development, as indicated by several studies. Regions with higher SDI values tend to exhibit lower rates of both incidence and mortality from LRIs. Conversely, in certain low-income countries, such as the sub-Saharan African region, LRIs impose the heaviest burden[1,3,4].

As the primary body part to interact with the environment, hands often harbor a multitude of microorganisms [5]. The lack of effective handwashing can further lead to the cross-contamination of microorganisms, including pathogens, resulting in the occurrence and progression of infectious diseases, including LRIs [6]. According to the World Health Organization's Infection Prevention and Control (IPC) report, maintaining good hand hygiene can effectively curb the occurrence and progression of infectious diseases [7]. Having adequate handwashing facilities is a prerequisite for maintaining hand hygiene. According to a recent GBD study conducted in 2019, a lack of handwashing facilities globally was the third-largest risk factor contributing to LRIs, accounting for 14.4 % of the burden [1]. On a global scale, with advancements in economic and social progress, the situation of inadequate handwashing has improved. However, more than 2 billion people worldwide still lack access to effective handwashing facilities [8]. This is especially true in low-income countries, such as those in the sub-Saharan African region, where the percentage of the population unable to access handwashing facilities exceeds 50 % [9]. No access to handwashing facilities is identified as the third major risk factor contributing to the burden of LRIs. Currently, there are no reported studies attributing the burden of LRIs to no access to handwashing facilities. To have an overview of the mortality and DALY rates of LRIs caused by no access to handwashing facilities and investigate the effects of socioeconomic and demographic factors on the disease burden, an analysis of the mortality and DALY rates from LRIs attributable to no access to handwashing facilities by region, age, sex, and sociodemographic index (SDI) was provided in the study.

2. Methods

2.1. Data sources and definitions

Information for this article was downloaded from the 2019 Global Burden of Disease (GBD) study, available at http://ghdx.healthdata.org/gbd-2019. The Institute for Health Metrics and Evaluation (IHME) at the University of Washington manages the GBD database, which is regularly updated, with GBD 2019 as the latest release. We obtained data on the burden of LRIs attributable to the lack of access to handwashing facilities from 1990 to 2019 using the GBD Results Tool. These data include DALY numbers, death numbers, age-standardized death rates (ASDRs) and age-standardized mortality rates (ASMRs) of LRIs for different regions, nations, sexes, age categories and SDI levels.

In clinical practice, LRIs mainly refer to pneumonia or bronchiolitis. According to the International Classification of Diseases (ICD-10), this category includes diseases encoded by A48.1, A70, B97.4-B97.6, J09-J15.8, J16-J16.9, J20-J21.9, J91.0, P23.0-P23.4 and U04-U04.9 [2]. Handwashing facilities are defined by the WHO as tools created to hold, move or control water flow for handwashing [9]. The lack of handwashing facilities primarily refers to the scarcity of cleansing agents or water resources [10].

ASMR and ASDR refer to age-standardized mortality rates and age-standardized DALY rates, respectively, which are calculated based on the standard age distribution of the population. They are used to compare the burden of disease levels between countries and regions with different age structures, as reflected by mortality rates and DALY rates. DALY is calculated by adding Years of Life Lost (YLL) from early death and Years Lived with Disability (YLD), showing the total effect of a disease on a population's health. YLL is determined by multiplying the total deaths by the average life expectancy at the time of death, whereas YLD is determined by multiplying the total cases by the disability weight(DW) [11]. The SDI is frequently utilized as a measure to evaluate the level of development in a country or region. Data such as the fertility rate of women under 25, average education level and per capita income are mainly used to classify countries/regions into five SDI levels [12].

2.2. Statistical analysis

The estimated values used were those available in the GBD dataset, and the authors did not conduct any data analysis. The death data of GBD comes from population censuses, household surveys, civil registration and vital statistics, disease registration, health service usage, air pollution monitors, satellite imaging, disease notifications, and other sources [11]. A comparative risk assessment was conducted to identify the potential risk factors for LRIs. The population attributable fraction (PAF) was calculated to quantify the contribution of no access to handwashing facility to the burden of LRIs. Finally, mortality or disability-adjusted life years (DALYs) of LRIs attributable to no access to handwashing facility were estimated by multiplying location-specific, year-specific, age-specific, and sex-specific PAFs with LRI mortality or DALYs[2,13]. To assess the mortality data attributable to the lack of access to handwashing facilities causing LRIs, the Cause of Death Ensemble model (CODEm) was utilized [14]. DisMod-MR 2.1 (a Bayesian meta-regression modeling framework) was used to estimate the incidence and prevalence of LRIs attributable to the lack of access to handwashing facilities [2]. Smoothing spline models are used to describe the relationships between different SDI levels and the ASDR and ASMR

[15]. By utilizing decomposition analysis, the effects of the lack of access to handwashing facilities on LRI-related DALYs can be disentangled into three driving factors: population aging, population growth, and epidemiological changes. This analytical approach enables the description of the impacts of these three factors on the changes in DALYs from 1990 to 2019 [16]. The estimated annual percentage change (EAPC) was used to estimate the annual variations from 1990 to 2019 attributed to the burden of LRIs due to the lack of access to handwashing facilities. The calculation method for the EAPC involves transforming the ASDR or ASMR into common

Table 1
Global and regional DALYs of lower respiratory infections attributable to the lack access to handwashing facility in 1990 and 2019, and EAPC of ASDR from 1990 to 2019.

location	DALY number in 1990	DALY number in 2019	ASDR in 2019 (per 100,000)	EAPC, 1990–2019
Global	33933220.79 (14733679.37to52981162.51)	14026391.99 (6245879.2to22068389.5)	203.55 (90.59to321.55)	−3.4 (−3.49 to −3.3)
Male	17938158.24 (7783569.47to28194194.49)	7313425.9 (3324596.51to11533082.08)	208.93 (95to329.66)	−3.47 (−3.6 to −3.34)
Female	15995062.55 (6769725.91to25362769.51)	6712966.09 (2994634.64to10493548.2)	199.22 (89.11to312.32)	−3.32 (−3.46 to −3.18)
High SDI	82678.8 (33113.19to135370.77)	71619.62 (27804.32to118798.81)	4.04 (1.57to6.74)	−3.04 (−3.57 to −2.51)
High-middle SDI	1356960.98 (573990.62to2173663.69)	234515.94 (96619.67to384096.22)	16.78 (6.9to27.06)	−7.12 (−7.39 to −6.85)
Middle SDI	6186869.06 (2622001.59to9834240.45)	1256088.58 (543028.73to2009966.28)	62.49 (27.12to99.93)	−5.48 (−5.62 to −5.33)
Low-middle SDI	12951281 (5568607.79to20197963.82)	4115693.46 (1824228.11to6355226.7)	257.38 (114.05to399.41)	−3.9 (−3.98 to −3.83)
Low SDI	13338340.35 (5870982.6to21111699.53)	8338804.65 (3764711.63to13073714.21)	629.51 (282.8to973.73)	−3.17 (−3.31 to −3.04)
Australasia	1122.45 (453.32to1854.96)	1156.49 (471to1933.51)	2.48 (1to4.14)	−2.88 (−3.24 to −2.51)
Central Asia	368463.21 (154934.42to600048.71)	71520.2 (28605.96to124316.29)	78.79 (31.48to136.63)	−6.1 (−6.41 to −5.78)
Eastern Europe	51629.5 (21220.05to84463.42)	34050.44 (13379.8to57676.05)	13.98 (5.44to23.77)	−3.06 (−3.97 to −2.15)
High-income Asia Pacific	24989.6 (9856.3to41037.36)	28326.9 (10845.42to47756.44)	5.76 (2.25to9.62)	−3.4 (−4.24 to −2.56)
East Asia	3910691.22 (1644167.23to6317024.07)	169695.88 (69204.96to278324.67)	14.06 (5.67to23.33)	−11.16 (−11.43 to −10.89)
Caribbean	178210.45 (80174.5to279223.43)	97672.61 (41802.13to154680.25)	229.39 (98.8to364.03)	−2.01 (−2.18 to −1.84)
Southern Latin America	28333.52 (11764.55to45259.3)	16882.55 (6654.97to28465.32)	21.55 (8.58to36.36)	−3.31 (−3.74 to −2.87)
Central Latin America	349584 (147579.08to559136.56)	100606.87 (40508.59to166546.3)	44.02 (17.78to73.17)	−4.87 (−5.11 to −4.62)
Western Europe	19386.29 (7599.75to32429.99)	18154.39 (7093.66to30660.22)	1.94 (0.76to3.27)	−2.71 (−3.2 to −2.22)
Tropical Latin America	493883.47 (216975.4to792957.43)	126545.45 (51459.05to206229.96)	60.11 (24.5to98.94)	−5.48 (−5.83 to −5.13)
Central Europe	28817.1 (11677.74to48191.23)	6283.21 (2500.17to10475.69)	4.35 (1.74to7.32)	−6.87 (−7.37 to −6.36)
Southeast Asia	2069838.3 (873484.18to3512834.93)	520522.85 (221472.95to850662.44)	94 (39.7to153.86)	−4.65 (−4.88 to −4.42)
Oceania	57476.69 (25018.97to93863.59)	63120.59 (27072.92to111763.21)	375.55 (161.77to656.93)	−1.6 (−1.76 to −1.44)
Andean Latin America	258040.88 (110527.19to412978.69)	61451.93 (25306.48to101828.58)	103.87 (42.92to172.55)	−5.52 (−5.66 to −5.39)
Southern Sub-Saharan Africa	456693.26 (211532.87to701590.03)	340219.94 (151045.05to534074.25)	479.4 (211.26to753.13)	−1.26 (−1.74 to −0.78)
Eastern Sub-Saharan Africa	5353771.15 (2422939.16to8356390.65)	2686205.18 (1224509.05to4212627.59)	655.95 (296.97to1012.26)	−3.53 (−3.77 to −3.3)
North Africa and Middle East	1614577.79 (659948.65to2871052.37)	453029.18 (193335.23to745853.95)	82.31 (35.01to134.95)	−4.83 (−4.91 to −4.76)
Central Sub-Saharan Africa	1439861.37 (663439.06to2279805.68)	764812.16 (348919.59to1234624.03)	669.71 (300.97to1052.54)	−3.19 (−3.42 to −2.96)
High-income North America	14293.23 (5564.31to23654.56)	13124.23 (5117.04to21951.4)	2.35 (0.92to3.91)	−2.47 (−2.84 to −2.1)
South Asia	11549374.04 (4887309.53to17948274.32)	3209421.72 (1401552.28to5057978.47)	207.21 (90.57to325.98)	−4.38 (−4.54 to −4.22)
Western Sub-Saharan Africa	5664183.28 (2567829.15to9101509.05)	5243589.21 (2377413.14to8280169.28)	920.27 (419.2to1426.51)	−2.35 (−2.54 to −2.16)

EAPC, estimated annual percentage change; DALYs, disability-adjusted life years; ASDR, age-standardized DALYs (disability-adjusted life years) rate.

logarithms for different years, taking the geometric mean of these values, and fitting a straight line using these geometric means as the dependent variable. Therefore, the formula is Y = Lg(ASMR or ASDR) + aX, where X represents the year. Subsequently, the EAPC is calculated as (10^a - 1) * 100 %. An EAPC >0 indicates a yearly increase in incidence or mortality rates, while an EAPC <0 signifies the opposite trend [17].

All data reported in this paper were calculated with their corresponding 95 % uncertainty intervals (UIs). Furthermore, the rates presented in this study represent levels per 100,000 people. The tools utilized for data analysis and graphical representation in this paper are based on R Version 4.2.1.

3. Results

3.1. Global level

In 1990, the number of deaths attributed to LRIs due to a lack of access to handwashing facilities reached as high as 460,000 (95 % uncertainty interval (UI), 199,400–718,000), accompanied by DALYs of 33.93 million (95 % UI, 14.73 million-52.98 million). There

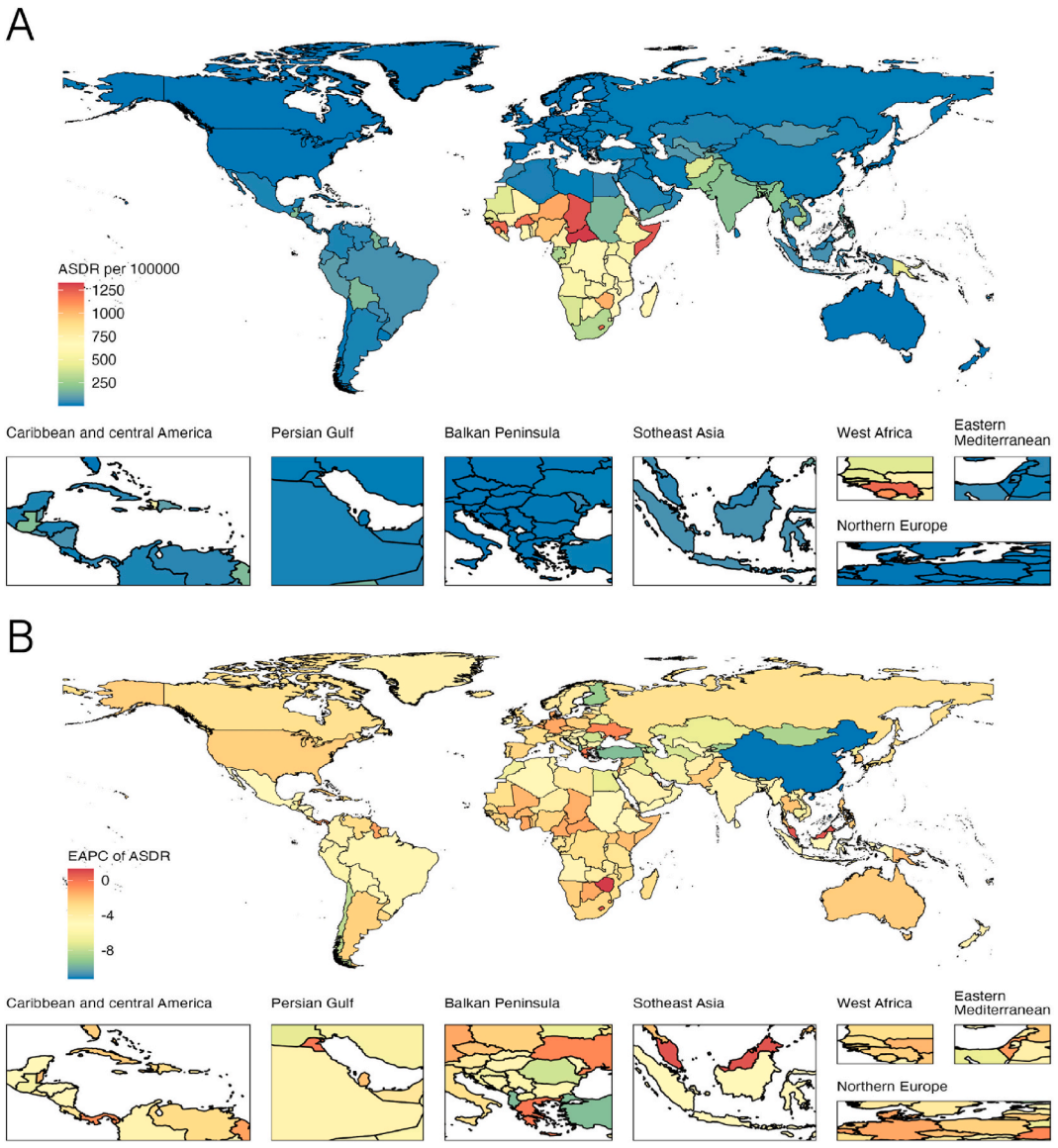

Fig. 1. The global distribution of the ASDR of LRIs attributable to the lack of access to handwashing facilities in 2019, and the EAPC of ASDR from 1990 to 2019. ASDR of LRIs attributable to the lack of access to handwashing facilities in 204 countries and territories in 2019 (A). EAPC of ASDR of LRIs attributable to the lack of access to handwashing facilities from 1990 to 2019 in 204 countries and territories (B); ASDR, age-standardized disability-adjusted life years (DALYs) rate; LRIs, lower respiratory infections; EAPC, estimated annual percentage change.

are significant improvements in the burden of LRIs caused by the lack of access to handwashing facilities over the past 30 years, the deaths of LRIs attributable to the lack of access to handwashing facilities still reached 270,000 in 2019 (95 % UI, 119,500–421,000), while DALYs remained high at 14.02 million (95 % UI, 6.25 million - 22.06 million). The ASMR per 100,000 people globally was approximately 3.74 (95 % UI, 1.66–5.83), while the ASDR was 203.55 (95 % uncertainty interval, 90.59–321.55) (Table 1, Table S1).

3.2. Regional and national levels

A global analysis of 21 different regions revealed that the western sub-Saharan Africa region bears the greatest burden of LRIs due to the lack of access to handwashing facilities, with an ASDR as high as 920.27 (95 % UI, 419.2–1426.51) in 2019, accompanied by an AMSR of 23.15 (95 % UI, 10.81–35.6). All regions globally experienced varying degrees of decline in the burden of LRIs attributable to the lack of access to handwashing facilities. Notably, the East Asia region exhibited a significant decrease in the burden of LRIs caused by the lack of handwashing facilities, with an EAPC in the ASDR from 1990 to 2019 reaching −11.16 (95 % UI, −11.43 to −10.89) and an EAPC in the AMSR of −8.4 (95 % UI, −8.74 to −8.05). Comparatively, the global EAPC of the ASDR was −3.4 (95 % UI, −3.49 to −3.3), and that for the AMSR was −2.82 (95 % UI, −2.92 to −2.72) (Table 1, Supplementary Table S1).

An analysis of 204 different countries and territories globally in 2019 revealed that the Central African Republic, Chad and Somalia exhibited the highest ASDRs attributed to LRIs due to the lack of handwashing facilities, with ASDRs per 100,000 people of 1325.67 (95 % UI, 578.34–2269.12), 1276.28 (95 % UI, 576.12–2051.24), and 1269.99 (95 % UI, 587.21–2100.43), respectively (Fig. 1A, Table S2). Conversely, Finland, Austria, and Italy had the lowest ASDRs per 100,000 people, with rates of 0.79 (95 % UI, 0.31–1.32), 0.88 (0.34–1.5), and 1 (0.39–1.69), respectively (Fig. 1A–Table S2). Similarly, the countries with the highest ASMRs attributed to LRIs due to the lack of handwashing facilities were Central African Republic countries, with an ASMR per 100,000 people of 34.82 (95 % UI, 15.93–57.29), while Finland had the lowest ASMR per 100,000 people at 0.05 (95 % UI, 0.02–0.08) (Fig. S1A, Table S3). From 1990 to 2019, there was an overall decreasing trend in the burden of LRIs caused by the lack of handwashing facilities, reflected in declines in the ASDR and ASMR. From 1990 to 2019, China experienced the most significant decrease in the ASDR, with an estimated annual percentage change (EAPC) of −11.27 (95 % UI, −11.58 to −10.95) (Fig. 1B–Table 1). On the other hand, Finland showed the most substantial decline in the ASMR, with an EAPC of −9.41 (95 % UI, −10.45 to −8.36) from 1990 to 2019 (Table S3, Fig. S1B). However, there were exceptional cases where countries such as Brunei Darussalam, Lesotho, Malaysia, Seychelles and Zimbabwe saw increases in ASDR attributed to LRIs from the lack of handwashing facilities. Furthermore, an increase in the ASMR attributed to LRIs due to the lack of handwashing facilities was observed in Barbados, Brunei Darussalam, Greece, Kuwait, Lesotho, Malaysia, Monaco, Seychelles, Thailand and Zimbabwe (Table S3, Table S4, Figs. S1A and B).

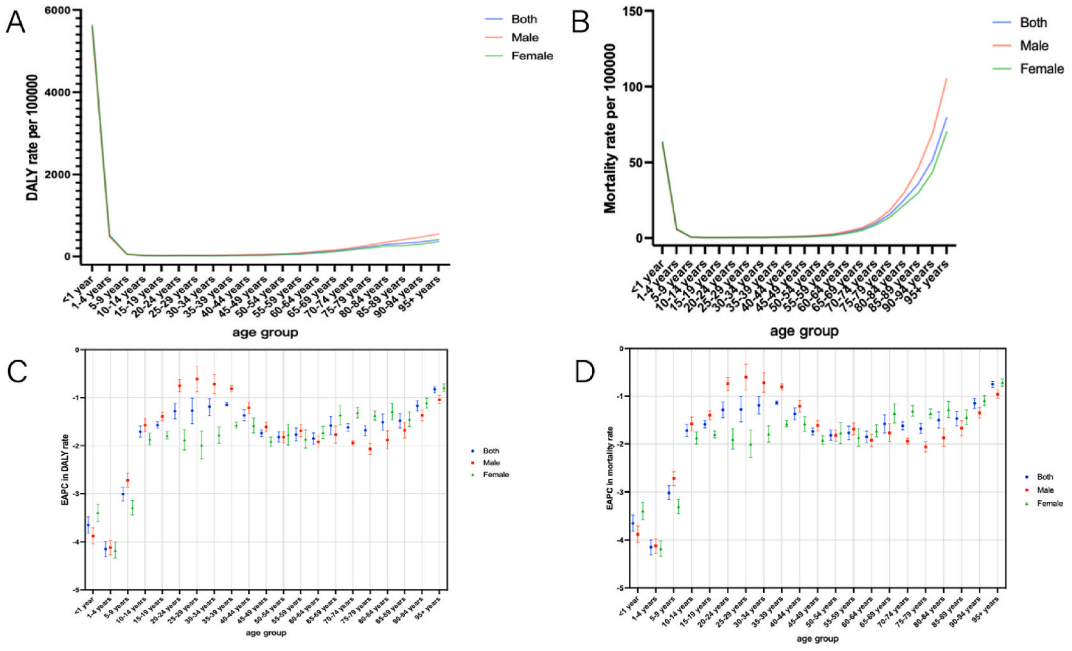

Fig. 2. The DALY rates and mortality rates of LRIs attributable to the lack of handwashing facilities, in 2019, and the EAPC of the death rates and DALY rates from 1990 to 2019, vary among different age groups and genders globally. Global DALY (A) and mortality (B) rates of LRIs attributable to the lack of access to handwashing facilities in different age groups by genders in 2019. The EAPCs in the global DALY (C) and mortality (D) rates of LRIs attributable to the lack of access to handwashing facilities in different age groups by genders from 1990 to 2019. DALY, disability-adjusted life year; LRIs, lower respiratory infections; EAPC, estimated annual percentage change.

3.3. Age and sex patterns

The mortality rates and DALY rates tended to increase at both ends of the age spectrum and decreased in the middle age groups. In the population under 1 year of age, the DALY rate peaked at 5591.83 (95 % UI, 2516.78–8901.75) (Fig. 2A), while the highest mortality rate was observed in the population over 95 years of age at 79.43 (95 % UI, 32.32–131.04) (Fig. 2B). The DALY rates showed a sharp decline in the population over 1 year old, followed by a stable trend until a slight increase was observed in the population over 55 years old (Fig. 2A). Similarly, the mortality rates attributed to LRIs due to the lack of handwashing facilities significantly decreased in the population over 1 year old but notably increased in the population over 55 years old, reaching a peak in the population over 95 years old (Fig. 2B). Fig. 2C and D demonstrate a decrease in the burden of LRIs caused by the lack of handwashing facilities across all age groups over the past 30 years, with a negative EAPC in mortality rates and DALY rates from 1990 to 2019, showing a significant decline in the age group of 1–9-year-old children. Furthermore, a sex-stratified analysis was conducted on populations of different age groups. The overall trends in mortality rates and DALY rates were similar across different sexes and age groups. However, male mortality rates and DALY rates were greater than female mortality rates in most age groups, with the sex differences becoming more pronounced with increasing age (Fig. 2A and B). In the different strata of the SDI regions, male mortality rates and DALY rates were greater than those of females, but the difference between the two sexes gradually narrowed over the past 30 years (Fig. 3).

3.4. Connection to the sociodemographic index

The study categorized worldwide areas according to their SDI levels and revealed a notable decrease in the burden of LRIs due to the lack of handwashing facilities in the five main SDI categories. With the exception of high-SDI regions, the degree of decline in the burden of LRIs caused by the lack of handwashing facilities was positively correlated with the SDI level (Table 1, Table S1, Fig. S3). Fig. 4A illustrates that, in 21 global regions, apart from southern sub-Saharan Africa, the ASDRs and ASMRs attributed to LRIs due to the lack of access to handwashing facilities were negatively correlated with the local SDI development level. From 1990 to 2019, the southern sub-Saharan Africa, western sub-Saharan Africa and central sub-Saharan Africa regions demonstrated significantly greater ASDRs and ASMRs based on their SDIs than expected (Fig. 4A, Fig. S2A). Furthermore, at the country level, the SDI was also significantly negatively correlated with the ASDR and ASMR, with the exception of Lesotho and Zimbabwe, where both the ASDR and ASMR were notably greater than the predicted values (Fig. 4B, Fig. S2B).

3.5. Decomposition analysis of changes in DALYs

Decomposition analysis was conducted to assess how population aging, population growth, and epidemiological changes(population standardized morbidity and mortality rates) [18] affected the changes in DALYs due to the lack of access to handwashing facilities from 1990 to 2019 worldwide and in various SDI regions. The results suggest a decrease in DALYs associated with LRIs due to

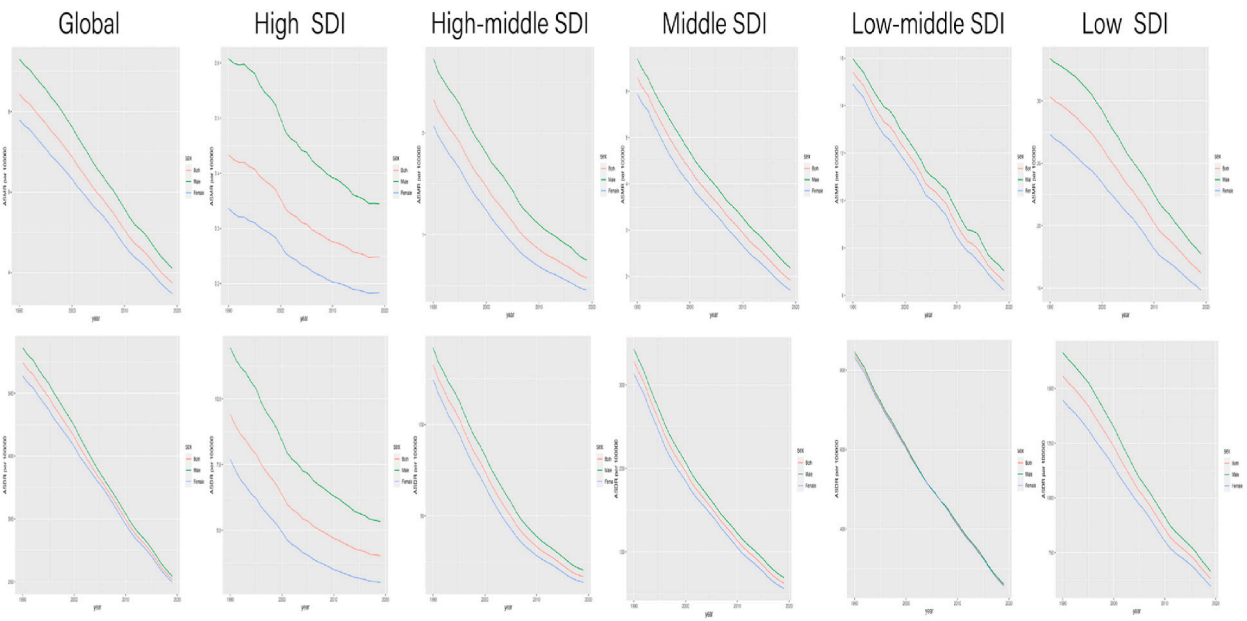

Fig. 3. The sex disparity in the burden of LRIs is attributable to the lack of access to handwashing facilities across SDI regions. The temporal trends in the ASMRs and ASDRs of LRIs attributable to the lack of access to handwashing facilities from 1990 to 2019 in different SDI regions. ASMR, age-standardized mortality rate; ASDR, age-standardized disability-adjusted life years (DALY) rate; LRIs, lower respiratory infections; SDI, sociodemographic index.

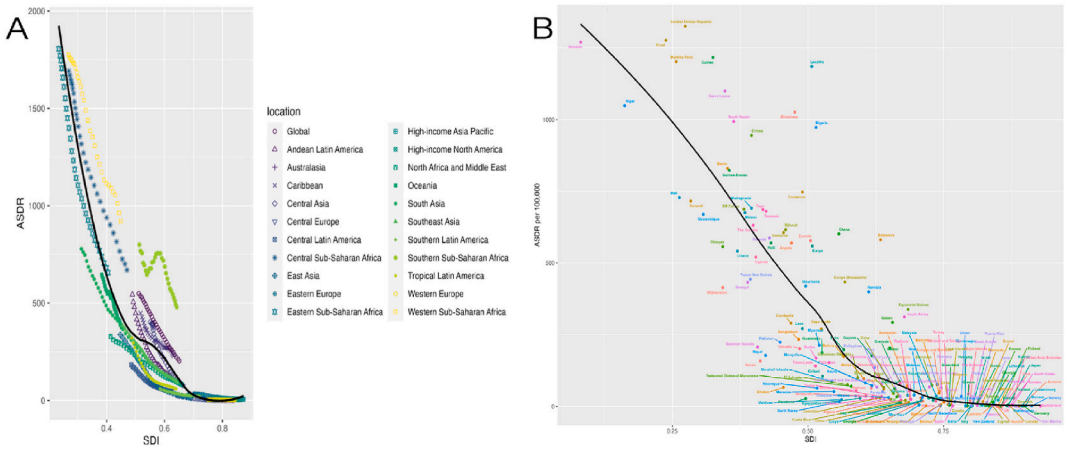

Fig. 4. The association between ASDRs of LRIs attributable to the lack of handwashing facilities and the SDI levels in different regions from 1990 to 2019; ASDRs corresponding to SDI levels in different countries and territories in 2019. ASDRs and SDIs across all regions between 1990 and 2019 (A). ASDRs across all countries and territories in 2019 according to the SDI (B). The black line represents the expected ASDR corresponding to the SDI. ASDR, age-standardized disability-adjusted life years (DALY) rate; LRIs, lower respiratory infections; DALY, disability-adjusted life year; SDI, sociodemographic index.

the lack of handwashing facilities in every SDI region and worldwide over the past 30 years (Fig. 5, Table S4). Epidemiological changes have been identified as the primary driver behind the decrease in DALYs, particularly in high-SDI regions, constituting 482.67 % of the total change. The aging of the population has led to a rise in DALY rates in high-SDI areas (−231.62 %) but has also resulted in a decline in DALYs worldwide and in other SDI regions. Conversely, population growth has played a role in the increase in DALYs globally and in various SDI regions, yet its effects have been counteracted by the decrease in DALYs resulting from epidemiological changes and population aging.

4. Discussion

This is the first study to thoroughly investigate the impact of a lack of access to handwashing facilities on LRIs. Although lack of access to handwashing facilities is only the third most important risk factor for LRIs, it contributes significantly to the overall burden of LRIs after child malnutrition and household air pollution from solid fuels [1]. Globally, the burden of LRIs caused by the lack of handwashing facilities has decreased significantly in the last three decades, with the most notable reduction observed in the East Asia region, particularly in China. This trend aligns closely with the distribution patterns of most disease burdens [11]. The disease burden attributed to the lack of handwashing facilities correlated negatively with the level of socioeconomic development, with low-SDI regions, such as sub-Saharan Africa, showing significantly greater disease burdens than expected. The impact of the lack of

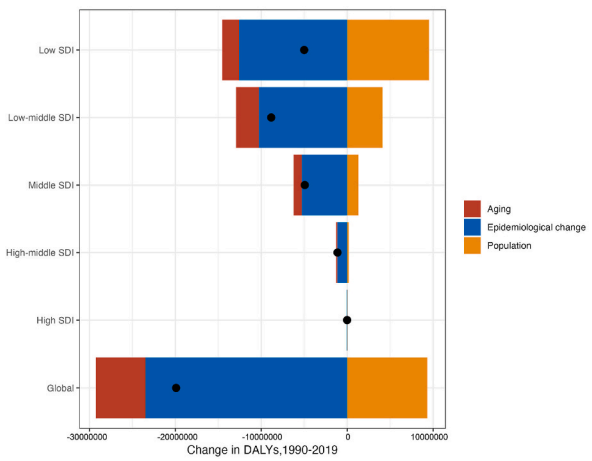

Fig. 5. Decomposition analysis of the change in DALYs. Changes in the DALYs of LRIs attributable to the lack of access to handwashing facilities from 1990 to 2019 at the global level and five SDI regions decomposed by three population-level determinants: population aging, population growth and epidemiological changes. The black dots indicate the total value of change attributable to all three components. DALYs, disability-adjusted life years; LRIs, lower respiratory infections; SDI, sociodemographic index.

handwashing facilities on LRIs was most pronounced among elderly people and children, especially those under 1 year old (highest DALY rate) and over 95 years old (highest mortality rate). When viewed through a gender lens, males bear a heavier disease burden, and this burden gap between genders becomes more pronounced with increasing age. The results from the decomposition analysis of the changes in DALYs attributed to LRIs caused by the lack of access to handwashing facilities highlight that epidemiological changes are the primary driving force behind the decline in DALYs.

Previous studies have predominantly focused on the incidence, mortality rates, etiological estimates and risk factor analysis of LRIs in global countries and various regions[1,2,19], encompassing differences in burden levels across different sexes and age groups [2]. However, there is scarce research on the estimation of the attributable burden of LRIs, with only one study analyzing the disease burden of LRIs attributable to PM2.5 [16]. Previous studies have consistently reported a declining trend in the burden of LRIs from 1990 to 2019[1,2,19]. Low-SDI regions, such as sub-Saharan Africa and South Asia, bear the greatest weight of LRIs [1]. Moreover, the mortality rates and DALYs of LRIs are elevated in children (especially those under 1 year old) and in the elderly population (particularly individuals aged 70 and above) [2]. The distribution patterns of mortality rates and DALYs attributed to LRIs caused by the lack of access to handwashing facilities, as discovered in this study, mirror previous research findings on the overall burden of LRIs. The mortality rates and DALYs attributed to LRIs caused by the lack of access to handwashing facilities are greater in elderly individuals and children, particularly in low-SDI regions of sub-Saharan Africa. Handwashing has been proven to be an effective physical preventive measure for halting the transmission of viruses[20,21].

A study focusing on the global distribution of handwashing facilities reported that more than 2 billion people worldwide lack access to handwashing facilities [10]. The shortage of handwashing facilities persists in low-income countries, particularly in regions such as sub-Saharan Africa [22], which also explains why the burden of LRIs attributed to the lack of handwashing facilities is more severe in low-income countries. As the popularity of handwashing facilities depends to a certain extent on the level of the local economy and the adequacy of water resources, studies have shown that the use of tippy-tap handwashing stations in resource-poor areas is also effective in reducing the incidence of disease [23]. Despite the substantial financial investment required to promote handwashing facilities in underdeveloped regions, a recent study indicated that the projected cost of disseminating handwashing facilities in 46 underdeveloped countries will exceed 10 billion US dollars. However, the international assistance received by these countries in 2019 surpassed 50 billion US dollars [24]. As a cost-effective and practical method for preventing infectious diseases, the promotion of handwashing facilities and the advocacy of hand hygiene should become a focal point of public health in every nation.

The populations most affected by the burden of LRIs attributed to the absence of handwashing facilities are children and elderly individuals. This is related to the fact that LRIs, as a class of infectious disease, have higher incidence rates in susceptible populations, such as elderly individuals and children [25]. When examining gender differences, males had a greater burden of LRIs attributed to the lack of access to handwashing facilities compared with females, with the difference becoming more pronounced with age. One possible explanation for this finding is that males are more likely than females to be exposed to LRI-related risk factors, such as alcohol consumption and smoking. The detrimental effects of smoking on the immune system and respiratory defense mechanisms are well established in the scientific community [26]. Research has shown that men are more likely to die than women, with smoking as a key factor in this disparity [27]. As people age, the negative impacts of these risk factors on immune and respiratory defenses become more noticeable, potentially contributing to the growing difference in the prevalence of LRIs between men and women as they age. Additionally, there are differences in immune levels between males and females, with research indicating that females mount stronger immune responses to viruses than males [28].

Notably, in the last three decades, the ASDR and ASMR attributed to LRIs caused by the lack of handwashing facilities have significantly decreased in East Asia, especially in China. A study revealed that the proportion of the population in East Asia who could not access soap and water decreased from 26.1 % (95 % UI, 24.2, 28.1) in 1990 to 7.7 % (95 % UI, 6.9, 8.4), making it the largest decrease globally. This reflects a significant improvement in the prevalence of handwashing facilities in East Asia over the past 30 years [9]. According to data reported by the World Health Organization, 97 % of the population in China will have hand-washing facilities, including soap and water, by 2020 (https://data.who.int/zh/indicators/i/D1223E8). The SDI is a comprehensive indicator reflecting the socioeconomic development level of a country or region. There was a negative correlation between the SDI and the burden of LRIs due to the lack of access to handwashing facilities. High-SDI regions often have higher levels of economic development and better health education, which play significant roles in promoting the dissemination of handwashing facilities and encouraging effective handwashing practices, thereby increasing the burden of LRIs [10,29]. The results of the decomposition analyses show that the main factor attributable to the decline in DALYs in LRIs due to the lack of hand-washing facilities is the change in epidemiology, which is closely related to the continuous improvement in global health policies and practices and economic and social development over the years, where the burden of communicable diseases has been surpassed by that of chronic diseases in many countries [30]. It is crucial to acknowledge that, despite numerous updates over the years to the GBD database, there are still ongoing challenges in gathering primary data in certain countries and regions. As a result, some data are predicted through mathematical modeling methods, such as CODEm and DisMod-MR, which may introduce certain deviations from actual data [11].

Although the burden of LRIs attributed to the lack of access to handwashing facilities has shown a decreasing trend globally, the absolute disease burden remains high due to the high mortality rates and DALY rates of LRIs. This poses a significant threat, especially to elderly people and children. In some underdeveloped regions, the lack of handwashing facilities due to economic underdevelopment and low education levels results in a substantial burden on LRIs. The World Health Organization promotes hand hygiene as an essential element of infection prevention and control programs. A study surveying the global implementation of IPC practices indicated that only 12.5 % of countries met all the core components of IPC programs [31]. The World Health Organization established World Hand Hygiene Day as early as 2009 to promote the importance of handwashing for disease prevention, but a recent study showed that the importance of hand hygiene has not been effectively communicated to the public at the national level, which explains the low

prevalence of handwashing facilities and the low level of knowledge about healthy hand hygiene in many countries [32]. Promoting handwashing facility accessibility and healthy hand hygiene knowledge is important for reducing the burden of LRIs attributable to a lack of handwashing facilities, especially at the national level, where policy support and public awareness are indispensable tools.

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Ethics approval and consent to participate

Not applicable.

Data availability

This study analysed publicly available datasets. All data are available at https://vizhub.healthdata.org/gbd-results/.

CRediT authorship contribution statement

Zhenyu Mao: Writing – original draft, Software, Conceptualization. **Xiaoyan Zhu:** Methodology. **Yuchen Huang:** Software. **Pengdou Zheng:** Data curation. **Lingling Wang:** Validation. **Fengqin Zhang:** Visualization. **Huiguo Liu:** Investigation, Funding acquisition. **Hai Li:** Writing – review & editing. **Ling Zhou:** Writing – review & editing. **Wei Liu:** Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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