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The Burden of Lower Respiratory Infections and the Risk Factors across Regions in Ethiopia: Global Burden of Diseases Study 1990-2019

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-068498
Article Type:	Original research
Date Submitted by the Author:	13-Oct-2022

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Keywords:	Epidemiology < INFECTIOUS DISEASES, Respiratory infections < THORACIC MEDICINE, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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The Burden of Lower Respiratory Infections and the Risk Factors across Regions in Ethiopia: Global Burden of Diseases Study 1990-2019

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- Main text word count: Current: 4487

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Abstract

Objective: This analysis is to present the burden and trends of morbidity and mortality due to LRIs, their contributing risk factors, and the disparity across administrative regions and cities from 1990 to 2019.

Design: This analysis is part of a collaborative and comparable systematic Global Burden of Disease (GBD 2019) study.

Study setting: The study includes nine region states and two chartered cities of Ethiopia

Outcome Measures: We calculated incidence, death, and years of life lost (YLLs) due to LRIs and contributing risk factors using all accessible data sources. We calculated 95% uncertainty intervals (UI) for the point estimates.

Results: In 2019, LRIs incidence, death, and YLLs among all age groups were 8313.7 (95% UI: 7757.6–8918), 59.4 (49.8–71.4) and 2404.5 (2059.4–2833.3) per 100000 people, respectively. From 1990, the corresponding decline rates were 39%, 61%, and 76%, respectively. Children under the age of five years account for 20% of episodes, 42% of mortalities, and 70% of the YLL of the total burden of LRIs in 2019. The mortality rate was significantly higher in predominantly pastoralist regions–Benishangul-Gumuz 101.8 (84.0–121.7) and Afar 103.7 (86.6–122.6). The Somali region showed the least decline in mortality rates. More than three-fourths of under-five child deaths due to LRIs were attributed to malnutrition. Household air pollution from solid fuel attributed to nearly half of the risk factors for all age mortalities due to LRIs in the country.

Conclusion: In Ethiopia, LRIs have reduced significantly across the regions over the years (except in elders), however are still the third leading cause of mortality, disproportionately affecting children younger than five years old, and predominantly pastoralist regions. Interventions need to consider leading risk factors, targeted age groups and pastoralist and cross-border communities.

Keywords: *Lower respiratory infections, regions, chartered cities, Ethiopia*

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What is already known on this topic

Lower respiratory infections (LRIs) remain a significant contributor to Ethiopia's morbidity and mortality. LRIs are one of the leading causes of under-five mortality and are expected to increase because of the current conflict, internal displacements, health care service interruption and the COVID-19 pandemic. This work is among the first to present a comprehensive analysis of LRIs effect on morbidity and mortality, and their risk factors across all the regional states of Ethiopia over an extended time period to support health decision making at subnational levels.

What this study adds

This is the first collaborative effort to provide the effects of LRIs and its risk factors on morbidity and mortality for Ethiopia's nine regions and two chartered cities from 1990 to 2019. This analysis highlights substantial decline morbidities and mortalities caused by LRIs over the last three decades, as well as the disparities between regions and chartered cities, and the opportunity to reduce LRIs burden of premature mortality by addressing specific geographic locations, risk factors and age-groups with cost-effective interventions.

How this study might affect research, practice or policy

The results identify regions and segments of the population highly affected by LRIs , and the leading risk factors contributing to premature mortalities. These could be potential priorities for action against LRIs that would reduce premature mortality. There is a need to enhance strategies addressing predominantly pastoralist regions and cross-border communities and for quality health-care services in underserved areas. Although morbidity and mortality have shown improvements over the past three decades, LRIs burden is still high in parts of Ethiopia.

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INTRODUCTION

Lower Respiratory Infections (LRIs) have been a predominant health problem worldwide, causing more than 2.3 million deaths in 2016 alone, amounting to a mortality rate of 32.2 per 100,000 people (1). LRIs comprise diseases of the lower airways such as pneumonia, bronchitis, and bronchiolitis, among others (2). Nearly all (99%) of LRI deaths occur in low and middle income countries and highly affect children under the age of 5 years (3). In sub-Sahara African countries, the mortality rate is 66.4 per 100,000 people, which is four times the mortality rate in East Asia and twice the global average (2).

Ethiopia ranked in the top three African countries in the number of under-five child deaths from LRIs (4). To prevent child death from LRIs and other diseases in early life, Ethiopia has been implementing the "Integrated management of childhood illness" program since 1997 which was scaled up to the national level in 2007 (5). LRIs, and pneumonia in particular, have been among the top three leading causes of childhood mortality in the country (6). Among LRIs' aetiologies, S. pneumonia contributed to more deaths than the other LRIs aetiologies combined (3). In 2011, the country introduced 10-valent pneumococcal conjugate vaccine (PCV 10) into its national immunization program to reduce the burden of Streptococcal pneumonia (7).

Morbidity and mortality from LRIs are attributable to multiple underlying factors. Malnutrition is one of the main underlying risk factors (8, 9). The other main attributable factor are poor living conditions that include household crowding, parental smoking, high use of household solid fuel/biomass consumption, poor ventilation, and lack of hand-washing facilities (10-12). In addition, bottle feeding also contributes to the burden of LRIs in children (13).

The flagship Ethiopian Health Extension Program (HEP) has been the backbone of the country's health system strategies to reduce the burden of LRIs and other diseases through preventive and

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health promotion activities at the community level. The HEP has also improved broader access to health care, availability of essential antibiotics, and immunization mainly to the rural population since 2004 (14). In 2010, the country also introduced the "integrated community case management" (ICCM) approach to treat pneumonia through trained health cadres of health extension workers (HEWs) implementing HEP (15).

Currently, Ethiopia is implementing its Health Sector Transformation Plan-2 (HSTP-2) which is adapted from the Sustainable Development Goals. Some of the aims include increasing the proportion of under-five children with pneumonia who received antibiotics from 48% to 69% and improving full vaccination coverage from 44% to 69% between 2020 and 2025 (16). Commitment to international goals such as The Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea by 2025 could be reached if enough investment is made in high LRI burden countries like Ethiopia (17).

As Ethiopia is a country of stark contrasts in socioeconomic, epidemiological, and geographical variations, estimating disease burden at the regional level could provide valid and reliable information to inform policy decisions, including efficient resource allocation to match the burden in the subnational states. Hence, this paper presents the 2019 Global Burden of Diseases, Injuries, and Risk Factors study (GBD) results on the burden, trends and regional variations of LRIs in Ethiopia from 1990 to 2019.

METHODS

Study Setting

Ethiopia is the second-most populous country in Africa next to Nigeria, with an estimated population of 112 million in 2019 (18). More than half of the country's population is under 20, and

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over 80% of the population resides in rural areas (19). The country is subdivided into ten regional states (Afar, Amhara, Benishangul-Gumuz, Gambella, Harari, Oromia, Somali, Sidama, Southern Nations and Nationalities and Peoples (SNNP), and Tigray) and two chartered cities (Addis Ababa and Dire Dawa). During this study, Sidama was a zonal administration under the SNNP region. Oromia, Amhara, and SNNP are the highly populated regions. In this study, we classified the regions into urban (Addis Ababa, Dire Dawa, and Harari), agrarian (Oromia, Amhara, SNNP, Tigray), and pastoralist (Benishangul-Gumuz, Afar, Gambella, and Somali). The healthcare system of the country is a three-tiered system consisting of primary, secondary, and tertiary levels of healthcare delivery units with 21,154 functioning health facilities and 159,545 health workforce in 2019 (16). The primary health care unit (PHCU) consists of health posts (staffed by HEWs), health centres, and primary hospitals. The secondary level of care consists of general hospitals and the tertiary level of care includes national referral hospitals which provide specialized services (16).

Data Sources and Analysis

The analysis and findings of LRIs presented in this paper were produced by the Ethiopia Subnational Burden of Disease Initiative, a collaborative endeavour between the National Data Management Center for Health (NDMC) at the Ethiopian Public Health Institute (EPHI) and the Institute for Health Metrics and Evaluation (IHME), as part of GBD. The details of the methodology were described elsewhere (20). In brief, woreda (district) level geographic boundary mapping of regions and cities was used because woredas were relatively stable government structures (compared to lower or higher level administrative structures) during political or government changes and through the three census years (1984, 1994, and 2007). First, the analysis was estimated by mapping population and demography at the district level by time and region.

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Then, the data sources were mapped by regions before processing the data in the GBD analysis based on GBD protocol. EPHI, in collaboration with IHME, gathered all accessible data sources by location for Ethiopia and all regions and cities that included census, demographic surveillance, household surveys, diseases registry, health service utilization, disease notification, and other data for this analysis. A comprehensive description of data sources, quality, and modelling for GBD 2019 has been reported on the following online portal: (http://ghdx.healthdata.org/gbd-2019/data-input-sources).

GBD Methods and Tools

The GBD details are reported elsewhere (21). Diseases and injuries within the GBD were organized into levels: Level 1 being the broadest causes of death and disability to Level 4 being the most specific. Within the three Level 1 causes (communicable, maternal, neonatal, and nutritional diseases; non-communicable diseases; and injuries), there were 174 Level 3 causes. The GBD 2019 study has estimated the burden of disease, including LRIs, for Ethiopia's national and subnational states. LRIs comprise diseases of the lower airways such as pneumonia, bronchitis, and bronchiolitis, among others (2). LRI mortality was estimated by age, sex, geography, and year using a modelling platform called the Cause of Death Ensemble model. LRI morbidity, including incidence, was modelled using a meta-regression platform known as DisMod-MR, a Bayesian, hierarchical, mixed-effects meta-regression platform (22). Years of life lost (YLLs) were computed by multiplying cause-specific deaths by the life expectancy at the age of death (23, 24). Population risk assessments over time and among risks were estimated using the comparative risk assessment approach developed for the GBD study (25, 26). The GBD risk factors were categorized as follows: Level 1 risk factors are behavioural, environmental, occupational, and

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metabolic; Level 2 risk factors include 20 clusters of risks; Level 3 consists of 52 clusters of risks; and Level 4 contains 69 specific risk factors (21).

Presentation of results

We present the burden of LRIs in Ethiopia and its regional states using incidence, deaths, and YLLs categorized by sex, age groups, and year. We used numbers, rates, and percent change for the quantification of the burden. We also estimated the risk factors contributing to LRIs in Ethiopia and the percent change between 1990 and 2019. We reported GBD causes and risk factors using level 3 classifications, with 95% Uncertainty Intervals (UI). Additional tables and figures are attached in the supplementary appendix.

Patient and public involvement

Patients and the public were not involved in this study.

RESULTS

Morbidity Due to LRIs

In 2019, an estimated 6,628,673.6 (95% UI: 6,108,786.2–7,230,986.3) new cases of LRIs occurred in Ethiopia resulting in an age-standardized incidence rate of 8313.7 per 100,000 people (7757.6–8918). Out of the total LRI episodes, 22% (1,448,680.0 new cases [1,150,089.8–1,799,704.4]) of new cases occurred among children younger than 5 years, yielding an annual incidence rate of 8685.0 per 100,000 children (6895.1–10,789.8). In adults older than 70 years, there were 725,273.3 (640,315.4–837,746.3) new cases of LRIs with an annual incidence of 38,394.4 per 100,000 people (33,896.9–44,348.5) (Appendix Table 1 and Table 2).

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Compared to national estimates, a significantly lower age-standardized incidence rate of LRIs per 100,000 people was observed in the chartered cities (6788.1 [6285.1–7339.1] in Addis Ababa, 7148.8 [6634.6–7750.7] in Dire Dawa), and in Harari region (7190.5 [6684.1–7718.6]). The highest rates of age-standardized incidence per 100,000 people were observed in Afar (9350.2 [8648.8–10,157.4]), Somali (9220.0 [8515.9–10,046.4]), and Benishangul-Gumuz (9054.6 [8394.2–9766.0]) although not significant compared to the national estimate (Figure 1; Figure 2; Appendix Table 2).

In children younger than 5 years, the lowest incidence rates were observed in Addis Ababa (4927.2 [3812.5–6231.8]), Harari (6821.6 [5373.5–8607.3]), and Gambella (6791.1 [5370.4–8460.1]) per 100,000 people, substantially below the national estimate. The highest incidence of LRIs per 100,000 children were recorded in Benishangul-Gumuz (10,481.8 [8269.5–13,219.0]), Somali (10,062.7 [7949.6–12,802.8]), Afar (9365.5 [7421.7–11,714.7]), and Oromia (9039.4 [7080.5–11,277.7]).

The age-standardized decline rate between 1990 and 2019 was 39% for both sexes, and it was 56% in under-five children and 13% in adults older than 70. The lowest decline in age-standardized incidence rate was in Somali (19%); while it was between 38% and 44% for the remaining regions (Appendix Table 2).

In children younger than 5, the incidence rates increased slightly between 1990 and 1995, except in Addis Ababa and Amhara region. The highest decline rates were found between the years 2005 and 2015 across all regions (Appendix Figure 1).

Mortality due to LRIs

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In 2019, LRIs caused 46,300.7 (95% UI: 39,515–54,642) deaths in Ethiopia, giving the age-standardized mortality rate of 86.4 (75.3-97.6) per 100,000 people. Under-five mortality accounted for 42% (19,591.8 [14,018.4–26,899.0]) of all deaths due to LRIs which resulted in a mortality rate of 117.4 (84.0–161.2) per 100,000 children. Of the under-five deaths, 71% (13,919.0 [9946.0–18,860.0]) occurred in the first year of life. In adults older than 70 years, LRIs caused 14,627.6 (12,393.7–16,892.8) deaths, which was a mortality rate of 774.3 (656–894.2) deaths per 100,000 adults (Table 1; Appendix Table 3).

In 2019, the number of deaths in all age groups by region were highest in Oromia (18,206 [15,193–21745]), Amhara (9525 [7530–11872]), SNNP (9494 [7713–11649]), and Somali (3907.5 [3007.4–4959.4]), followed by Tigray (2551.4 [2090.3–3028.6]), Afar (706.2 [567.7–869.6]), Benishangul-Gumuz (619 [470.7–803.0]), Dire Dawa (154.6 [120.6–193.8]) and Gambella (123.2 [98.2–151.9]). Harari (93.1 [73.8–116.0) had the lowest number of deaths. (Appendix Table 3).

Between 1990 and 2019, the age-standardized mortality rate declined by 61%, and the decline in under-five children and adults over 70 years was 86% and 30%, respectively (Table 1).

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Table 1: Lower Respiratory Infections mortality rates and percentage changes between 1990 and 2019 in Ethiopia, both sexes, with different age groups

	Age standardized			Children younger than 5			People older than 70		
Location	Deaths per 100 000 people [95% UI], 1990	Deaths per 100 000 people [95% UI], 2019	Cha-nge, %	Deaths per 100 000 children [95% UI], 1990	Deaths per 100 000 children [95% UI], 2019	Cha-Nge,%	Deaths per 100 000 people [95% UI], 1990	Deaths per 100 000 people [95% UI], 2019	Cha-nge,%
Addis Ababa	163.4[134.6-206.9]	59.4[49.8-71.4]	64	441.5[320.4-602.7]	23.4[14.1-36.4]	95	909.2[669.5-1264.6]	503.6[410.5-633.7]	45
Oromia	241.3[188.5-292.8]	89.3[75.9-103.1]	63	920.7[629.5-1264.1]	122.3[84.8-171]	87	1174.1[842.8-1543]	849.5[687.3-1009]	28
Amhara	197.7[163.5-236.5]	74.3[59.4-91]	62	691.3[531.7-883.4]	94.9[55.6-146.1]	87	1017.9[755.4-1324]	682.7[537.4-857.9]	33
SNNPs	243.7[196.4-296.9]	98.9[83.8-116.6]	59	971.9[697.2-1273.2]	118.4[79-168.5]	88	1161.3[584.7-822.3]	845.4[685.6-018.1]	28
Tigray	242.7[200.5-292]	84.6[69.2-100.1]	65	780.4[593.5-1009.1]	67.2[43.5-98.3]	92	1166.7[838.2-1586]	788.6[637.9-956.8]	33
Harari	240.2[182.6-303.1]	77[63-92.5]	68	1146.7[730-1604.1]	89.9[51.1-138]	93	762.3[412-1223.7]	694.3[551.9-849]	9
Afar	244.8[186.5-316.9]	103.7[86.6-122.6]	58	723.7[481.5-1023.7]	101.7[65-152.4]	86	1010[658-1541.7]	917.6[720.6-146.8]	10
Somali	147.6[113.8-192.6]	97.5[79.2-118.6]	34	455.9[313-628.5]	197.3[135-279.8]	57	798.8[519.2-1177.6]	765.1[588.8-972.4]	5
BG	284.1[221.8-358.1]	101.8[84-121.7]	64	1266.4[846.7-790.9]	215.1[141.4-311]	84	975.3[656.5-1379.3]	671.9[532.7-848.7]	32
Dire Dawa	220.1[171.6-270.9]	69.9[56.5-84]	68	1084.2[689.1-503.2]	83.7[44.7-135.9]	93	868.7[604.5-1205.5]	621.3[496.4-766.1]	29
Gambella	231.5[176.8-297.4]	82.4[68.3-97.1]	64	1265.5[805.4-764.3]	57[32.4-89.6]	96	739.6[477.7-1074.9]	678.3[540.4-835.3]	9
Ethiopia*	223[184.7-264.3]	86.4[75.3-97.6]	61	822.2[635-1051.2]	117.4[84-161.2]	86	1092.3[844-1391.5]	774.3[656-894.2]	30

N.B: all changes are in decreasing percent. SNNPs: Southern Nations, Nationalities, and Peoples; BG: Benishangul-Gumuz; *national estimate

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In Ethiopia, the age-standardized mortality rate was higher among males (100.6 [84.1-121.4]) than females (71.8 [60.2–82.9]) (Appendix Table 4).

In 1990, the age-standardized mortality rate per 100,000 people was the highest in Benishangul-Gumuz (284.1 [221.8–358.1]), Afar (244.8 [186.5–316.9]) and SNNP (243.7 [196.4–296.9]), although it is not significantly different from the national estimate. On the other hand, the lowest age standardized mortality rate was exhibited in Somali (147.6 [113.8–192.6]). Although the value was not significantly different from the national value in 1990, Addis Ababa showed the second lowest age-standardized mortality rate (163.4 [134.6–206.9]) (Table 1).

In 2019, the age-standardized mortality rate per 100,000 people was significantly lower in Addis Ababa (59.4 [49.8–71.4]) when compared to other regions, although not significantly lower than Gambella and other urban areas (Harari and Dire Dawa). Dire Dawa showed a significantly lower age-standardized mortality rate when compared to Benishangul-Gumuz, Afar, and SNNP. Compared to the national estimate, the regions of Afar (103.7 [86.6–122.6]) and Benishangul-Gumuz (101.8 [84.0–121.7]) recorded the highest age-standardized mortality rates per 100,000 people, although the difference is not statistically significant (Table 1). Compared to the 1990s, there was a 58% to 68% decrease in the age-standardized mortality rates across all regions. However, the Somali region recorded a 34% reduction in mortality rates (Table 1 and Figure 3).

Among children below the age of 5, the mortality rate per 100,000 people was significantly lower in Addis Ababa (23.4 ([14.1–36.4]) than other regions, although it was not significantly less than Gambella in 2019. The mortality rate was the highest in Benishangul-Gumuz (215.1 [141.4–311.0]), Somali (197.3 [135.2–279.8]), and Oromia (122.3 [84.8–171.0]) despite being not significantly higher than the national estimate (Table 1). Dire Dawa showed a significantly lower mortality rate than Benishangul-Gumuz and Somali. Harari had a significantly lower mortality rate

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than Benishangul-Gumuz. For all regions, the mortality rate declined for children younger than 5-years between 1990 and 2019 by between 84% (in Benishangul-Gumuz) and 96% (in Gambella), except in Somali, which showed a 57% decline (Table 1). The mortality rate increased slightly between 1990 and 1995 and between 2010 and 2015 in Somali region (Appendix Figure 2).

The mortality rate in adults older than 70 was the lowest in Addis Ababa (503.6 [410.5–633.7]). Other regions and cities have not shown a statistically significant difference from the national estimate. The decline in mortality rates between 1990 and 2019 is below 50% across all regions (Table 1). The mortality rate increased in Afar and Somali between 2005 and 2019 and in Gambella between 1990 and 2005 (Appendix Figure 3).

Premature Mortality due to LRIs

In 2019, premature death due to LRIs was 2,445,093.7 (95% UI: 1,934,420.8–3,119,838.6) YLLs, yielding an age-standardized rate of 2404.5 per 100,000 people (2059.4–2833.3). Compared to 1990, the age-standardized YLL rate declined by 76% in 2019. In parallel, 70% of all premature mortality occurred in children younger than five, which accounted for 1,721,122.3 (1,231,032.1–2,362,958.7) YLLs. The YLL rate of 72,055.4 (55,718.5–92,064) per 100,000 under-five children in 2019 declined by 86% compared to the YLL rate in 1990. Adults over 70 years contributed 8% of all YLLs due to LRIs (194,756.2 [165,462.0–225,502.1]), yielding a rate of 10,309.9 (8759.2–11,937.6) YLLs per 100,000 people (Table 2; Appendix Table 5 and Table 6).

Compared to 1990, the number of YLLs has decreased by 70% in all age groups and by 76% in children younger than five in 2019. However, the number of YLLs has increased by 45% in adults older than 70 (Appendix Table 5).

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The age-standardized YLL rate was significantly lower in Addis Ababa (1285.6 [1065–1561.8]) in 2019 compared to the national average. The highest age standardized YLL rate were in Benishangul-Gumuz (3571.1 [2772.4–4510.7]), Somali (3236.4 [2537.4–4006]), and Afar (2824.6 [2323–3414]), although not statistically significant compared to the national estimate (Table 2).

In children younger than five years, Addis Ababa (2069 [1253–3217.5]) had a significantly lower YLL rate than the national estimate. The YLL rate was observed to be the lowest in Gambella (5031.8 [2867.2–7885.7]), although not significantly lower than the national estimate (Table 2).

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Table 2: Lower Respiratory Infections YLL rates and percentage changes between 1990 and 2019 in Ethiopia, both sexes, with different age groups

	Age-standardized			**Children younger than 5 years**			People older than 70		
Location	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%
Addis Ababa	6362.2(5161.9-7847.9)	1285.6(1065-1561.8)	80	38824.7(28230.1-53092.4)	2069(1253-3217.5)	95	13587(9985.4-18978.3)	6857.1(5545.8-8721.2)	50
Oromia	11217.6(8517-14318)	2433.8(2042.2-2879.5)	78	80610.7(55103.7-110696)	10742.8(7456.7-15039.6)	87	18754.2(13297.1-24843)	11119.7(8939.1-13305)	41
Amhara	8690.4(7146.3-10453.8)	2016.4(1551.4-2541.8)	77	60663.3(46712.5-77511.5)	8355(4898.9-12845)	87	15950.4(11723.4-21059.7)	9059.7(7063.2-11529.2)	44
SNNPs	11633(9119.4-14477.9)	2698.1(2243.5-3250.2)	77	85114.7(61203.2-111502.1)	10409.3(6968.1-14819.3)	88	18842.6(13166.1-26081)	11736.6(9426.7-14238.6)	38
Tigray	10346.4(8522.9-12340.3)	1977.1(1593.9-2395)	81	68509.3(52185.7-88712.2)	5927.9(3839.4-8676.8)	92	19502.8(13914.1-26751.2)	10486.8(8439.5-12765.3)	47
Harari	12826.5(9336.5-16985.4)	2060.4(1595.6-2623.1)	84	100421.7(63898.7-140467.8)	7922.5(4518.7-12117.2)	93	11782.6(6360.4-19341.1)	9260.4(7338.7-11340.3)	22
Afar	10993.5(8520.8-14193.6)	2824.6(2323-3414)	74	63570.5(42296.6-89769)	8943.7(5734.6-13390.2)	86	16925.5(10923.7-26001.7)	11867.1(9346-14716.9)	30
Somali	6286.9(4860.5-7970)	3236.4(2537.4-4006)	49	40088.1(27543.7-55109)	17314.3(11890.7-24530)	57	11953.6(7599.2-17885.5)	10246(7797.8-13150.6)	15
BG	14965.1(11197.4-19998.6)	3571.1(2772.4-4510.7)	76	110847.2(74368-156588.4)	18868.3(12442.9-27281.8)	83	16397.3(10917-23228.5)	9541.9(7476.9-12112.3)	42
Dire Dawa	11749.7(8605.4-15249.5)	1832.8(1407.3-2363.1)	84	94905.3(60458.5-131584.5)	7371.3(3953-11962.1)	93	13207.9(9219.6-18328.2)	8371(6616.3-10408.2)	37
Gambella	13175.8(9291-17411)	1937.4(1567.6-2344.6)	85	110783.8(70576-154304.1)	5031.8(2867.2-7885.7)	96	11811.4(7673.5-17012.5)	10030.9(7730.2-12664.9)	16
Ethiopia*	10189.1(8347.5-12201.8)	2404.5(2059.4-2833.3)	76	72055.4(55718.5-92064)	10318.6(7380.4-14166.6)	86	17415.9(13362.7-22228.5)	10309.9(8759.2-11937.6)	41

SNNPs: Southern Nations, Nationalities, and Peoples; BG: Benishangul-Gumuz; *national estimate

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The age-standardized premature mortality rate between 1990 and 2019 showed a continuous decline in all regions, except Somali. Benishangul-Gumuz showed the highest burden between 1990 and 2019 (Figure 4).

The change in premature mortality in children younger than five was significant throughout the years. However, the reduction in premature mortality among adults older than 70 was not as significant (Appendix Figure 4 and Figure 5).

Risk Factors

Across all population groups, about half (48%) of the mortalities (measured in rates) due to LRIs in Ethiopia were attributed to household air pollution from solid fuel. In addition, lack of access to a hand-washing facility (23%), childhood wasting (23%), low birth weight (9%), short gestation period (7%), and ambient particulate matter pollution (6%) were also risk factors for mortality due to LRIs. The contribution of the risk factors to death due to LRIs in all regions was similar to the national estimate, except in Addis Ababa, where lack of access to hand-washing facilities, ambient particulate matter pollution, and low temperature were the main contributing factors. Ambient particulate matter pollution was also relatively higher in Dire Dawa, Harari, and Tigray regions (Appendix Figure 6).

In children younger than five, more than three-fourths of deaths due to LRIs were attributed to childhood wasting (54%) stunting (12%), and child underweight (10%) in Ethiopia. In addition, 50% of the LRIs mortalities were attributed to household air pollution from solid fuel. Lack of access to hand-washing facilities (23%), low birth weight (23%), short gestation period (17%), high (4%) or low temperature (4%), absence of exclusive breastfeeding (4%) were also the risk factors with evident contribution. The distribution of risk factors varied among the regions. Child

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wasting, low birth weight, and pre-term birth were the contributing factors of mortality in Addis Ababa. In Harari and Dire Dawa, child wasting, lack of access to hand-washing facilities, pre-term birth, and household air pollution from solid fuels contributed more to the death from LRIs than the other risk factors in 2019. All the risk factors except for ambient particulate air matter and low temperature were the highest in Somali and Benishangul-Gumuz (Appendix Figure 7).

Discussion

The findings from this study indicate that although the burden of LRIs, measured in incidence or mortality rates, have shown a significant decline, they are still the third leading cause of death after neonatal disorders and diarrheal diseases in 2019 in Ethiopia. Cities and predominantly urban areas had lower mortality rates than predominantly pastoralist regions of the country. The rate of decline in mortality between 1990 and 2019 varied slightly across regions and chartered cities. The mortality rate decreased by more than three-fourths among children under the age of five and only by one-third among adults older than 70 between 1990 and 2019. Half of LRIs mortalities are attributed to household air pollution from solid fuels in all age groups. About three-fourths of LRIs in children were attributed to malnutrition.

The mortality rate of LRIs among children below the age of 5 has declined by 86% between 1990 and 2019. This decline could be attributed to improvements in living conditions, access to healthcare, and immunization. The national health delivery infrastructure has grown from 2,600 health facilities in 1997 to 21,154 facilities, including 314 hospitals, 3,678 health centers, and 17,162 health posts and private health facilities in 2019. As a result, the health workforce has increased from 46,000 in 2007 to 159,545 in 2019 (16). The introduction of HEP since 2004 to provide preventive, health promotion, and curative treatment for pneumonia, malaria and diarrhoea

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had improved health outcomes for children (14). Moreover, Ethiopia has been implementing holistic child health improvement programs like IMCI since 1997 (15) and ICCM (5). Vaccination against Streptococcus pneumonia, which is responsible for about half of the LRIs mortality in African countries, with the PCV 10 vaccine since 2011 helped reduce the burden of LRIs (4). In addition, improved socioeconomic conditions have supported the reduction of the burden of LRIs in the country (27).

Despite the achievements reached in improving child health outcomes in Ethiopia, children are still disproportionately affected by LRIs. Out of the total burden of LRIs, 42% of all the deaths were among children younger than five. In that regard, this study has shown that one out of ten child deaths are due to LRIs. However, another study estimated that pneumonia alone shared about 17% of all deaths in children younger than five years (28)**.** Among children under five, children younger than one carry the highest burden of LRIs. Furthermore, the mortality rate among children younger than one (397.7 per 100,000 people) was more than nine times higher than that of children between one and four years old (43 per 100,000 people). Although most studies on the high burden of LRIs corroborate our findings, the findings from Global Health Observatory (GHO) estimated a much higher mortality rate than the estimates of this study (i.e. 481.9 in children less than one year and 51.1 per 1000,000 population in children between one and four years) (8). Although we could not explain why this variation occurs, the estimates from GBD are also less than the estimate from findings of the Child Health Epidemiology Reference Group (CHERG), which is primarily due to the difference in the types of data used (29).

Urban areas of the country, mainly Addis Ababa and Dire Dawa, had significantly lower mortality rates than pastoralist areas such as Benishangul-Gumuz and Somali. These regional variations could be attributed to gaps in availability and access to healthcare and socioeconomic status

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differences among the subnational states. A previously conducted study indicated that disease burden is high among people in the poorest wealth quintile and people located mainly in Afar, Somali, Oromia, SNNP, and Benishangul-Gumuz and also have the lowest level of health service utilization (30). The rural area of the country has less healthcare coverage and utilization than the urban areas. The coverage of all basic vaccination is 43% in the country. Across the regions, the coverage of all basic vaccination is lowest in Afar (20%) and highest in Addis Ababa (83%). Coverage of pentavalent vaccines in children is 72% among the urban population while it is 56% among the rural population (15, 28). There is a variation in the performance of immunization across regions. Addis Ababa, Ethiopia's capital has PCV3 coverage of 93% among 1-year-olds in 2019, whereas this coverage is only 23% in Afar and Somali. The wasting rate in Somali was 21% in children under five, while it was just 2% in Addis Ababa in 2019 (31)

In addition to children, LRIs affects people older than 70 years. The number of people dying from LRIs increased over the years in people older than 70 years, partly due to the increase in the aging population. However, the mortality rate declined by 30% between 1990 and 2019 (3, 32). The incidence rate did not show a significant improvement across the study years, showing only 15% reductions between 1990 and 2019. Among the regions, Somali and Afar have recorded an increased incidence rate between 1990 and 2019. This could partly be explained by poor accessibility and availability of health facilities in the regions (31).

Wasting, stunting, and underweight were major risk factors contributing to the death of children younger than five years due to LRIs (33-35). More than 37% of children under five are stunted, with a higher percentage in rural areas (41%) than in urban areas (26%). Similarly, the prevalence of child underweight and wasting is 21% in the rural and 7% in the urban parts of Ethiopia (36). This indicates that more investment is needed to reduce the burden on malnutrition among children

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and in the rural parts of the country to attain better health outcomes, protecting against LRIs. Although the prevalence of stunting, wasting, and underweight has decreased markedly over time, they are still major risk factors for death caused by LRIs. In the Millennium Development Goals (MDG) era, between 1990 and 2015, about half of the deaths averted due to LRIs were attributed to improvement in the nutritional status of children (reduction in wasting and stunting) (15).

Ambient particulate matter and household air pollution from solid fuel use were the two essential components of air pollution. Household air pollution from solid fuel use the was the second leading risk factor for LRIs, and ambient particulate matter is the eight leading risk factor among the top ten risk factors for LRIs (37-39). This indicates that improvement in socio-demographic factors will have a more substantial contribution as the use of electricity and natural gas for cooking increases (3).

To reduce the burden of LRIs, both national and global efforts are underway. The Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea (GAPPD), established by the World Health Organization, set goals in 2013 to reduce child LRI mortality rates to below 3 in 1,000 live births and to reduce severe LRI incidence by 75% of the 2010 baseline by 2025. To achieve these goals, reaching 90% of children with full-dose vaccine coverage, 90% access to pneumonia treatment, 50% coverage of exclusive breastfeeding in the first six months, and exclusive breastfeeding promotion were set as prerequisites (17). However, a 6% average annual mortality reduction was recorded between 2000 and 2018 in Ethiopia. With this, the country can only reach the 2025 GAPPD target in 2035, ten years behind the target, according to the Maternal and Child Epidemiology Estimation Group (MICE) estimation (28).

Ethiopia's major health sector strategic plan, the Health Sector Transformation Plan-2 (HSTP-2) for the year 2021-2024, aims to reduce the infant mortality rate to 35, the neonatal mortality rate

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to 21 and the children under-5 mortality rate to 43 per 1,000 live births. Similarly, the 2030 Sustainable Development Goals (SDG) has set targets to reduce childhood mortality significantly. These targets can be achieved if the country implements high-impact priority curative and preventive interventions against LRIs (40). To achieve this, concerted action to improve policies, increase investment, foster innovations, and scale-up evidence-based interventions has paramount importance. Parallel to this, an estimated $274 billion for health is required to achieve the health-related SDGs by 2030 in 67 low and middle-income countries, including Ethiopia. One of the strategies to mobilize the needed resources is to increase government expenditure by 15% and share the population's costs through taxes or insurances (41).

This study is not without limitations; limitations in the GBD methods also apply to this study. One of the limitations is the incompleteness of data. A previously conducted study showed that most countries in Africa, including Ethiopia, have had a vast amount of incomplete vital records data (42). This increases the uncertainty in the estimates, which might compromise the accuracy of the findings and reduce the use of these findings for policy decision-making (1). However, to improve the quality of the estimates, the best available data are used and GBD estimates are continuously updated.

Conclusion

Despite the substantial reduction in morbidity and mortality at national and regional states, LRIs still remain one of the leading causes of the burden of disease in Ethiopia. Children and elders are still disproportionately affected by LRIs. The burden of illness and death due to LRIs varies across regional states in Ethiopia, with lower rates in cities and predominantly urban areas while predominantly pastoralist areas of the country have higher rates. Efforts should be made to tackle

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the major risk factors contributing to death by LRIs. Improving child nutrition, access to immunization and curative health services, as well as universal electrification to reduce indoor air pollution will be very useful strategies to reduce deaths due to LRIs in Ethiopia. Furthermore, improvement in socioeconomic factors will also help to reduce LRI burden at national and regional levels. To reach the targets set at the national and international level, mobilizing resources to health and improving the provision of health services to the community according to the needs of the regions is of paramount importance.

List of abbreviations

EPHI: Ethiopian Public Health Institute; GAPPD: Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea GBD: Global Burden of Disease; GHO: Global Health Observatory; HSTP: Health Sector Transformation Plan; ICCM: integrated community case management; IHME: Institute of Health and Metric Evaluation; LRIs: Lower Respiratory Infections; NDMC: National Data Management Center for health; PCV: Pneumococcal Conjugate Vaccine; SDG: Sustainable Development Goals; SNNPs: Southern Nations, Nationalities and Peoples; UI: Uncertainty Interval; WHO: World Health Organization; YLL: Years of Life Lost.

Ethics approval and consent to participate

This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

Consent for publication

Not applicable.

Availability of data and material

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All relevant data are submitted with this manuscript.

Competing interests

The authors declare that they have no competing interests.

Funding

Bill and Melinda Gates Foundation has funded Ethiopia subnational burden of disease EPHI-IHME collaborative initiative. The funder of this study had no role in study design, data collection, data analysis, data interpretation, or the writing of the report.

Authors' contributions

Please see appendix section C for more detailed information about individual author contributions to the research, divided into the following categories: providing data or critical feedback on data sources; developing methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; and managing the estimation or publications process

Declarations

M A Gebremichael reports support for the present manuscript from the Bill and Melinda Gates Foundation.

Acknowledgements

The authors have no acknowledgements to declare

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Figure 1: Incidence of lower respiratory infections per 100,000 people in Ethiopia and its regions in 2019.

Figure 2: Trend in age-standardized incidence rate of LRIs per 100,000 people in Ethiopia, 1990-2019

Figure 3: Trend in LRIs age-standardized mortality rates per 100,000 people in Ethiopia, 1990-2019

Figure 4: Trend in LRIs age standardized years of life lost rates per 100,000 people in Ethiopia, 1990-2019

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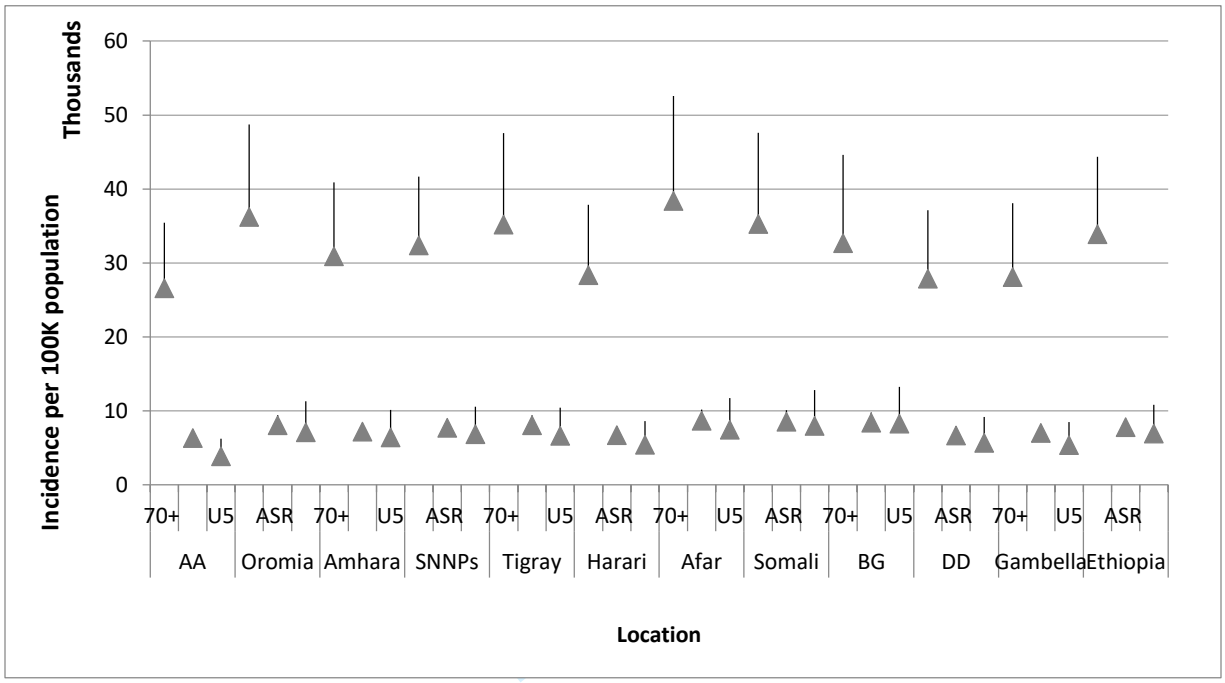
Figure 1: Incidence of lower respiratory infections per 100,000 people in Ethiopia and its regions in 2019.



Key: U5: children younger than 5 years; 70+: adults older than 70 years; ASR: Age-standardized rates; AA: Addis Ababa; DD: Dire Dawa; SNNPs: Southern Nations and Nationalities and Peoples; BG: Benishangul Gumuz

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Figure 2: Trend in age-standardized incidence rate of LRIs per 100,000 people in Ethiopia, 1990-2019

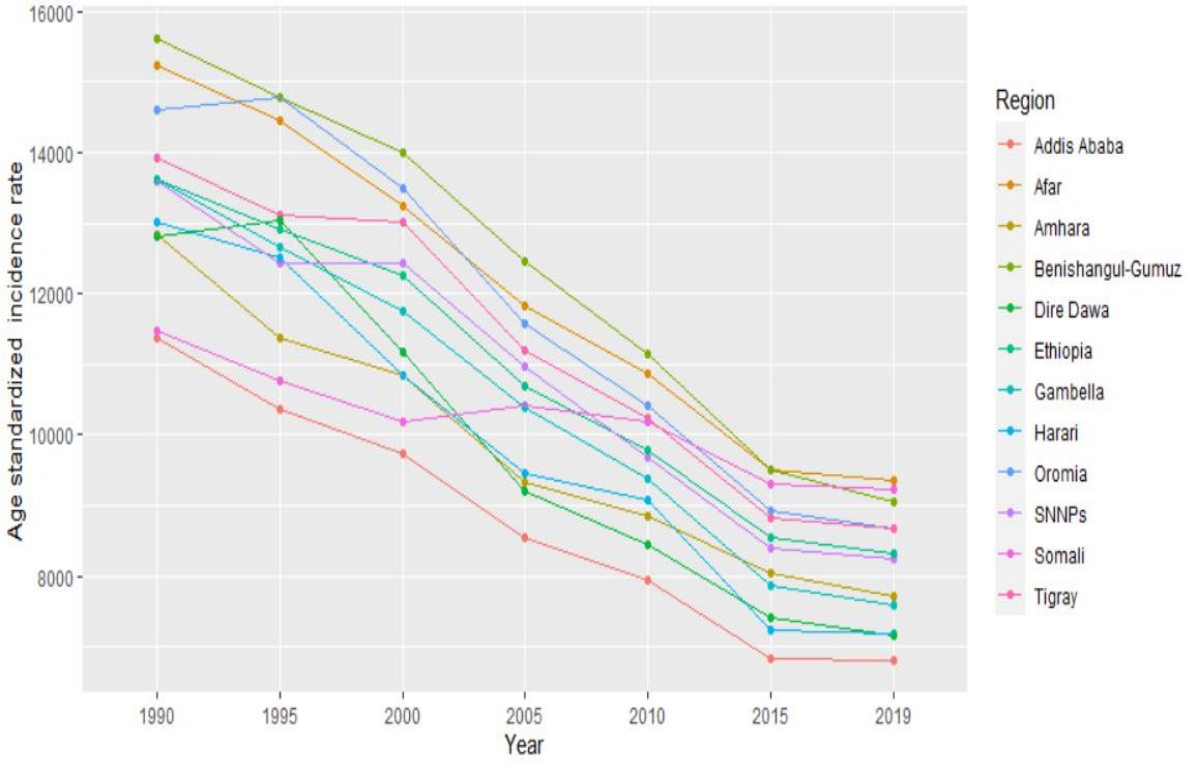

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Figure 3: Trend in LRIs age-standardized mortality rates per 100,000 people in Ethiopia, 1990-2019

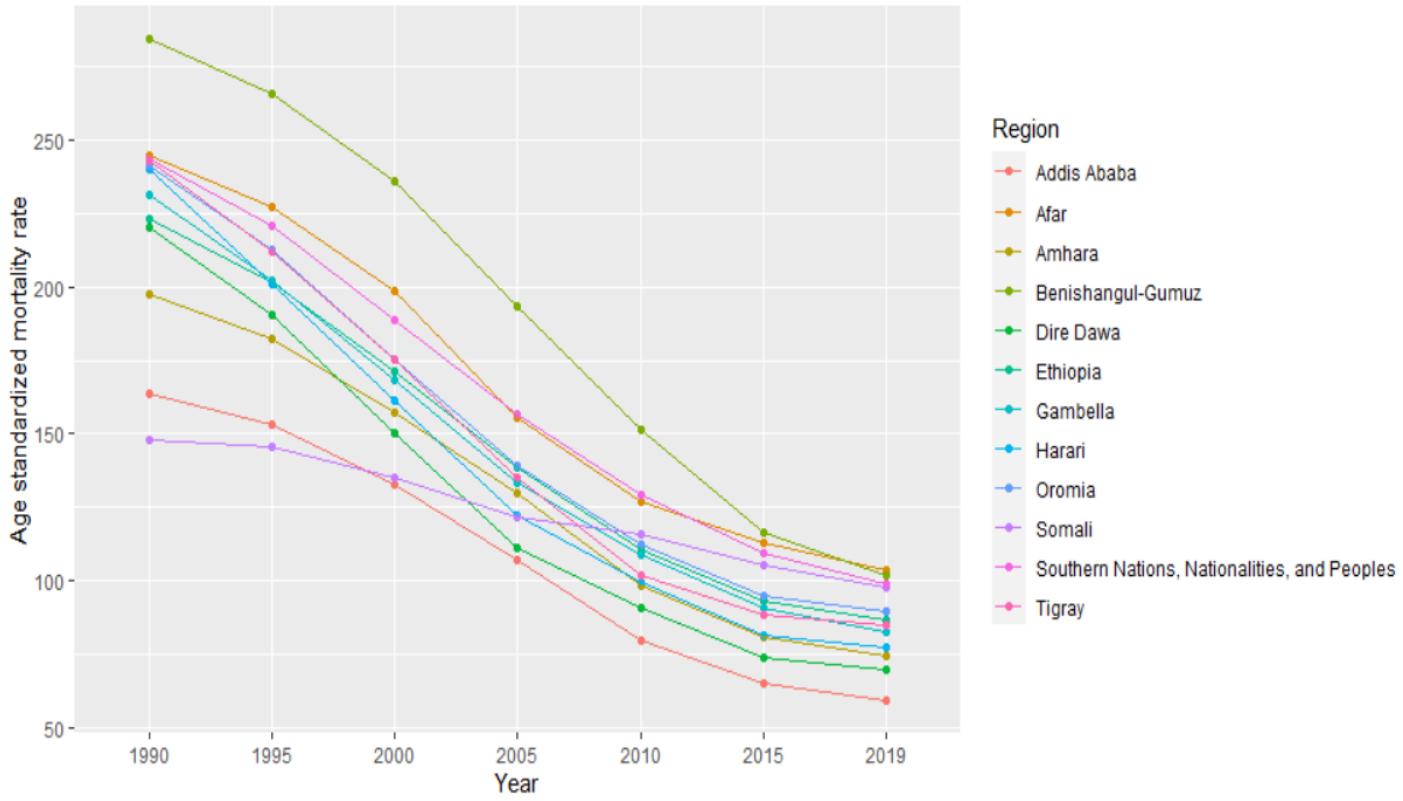

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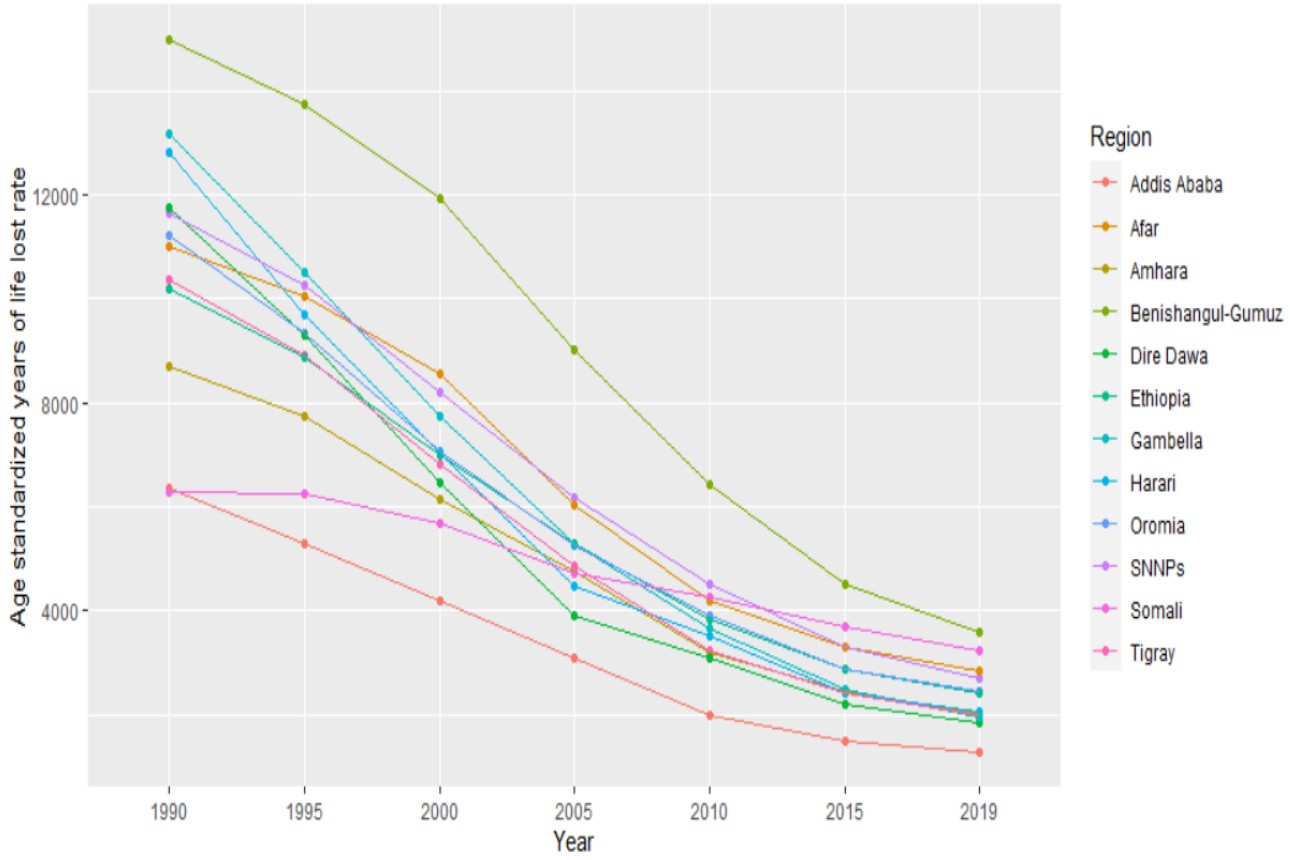
Figure 4: Trend in LRIs age standardized years of life lost rates per 100,000 people in Ethiopia, 1990-2019



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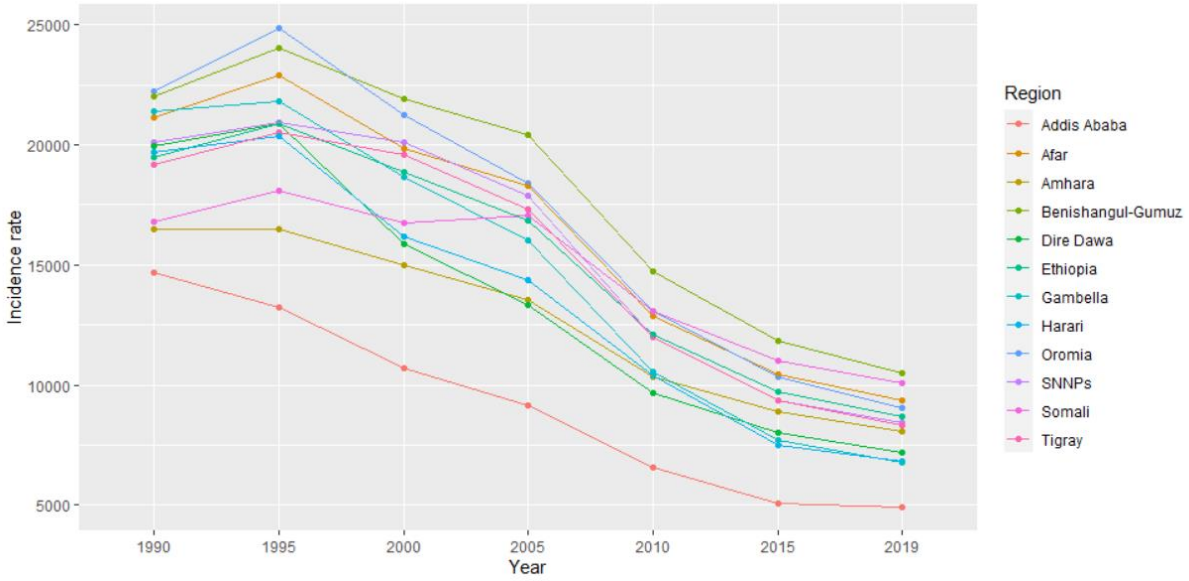
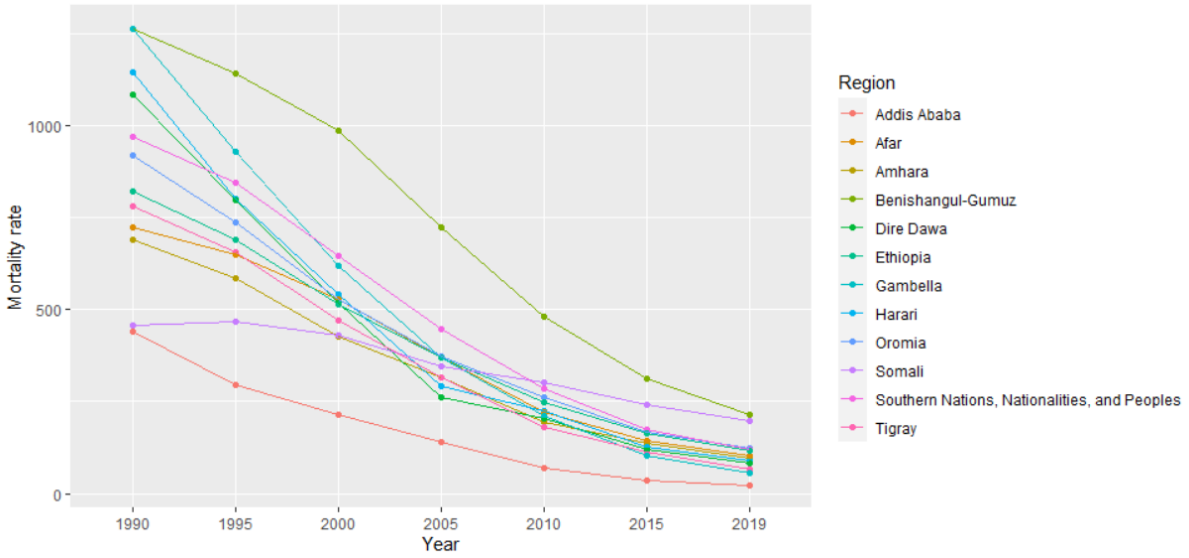
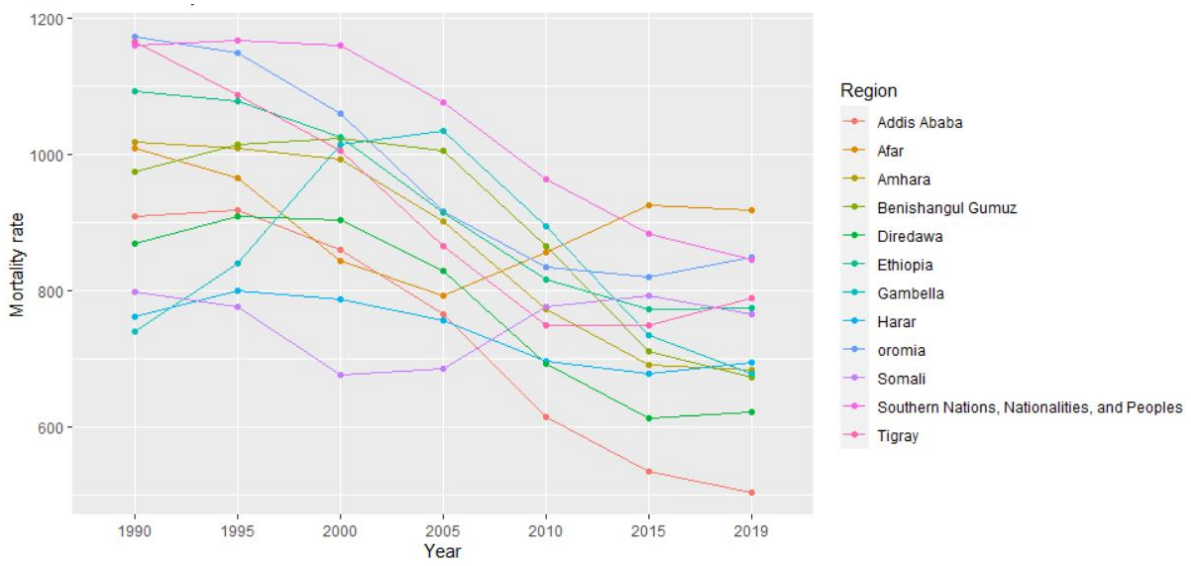


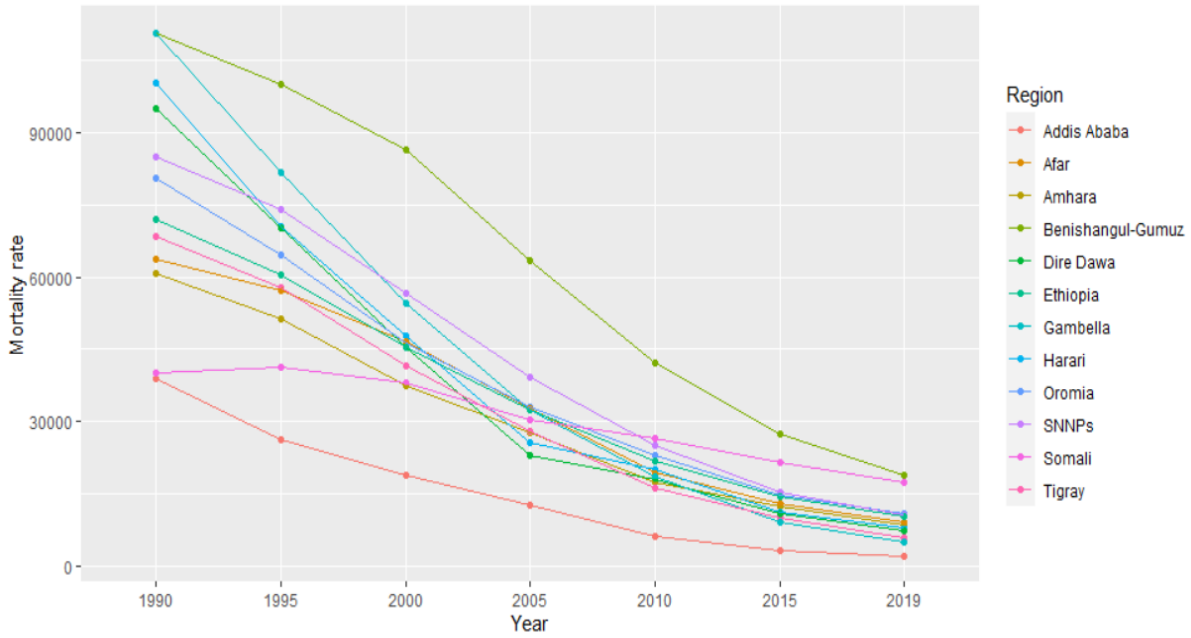
Appendix figure 1: Children under 5 years of age incidence rate per 100,000 populations due to LRI in Ethiopia, 1990- 2019



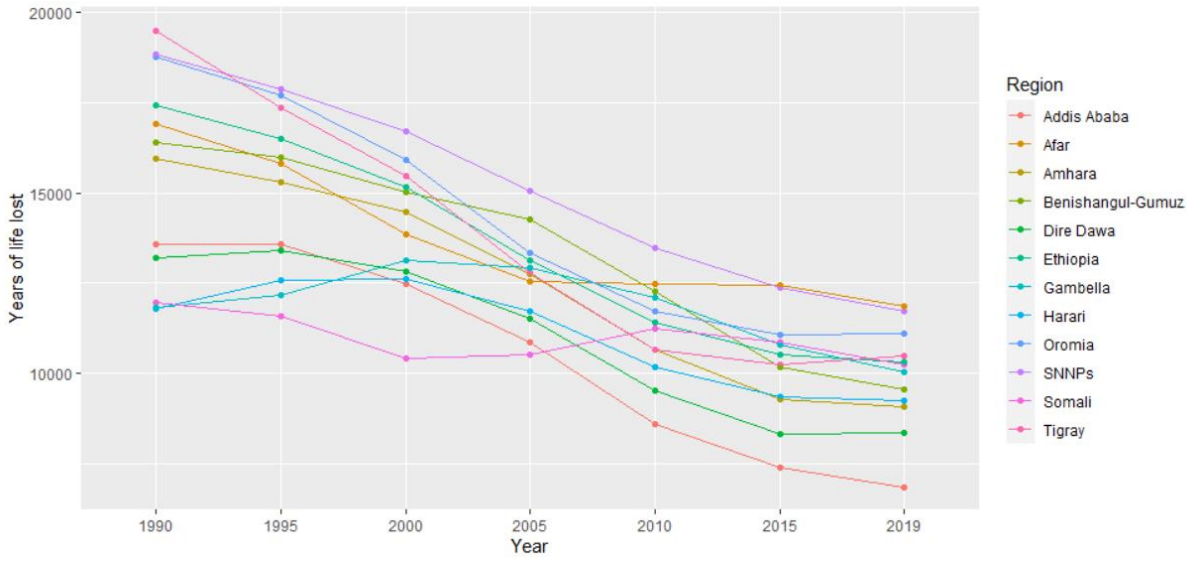
Appendix figure 2: Children younger than 5 years mortality rate per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019



Appendix figure 3: Adults older than 70 years mortality rate per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019



Appendix figure 4: Children younger than 5 years YLL per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019



Appendix figure 5: Adults older than 70 years YLL per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019

Location	Alcohol use	Ambient particulate matter pollution	Child stunting	Child underweight	child wasting	High temperature	Household air pollution from solid fuel-	Low birth weight	Low temperature	No access to handwashing facility	Non-exclusive breastfeeding	Secondhand smoke	Short gestation	Smoking
Addis Ababa	1.4	4	0.1	0.1	0.7	0	1.7	0.7	3.7	4.8	0.1	0.4	0.7	1
Oromia	0.6	2.5	2.5	1.9	11.2	0.9	21.6	4.3	2.2	10.3	0.9	0.6	3.5	1.3
Amhara	0.4	2.5	1.8	1.4	6.7	0.9	19.8	3.3	2.4	9.5	0.4	0.6	2.6	0.4
SNNPs	0.8	2.4	2.7	2.2	10.2	1.8	19.9	3.5	1.4	9.6	0.8	0.5	2.9	0.9
Tigray	0.7	3.3	0.8	0.8	4	1.1	17.7	2.8	1.2	9.4	0.3	0.5	2.4	0.4
Harari	1	3.8	0.9	0.7	5.3	0	9.6	2.4	1.1	7.6	0.6	0.6	2.1	3.2
Afar	0.4	2.1	1.8	1.9	8.5	6.3	21	4.5	0.1	9.4	0.9	0.6	3.6	1.4
Somali	0.3	1.6	3.3	3.8	22.2	4.8	31.6	7.2	0.4	13.3	2.5	0.9	5.7	1.8
Benishangul-Gumuz	0.4	3.4	4.5	3.5	20	4.7	27.7	4.9	0.6	13.3	1.3	0.7	4	0.8
Dire Dawa	0.9	3.6	0.7	0.7	5.1	0.4	8.3	2.4	0.5	6.9	0.4	0.5	2	2.1
Gambella	0.8	2.2	0.4	0.4	3.2	2.5	9.3	2.2	0.1	5.4	0.4	0.3	1.9	2.1
Ethiopia	0.6	2.5	2.2	1.8	9.9	1.4	20.5	3.9	1.9	9.9	0.8	0.6	3.2	1

Appendix figure 6: Attribution of the risk factors to LRIs death rate per 100,000 population in all age groups between 1990 and 2019 for Ethiopia and its regions, both sexes, number of death, 2019. SNNPs: Southern Nations, Nationalities, and Peoples.

	Ambient particulate matter pollution	child stunting	Child under weight	child wasting	high temperature	Household air pollution from solid fuels	Low birth weight	Low temperature	No access to handwashing facility	Non-exclusive breastfeeding	Secondhand smoke	Short gestation
Addis Ababa	3.63	0.82	0.64	8.35	0.00	1.75	8.86	3.29	4.27	1.32	0.31	7.98
Oromia	6.41	14.75	11.45	67.14	2.34	60.08	25.95	6.05	28.32	5.25	1.66	21.03
Amhara	5.40	13.01	9.84	48.10	2.02	46.86	23.47	5.46	21.99	2.81	1.36	18.88
SNNPs	6.36	16.67	13.77	63.88	5.03	57.68	21.95	4.12	27.49	5.28	1.38	18.31
Tigray	5.03	6.15	5.75	29.88	1.87	29.89	20.59	2.00	15.32	1.91	0.79	17.45
Harari	9.12	7.21	5.80	43.66	0.01	25.51	19.63	2.74	19.30	5.00	1.62	17.18
Afar	4.88	11.42	11.57	52.76	15.77	53.12	28.03	0.26	23.50	5.49	1.33	22.31
Somali	5.40	18.08	20.92	121.83	16.76	110.21	39.76	1.46	46.07	13.99	3.18	31.30
Benishangul-Gumuz	12.63	28.22	22.25	125.72	17.81	105.51	30.75	2.22	50.23	8.05	2.61	24.89
Dire Dawa	9.38	5.50	5.64	42.47	1.11	23.88	19.72	1.42	18.88	3.67	1.50	16.71
Gambella	4.75	3.13	3.08	25.92	6.16	23.51	18.20	0.18	13.02	2.86	0.60	15.31
Ethiopia	6.06	14.39	11.93	64.00	4.28	58.22	25.08	4.73	27.20	5.22	1.58	20.40

Appendix figure 7: Attribution of the risk factors to LRIs death rate per 100,000 population in children younger than 5 years between 1990 and 2019 for Ethiopia and its regions, both sexes, number of death, 2019. SNNPs: Southern Nations, Nationalities, and Peoples.

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Appendix table 1: Number and percentage changes of episode attributable to LRIs in 1990 and 2019 for Ethiopia, its regions, both sexes

	All ages			Children younger than 5 years			People above 70		
Location	Episode, (95%UI),1990	Episode, (95%UI),2019	Change, %	Episode, (95%UI),1990	Episode, (95%UI),2019	Change, %	Episode, (95%UI),1990	Episode, (95%UI),2019	Change,%
Addis Ababa	194122.9(175403.8-213856.2)	176027.6(162152.3-190557.8)	10	44940.6(35673.3-56859.6)	14522.3(11237-18367.5)	68	8099.5(6891.6-9463.2)	24034.2(20749.5-27702.3)	196**
Oromia	2164243.7(1957719.5-2397957.9)	2597863.9(2372089.2-2859925.6)	20	739239.6(578477-935022.8)	613676.6(480687.2-765626.5)	17	110627.2(95303.7-129579.9)	292179.4(254670.4-342438.5)	164**
Amhara	1508431.4(1368059.8-1671550.1)	1400682.4(1285323-1530939.8)	8	423999.3(334700.8-538426.8)	261397.4(206754.7-327889.7)	39	116332.8(98774.4-137194.5)	198977.5(173809.4-229925.5)	71**
SNNPs	1235554.9(1108317.9-1368520.3)	1330491.5(1217176.7-1452694.1)	7	421825.6(335087.1-526155.2)	307771.3(248326.4-385053.7)	28	68084.5(57450-79640.8)	99723(88168.3-113438)	46**
Tigray	360795.1(328276.3-400714.9)	409829.8(376290.4-445030.2)	13	109047.9(86435.2-137691.1)	69958.2(55210.7-87468.6)	36	20653.3(17469.9-24256.6)	62677.2(53933.1-72927.6)	203**
Harari	15145.9(13618.9-16851.9)	13765.3(12657-15054.7)	10	4693.6(3691.4-5990.1)	2188.4(1723.8-2761.3)	54	307.2(259.6-357)	1614.8(1396-1863.6)	425**
Afar	113506.8(102317-126084.3)	113210.3(102987.9-124578)	1	32991.6(25672.4-42147.6)	26177.2(20744.1-32743.3)	21	2640.2(2212.5-3150.9)	7222.5(6246.8-8559.1)	173**
Somali	300306.3(268988-336331.8)	463220.4(420429.8-516009.4)	54	103526.3(81391.3-131352.8)	126089.6(99611.9-160423.3)	21**	6182.3(5316-7370.4)	30203.2(25942.8-35038.5)	388**
BG	68501.6(61804.9-75736.4)	71675.7(64972.1-79105.8)	4	20970.5(16626.7-26454.5)	18175.6(14339.5-22922.1)	14	3288.9(2784.8-3911.4)	4311.3(3743.8-5113.9)	31**
Dire Dawa	30607.1(27359.8-34252.2)	26221.1(24010.1-28647.8)	15	9547.4(7523-12185)	4387.7(3439.6-5583.9)	55	1274.8(1090.1-1483.5)	2840.1(2469-3289.5)	122**
Gambella	19687.9(17723.9-21945.7)	25685.2(23516.6-28093.2)	30**	6747.7(5338.7-8613.7)	4335.4(3428.4-5400.9)	36	1568.1(1316.6-1825.8)	1489.6(1281.4-1737.3)	6
Ethiopia*	6010904.2(5467801.6-6648644.3)	6628673.6(6108786.2-7230986.3)	10**	1917530.8(1518850.1-2400978.5)	1448680.4(1150089.8-1799704.4)	25	339059.4(293491.9-387514.2)	725273.3(640315.4-837746.3)	**113****

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 1990 and 2019*

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Appendix table 2: Rate and percentage changes of episodes attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes

	Age standardized			Children younger than 5 years			People above70		
Location	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%
Addis Ababa	11373(10484.2-12197.4)	6788.1(6285.1-7339.1)	40	14666.9(11642.4-18556.9)	4927.2(3812.5-6231.8)	67	35138(29897.7-41054.2)	30748.4(26546-35441.2)	13
Oromia	14613.1(13525.9-15725.8)	8659.9(8040.1-9411.6)	41	22232(17397.2-28120)	9039.4(7080.5-11277.7)	60	46498.3(40057.6-54464.4)	41564.6(36228.7-48714.4)	11
Amhara	12826.4(11830-13882.8)	7716.9(7162.3-8321.3)	40	16487.1(13014.7-20936.6)	8061.7(6376.4-10112.3)	52	43580(37002.4-51395.2)	35377.7(30902.9-40880.2)	19
SNNPs	13591.9(12538.6-14646.8)	8235.5(7670.5-8846.4)	39	20106.4(15972-25079.3)	8427.1(6799.4-10543.2)	59	44628.1(37657.5-52203.1)	36616.1(32373.5-41652)	18
Tigray	13927.2(12858.2-15100.7)	8663.8(8034-9382.3)	38	19185.4(15207-24224.8)	8342.1(6583.5-10430.1)	57	43748.4(37005.1-51381)	40859(35158.8-47541.2)	7
Harari	13014.6(11941-14066.7)	7190.5(6684.1-7718.6)	45	19672.6(15471.9-25106.9)	6821.6(5373.5-8607.3)	66	33916.7(28665.1-39416.7)	32797.4(28354-37850.7)	4
Afar	15245.7(14050.8-16525.6)	9350.1(8648.8-10157.4)	39	21151.6(16459.1-27021.7)	9365.5(7421.7-11714.7)	56	39849(33393.8-47557.2)	44368.7(38375.2-52580.1)	11**
Somali	11482.7(10638.1-12368.7)	9220(8515.8-10046.3)	20	16792.9(13202.4-21306.6)	10062.7(7949.6-12802.8)	41	32748.3(28159.7-39042.1)	41031.2(35243.4-47600)	25**
BG	15628.1(14481-16809.3)	9054.6(8394.2-9766)	42	22041.1(17475.5-27805)	10481.8(8269.5-13219)	53	42911.6(36334.5-51032.5)	37592.7(32643.9-44591.2)	13
Dire Dawa	12806.6(11807.9-13871.4)	7148.8(6634.6-7750.7)	44	19968.2(15734.3-25484.7)	7191.5(5637.6-9152.1)	64	38333(32779.4-44607)	32033.6(27847.4-37101.4)	17
Gambella	13623.1(12637.4-14572.4)	7575.8(7002.3-8128.2)	44	21419.8(16947.2-27343.2)	6791.1(5370.4-8460.1)	69	40197.8(33751.8-46803.7)	32657.1(28093.9-38087.2)	19
Ethiopia*	13619.7(12640.8-14588.6)	8313.7(7757.6-8918)	39	19486.4(15434.9-24399.3)	8685.3(6895.1-10789.8)	56	44092.2(38166.5-50393.4)	38394.4(33896.9-44348.5)	13

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate*; ***percentage increase between 2019 and 1990*

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Appendix table 3: Number and percentage changes of death attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes.

	All age			**Children younger than 5**			**People above 70 years**		
Location	death, (95%UI),1990	death, (95%UI),2019	Change,%	death, (95%UI), 1990	Death, (95%UI),2019	Change, %	Death , (95%UI),1990	Death, (95%UI),2019	Change,%
Addis Ababa	2159.3(1731.9-2690.7)	918.8(767.4-1116.9)	58	1353(981.9-1846.7)	69.1(41.7-107.4)	95	209.5(154.3-291.5)	393.6(320.9-495.3)	87**
Oromia	40004.4(29432.4-51942.2)	18206.1(15193.3-21745.4)	55	30614.3(20932.5-42033.5)	8306.2(5763.5-11611.8)	73	2793.5(2005.1-3673)	5971.6(4831.7-7093.4)	113**
Amhara	25449.3(20869.5-30724.8)	9525.5(7530.5-11872.2)	63	17780.1(13674.3-22720.1)	3079.5(1805.3-4737.3)	83	2717.2(2016.4-3535.8)	3839.9(3022.6-4825.6)	41**
SNNPs	26044.7(20108-33017)	9494.7(7713.5-11649)	-64	20390.6(14627.6-26712.9)	4326.6(2891.3-6157.2)	79	1771.7(1254.5-2417.6)	2302.6(1867.3-2772.8)	29**
Tigray	6463.8(5272.1-7762.9)	2551.4(2090.3-3028.6)	61	4436(3373.5-5736)	564.2(364.9-825)	88	550.8(395.7-749.1)	1209.7(978.5-1467.8)	119**
Harari	336(233.3-448.8)	93.1(73.8-116)	73	273.5(174.1-382.7)	28.8(16.4-44.3)	90	6.9(3.7-11)	34.1(27.1-41.8)	395**
Afar	1717.5(1300.7-2243.4)	706.2(567.7-869.6)	-59	1128.9(751.1-1596.7)	284.2(182.5-426)	75	66.9(43.5-102.1)	149.3(117.3-186.6)	123**
Somali	3603.8(2620-4713.6)	3907.5(3007.4-4959.4)	#N/A	2811.1(1929.6-3874.8)	2472.2(1695.2-3506.8)	13	150.8(98-222.3)	563.1(433.4-715.8)	273**
BG	1549.2(1131.1-2097)	619(470.7-803)	61	1204.8(805.6-1703.9)	373(245.3-539.3)	70	74.7(50.3-105.7)	77(61.1-97.3)	3**
Dire Dawa	632.3(445.5-830.9)	154.6(120.6-193.8)	76	518.4(329.5-718.7)	51(27.3-82.9)	91	28.8(20.1-40)	55(44-67.9)	90**
Gambella	475.9(328.5-635.7)	123.2(98.2-151.9)	75	398.6(253.7-555.7)	36.4(20.7-57.2)	91	28.8(18.6-41.9)	30.9(24.6-38.1)	7**
Ethiopia*	108436.6(87669-132758.3)	46300.7(39515.8-54642.2)	58	80909.9(62491.6-103448.8)	19591.8(14018.4-26899)	76	8400.1(6490.3-10700.9)	14627.6(12393.7-16892.8)	74**

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 2019 and 1990*

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Appendix table 4: Age standardized mortality rate, Ethiopia and its regions, by sex, 2019.

Age standardized mortality rate per 100,000 people, 2019		
Location	Female	Male
Addis Ababa	47(35.5-62.5)	73.6(55-98.3)
Oromia	77.3(62-92.4)	100.3(79.9-123.5)
Amhara	57.9(44.1-73.7)	92.5(70.5-122.1)
SNNPs	79.2(63.5-95.2)	118.8(94.3-146.3)
Tigray	73.2(55.9-93.5)	96.9(74.8-122.3)
Harari	63(49-79.9)	95.7(72.5-123.4)
Afar	112.4(87.3-142.3)	98.7(76.9-127.3)
Somali	88.3(69-111.4)	101.7(77.2-130.7)
Benishangul-Gumuz	109.2(82.6-138.8)	95.8(74.6-124.1)
Dire Dawa	56.2(42.5-71.3)	85.4(67.3-109.5)
Gambella	47.9(34.6-60.1)	120.2(95.6-149.5)
Ethiopia	71.8(60.2-82.9)	100.6(84-121.4)

SNNP: Southern Nations, Nationalities, and Peoples

Appendix table 5: Number and percentage changes of YLL attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes

	all age			**Children younger than 5 years**			**People above 70**		
	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%
Addis Ababa	149543.9(115542.6-195437)	29703.1(23833.4-36855.7)	81	118961.7(86499.1-162678.7)	6098.2(3693.1-9483.3)	95	3131.8(2301.7-4374.6)	5359.8(4334.8-6816.8)	71**
Oromia	3019031.9(2144916.2-4057496.3)	981808.4(748459.2-1278135)	68	2680397.2(1832260.4-3680767.1)	729313.8(506226.4-1021016.9)	73	44619.5(31636-59105.6)	78166.1(62837.5-93527.9)	75**
Amhara	1813522.3(1445106.4-2246142.2)	428277.8(309674.7-583000.2)	77	1560078.3(1201305.4-1993362.8)	270909.2(158846-416496.1)	83	42578.2(31294.7-56216.9)	50955.1(39726.1-64844.6)	19**
SNNPs	1993643.3(1489598.4-2577052.3)	543135.8(405565.6-711397.4)	73	1785675.1(1284021-2339272.5)	380166.4(254486.8-541224.9)	79	28746.2(20086.2-39789.1)	31964.4(25673.6-38778.5)	11**

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Tigray	455613.4(364406.1-569702.1)	96429.9(74139.8-122350.5)	79	389399.3(296618.1-504230.2)	49712.6(32198.3-72764.9)	88	9207.1(6568.7-12629.1)	16086.6(12946.2-19581.8)	74**
Harari	26755.3(17866.5-36380.3)	4273.6(2999.1-5798.4)	85	23959.3(15245.4-33513.8)	2541.6(1449.6-3887.3)	90	106.7(57.6-175.1)	455.9(361.3-558.3)	327**
Afar	124052(89386.4-166880.5)	39507.6(29535.5-52178.5)	69	99155.3(65972.9-140018.8)	24998.1(16028.5-37426.3)	75	1121.4(723.7-1722.7)	1931.7(1521.3-2395.6)	72**
Somali	281532.2(201275.3-374880.8)	266379.4(193669.7-357880.7)	6	247138.5(169803.8-339740.3)	216954(148995.2-307369.5)	13	2256.6(1434.6-3376.4)	7542.1(5740-9680.2)	234**
BG	119211.2(83517.3-165095.7)	42245.6(30388.8-57591.8)	-65	105463.5(70756-148983.1)	32718.1(21576.4-47307.2)	69	1256.7(836.7-1780.3)	1094.3(857.5-1389.1)	13
Dire Dawa	50024.5(33464.5-67580.6)	7267.7(5038-10264.7)	86	45377.4(28907.2-62914.9)	4497.4(2411.8-7298.3)	91	439.2(306.6-609.5)	742.1(586.6-922.8)	68**
Gambella	37680.8(24783.6-51516.1)	6064.4(4389.3-7853.6)	84	34899.5(22233.1-48609.4)	3212.2(1830.4-5034.1)	91	460.7(299.3-663.6)	457.5(352.6-577.6)	1
Ethiopia*	8070611.3(6356905.2-10091563.7)	2445093.7(1934420.8-3119838.6)	70	7090505.4(5482895.7-9059421.2)	1721122.3(1231032.1-2362958.7)	76	133924.6(102756.8-170932.9)	194756.2(165462-225502.1)	45**

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 2019 and 1990*

Appendix table 6: Rate and percentage changes of YLL attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes.

	all age			**Children younger than 5 years**			**People above 70**		
Location	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%
Addis Ababa	6362.2(5161.9-7847.9)	1285.6(1065-1561.8)	80	38824.7(28230.1-53092.4)	6857.1(5545.8-8721.2)	95	13587(9985.4-18978.3)	6857.1(5545.8-8721.2)	50
Oromia	11217.6(8517-14318)	2433.8(2042.2-2879.5)	78	80610.7(55103.7-110696)	11119.7(8939.1-13305)	87	18754.2(13297.1-24843)	11119.7(8939.1-13305)	41
Amhara	8690.4(7146.3-10453.8)	2016.4(1551.4-2541.8)	77	60663.3(46712.5-77511.5)	9059.7(7063.2-11529.2)	87	15950.4(11723.4-21059.7)	9059.7(7063.2-11529.2)	44
SNNPs	11633(9119.4-14477.9)	2698.1(2243.5-3250.2)	77	85114.7(61203.2-111502.1)	11736.6(9426.7-14238.6)	88	18842.6(13166.1-26081)	11736.6(9426.7-14238.6)	38
Tigray	10346.4(8522.9-12340.3)	1977.1(1593.9-2395)	81	68509.3(52185.7-88712.2)	10486.8(8439.5-12765.3)	92	19502.8(13914.1-26751.2)	10486.8(8439.5-12765.3)	47
Harari	12826.5(9336.5-16985.4)	2060.4(1595.6-2623.1)	84	100421.7(63898.7-140467.8)	9260.4(7338.7-11340.3)	93	11782.6(6360.4-19341.1)	9260.4(7338.7-11340.3)	22

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Afar	10993.5(8520.8-14193.6)	2824.6(2323-3414)	74	63570.5(42296.6-89769)	11867.1(9346-14716.9)	86	16925.5(10923.7-26001.7)	11867.1(9346-14716.9)	30
Somali	6286.9(4860.5-7970)	3236.4(2537.4-4006)	49	40088.1(27543.7-55109)	10246(7797.8-13150.6)	57	11953.6(7599.2-17885.5)	10246(7797.8-13150.6)	15
BG	14965.1(11197.4-19998.6)	3571.1(2772.4-4510.7)	76	110847.2(74368-156588.4)	9541.9(7476.9-12112.3)	83	16397.3(10917-23228.5)	9541.9(7476.9-12112.3)	42
Dire Dawa	11749.7(8605.4-15249.5)	1832.8(1407.3-2363.1)	84	94905.3(60458.5-131584.5)	8371(6616.3-10408.2)	93	13207.9(9219.6-18328.2)	8371(6616.3-10408.2)	37
Gambella	13175.8(9291-17411)	1937.4(1567.6-2344.6)	85	110783.8(70576-154304.1)	10030.9(7730.2-12664.9)	96	11811.4(7673.5-17012.5)	10030.9(7730.2-12664.9)	16
Ethiopia*	10189.1(8347.5-12201.8)	2404.5(2059.4-2833.3)	76	72055.4(55718.5-92064)	10309.9(8759.2-11937.6)	86	17415.9(13362.7-22228.5)	10309.9(8759.2-11937.6)	41

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate*; ***percentage increase between 2019 and 1990*

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BMJ Open

The burden of lower respiratory infections and associated risk factors across regions in Ethiopia: A subnational analysis of the Global Burden of Diseases 2019 Study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2022-068498.R1
Article Type:	Original research
Date Submitted by the Author:	26-Jun-2023
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Secondary Subject Heading:	Epidemiology, Respiratory medicine, Public health, Health policy, Global health
Keywords:	Epidemiology < INFECTIOUS DISEASES, Respiratory infections < THORACIC MEDICINE, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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The burden of lower respiratory infections and associated risk factors across regions in Ethiopia: A subnational analysis of the Global Burden of Diseases 2019 Study

Ethiopia Subnational-Level Lower Respiratory Infections Burden collaborators

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- Main text word count: Current: 4487

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Abstract

Objective: This analysis is to present the burden and trends of morbidity and mortality due to lower respiratory infections, their contributing risk factors, and the disparity across administrative regions and cities from 1990 to 2019.

Design: This analysis used Global Burden of Disease 2019 framework to estimate morbidity and mortality outcomes of lower respiratory infection and its contributing risk factors. The Global Burden of Disease study uses all available data sources and Cause of Death Ensemble model to estimate deaths from lower respiratory infection and a Meta-Regression Disease Modeling technique to estimate lower respiratory infection non-fatal outcomes with 95% uncertainty intervals.

Study setting: The study includes nine region states and two chartered cities of Ethiopia

Outcome Measures: We calculated incidence, death, and years of life lost (YLLs) due to LRIs and contributing risk factors using all accessible data sources. We calculated 95% uncertainty intervals (UI) for the point estimates.

Results: In 2019, LRIs incidence, death, and YLLs among all age groups were 8,313.7 (95% UI: 7,757.6–8,918), 59.4 (49.8–71.4) and 2,404.5 (2059.4–2833.3) per 100,000 people, respectively. From 1990, the corresponding decline rates were 39%, 61%, and 76%, respectively. Children under the age of five years account for 20% of episodes, 42% of mortalities, and 70% of the YLL of the total burden of LRIs in 2019. The mortality rate was significantly higher in predominantly pastoralist regions–Benishangul-Gumuz 101.8 (84.0–121.7) and Afar 103.7 (86.6–122.6). The Somali region showed the least decline in mortality rates. More than three-fourths of under-five child deaths due to LRIs were attributed to malnutrition. Household air pollution from solid fuel attributed to nearly half of the risk factors for all age mortalities due to LRIs in the country.

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Conclusion: In Ethiopia, LRIs have reduced significantly across the regions over the years (except in elders), however are still the third leading cause of mortality, disproportionately affecting children younger than five years old, and predominantly pastoralist regions. Interventions need to consider leading risk factors, targeted age groups and pastoralist and cross-border communities.

Keywords: *Lower respiratory infections, regions, chartered cities, Ethiopia*

Strengths and limitations of this study

- The analysis has considered political, government and administrative changes of regional states and cities over the years to map available data and populations
- The analysis used all available data identified through an extensive collaboration effort and involving more than 700 leading researchers and policy makers from Ethiopia
- When data were not available for a particular regional states or city, the modelling process used data from other locations borrowing strength from geographic locations and time, and use predictive covariates
- However, limited quality data availability and accessibility for the analysis resulted in wider 95% Uncertainty Intervals which largely affect policy debates, prioritization, and health decisions.

INTRODUCTION

Lower Respiratory Infections (LRIs) have been a predominant health problem worldwide, causing more than 2.3 million deaths in 2016 alone, amounting to a mortality rate of 32.2 per

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100,000 people (1). LRIs comprise diseases of the lower airways such as pneumonia, bronchitis, and bronchiolitis, among others (2). Nearly all (99%) of LRI deaths occur in low- and middle-income countries and highly affect children under the age of five years (3). In sub-Sahara African countries, the mortality rate is 66.4 per 100,000 people, which is four times the mortality rate in East Asia and twice the global average (2).

Ethiopia ranked in the top three African countries in the number of under-five child deaths from LRIs (4). To prevent child death from LRIs and other diseases in early life, Ethiopia has been implementing the "Integrated Management of Childhood Illness" program since 1997 later scaled up to the national level in 2007 (5). LRIs, and pneumonia in particular, have been among the top three leading causes of childhood mortality in the country (6). Among LRIs' aetiologies, S. pneumonia contributed to more deaths than the other LRIs aetiologies combined (3). In 2011, the country introduced 10-valent pneumococcal conjugate vaccine (PCV 10) into its national immunization program to reduce the burden of Streptococcal pneumonia (7).

Morbidity and mortality from LRIs are attributable to multiple underlying factors. Malnutrition is one of the main underlying risk factors (8, 9). The other main attributable factor are poor living conditions that include household crowding, parental smoking, high use of household solid fuel/biomass consumption, poor ventilation, and lack of hand-washing facilities (10-12). In addition, bottle feeding also contributes to the burden of LRIs in children (13).

The flagship Ethiopian Health Extension Program (HEP) has been the backbone of the country's health system strategies to reduce the burden of LRIs and other diseases through preventive and health promotion activities at the community level. The HEP has also improved broader access to health care, availability of essential antibiotics, and immunization mainly to the rural population since 2004 (14). In 2010, the country also introduced the "integrated community case

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management" (ICCM) approach to treat pneumonia through trained health cadres of health extension workers (HEWs) implementing HEP (15).

Currently, Ethiopia is implementing its Health Sector Transformation Plan-2 (HSTP-2) which is adapted from the Sustainable Development Goals. Some of the aims include increasing the proportion of under-five children with pneumonia who received antibiotics from 48% to 69% and improving full vaccination coverage from 44% to 69% between 2020 and 2025 (16). Commitment to international goals such as The Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea by 2025 could be reached if enough investment is made in high LRI burden countries like Ethiopia (17).

As Ethiopia is a country of stark contrasts in socioeconomic, epidemiological, and geographical variations, estimating disease burden at the regional level could provide valid and reliable information to inform policy decisions, including efficient resource allocation to match the burden in the subnational states. Hence, this article presents the 2019 Global Burden of Diseases, Injuries, and Risk Factors study (GBD) results on the burden, trends and regional variations of LRIs in Ethiopia from 1990 to 2019.

METHODS

Study Setting

Ethiopia is the second-most populous country in Africa next to Nigeria, with an estimated population of 112 million in 2019 (18). More than half of the country's population is under 20, and over 80% of the population resides in rural areas (19). The country is subdivided into ten regional states (Afar, Amhara, Benishangul-Gumuz, Gambella, Harari, Oromia, Somali, Sidama, Southern Nations and Nationalities and Peoples (SNNP), and Tigray) and two chartered cities

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(Addis Ababa and Dire Dawa). During this study, Sidama was a zonal administration under the SNNP region. Oromia, Amhara, and SNNP are the highly populated regions. In this study, we classified the regions into urban (Addis Ababa, Dire Dawa, and Harari), agrarian (Oromia, Amhara, SNNP, Tigray), and pastoralist (Benishangul-Gumuz, Afar, Gambella, and Somali). The socio-economy of the regions such as income per person, educational attainment, and total fertility rate (TFR) varies as measured in socio-demographic index (SDI) (20) (Figure 1).

The healthcare system of the country is a three-tiered system consisting of primary, secondary, and tertiary levels of healthcare delivery units with 21,154 functioning health facilities and 159,545 health workforce in 2019 (16). The primary health care unit (PHCU) consists of health posts (staffed by HEWs), health centres, and primary hospitals. The secondary level of care consists of general hospitals and the tertiary level of care includes national referral hospitals which provide specialized services (16).

Data Sources and Analysis

The analysis and findings of LRIs presented in this analysis were produced by the Ethiopia Subnational Burden of Disease Initiative, a collaborative endeavour between the National Data Management Center for Health (NDMC) at the Ethiopian Public Health Institute (EPHI) and the Institute for Health Metrics and Evaluation (IHME), as part of GBD. The details of the methodology were described elsewhere (21). In brief, woreda (district) level geographic boundary mapping of regions and cities was used because woredas were relatively stable government structures (compared to lower or higher level administrative structures) during political or government changes and through the three census years (1984, 1994, and 2007). First, the analysis was estimated by mapping population and demography at the district level by

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time and region. Then, the data sources were mapped by regions before processing the data in the GBD analysis based on GBD protocol. EPHI, in collaboration with IHME, gathered all accessible data sources by location for Ethiopia and all regions and cities that included census, demographic surveillance, household surveys, diseases registry, health service utilization, disease notification, and other data for this analysis. A comprehensive description of data sources, quality, and modelling for GBD 2019 has been reported on the following online portal: (http://ghdx.healthdata.org/gbd-2019/data-input-sources). This study outputs predates the COVID-19 and civil war occurred in the northern and other parts of the country and does not include the impact of COVID-19 or civil war.

GBD Methods and Tools

The GBD details are reported elsewhere (22). Diseases and injuries within the GBD were organized into levels: Level 1 being the broadest causes of death and disability to Level 4 being the most specific. Within the three Level 1 causes (communicable, maternal, neonatal, and nutritional diseases; non-communicable diseases; and injuries), there were 174 Level 3 causes. The GBD 2019 study has estimated the burden of disease, including LRIs, for Ethiopia's national and subnational states. LRIs comprise diseases of the lower airways such as pneumonia, bronchitis, and bronchiolitis, among others (2). LRI mortality was estimated by age, sex, geography, and year using a modelling platform called the Cause of Death Ensemble model. LRI morbidity, including incidence, was modelled using a meta-regression platform known as DisMod-MR, a Bayesian, hierarchical, mixed-effects meta-regression platform (23). Years of life lost (YLLs) were computed by multiplying cause-specific deaths by the life expectancy at the age of death (24, 25). Population risk assessments over time and among risks were estimated using the comparative risk assessment approach developed for the GBD study (26, 27). The

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GBD risk factors were categorized as follows: Level 1 risk factors are behavioural, environmental, occupational, and metabolic; Level 2 risk factors include 20 clusters of risks; Level 3 consists of 52 clusters of risks; and Level 4 contains 69 specific risk factors. All metrics were estimated separately for Ethiopia's nine regions and two chartered cities, and are presented with their 95% uncertainty intervals (UIs). All estimates produced for GBD report 95% uncertainty intervals (UIs) that account for sampling and non-sampling error associated with data and various assumptions of the modelling process and are derived from the 2·5th and 97·5th percentiles of 1000 draws(22, 28).

Presentation of results

We present the burden of LRIs in Ethiopia and its regional states using incidence, deaths, and YLLs categorized by sex, age groups, and year. We used numbers, rates, and percent change for the quantification of the burden. We also estimated the risk factors contributing to LRIs in Ethiopia and the percent change between 1990 and 2019. We reported GBD causes and risk factors using level 3 classifications, with 95% Uncertainty Intervals (UI). Additional tables and figures are attached in the supplementary materials.

Patient and public involvement

Patients and the public were not involved in the design of the study.

RESULTS

Morbidity Due to LRIs

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In 2019, an estimated 6,628,673.6 (95% UI: 6,108,786.2–7,230,986.3) new cases of LRIs occurred in Ethiopia resulting in an age-standardized incidence rate of 8,313.7 per 100,000 people (7,757.6–8,918). Out of the total LRI episodes, 22% (1,448,680.0 new cases [1,150,089.8–1,799,704.4]) of new cases occurred among children younger than 5 years, yielding an annual incidence rate of 8,685.0 per 100,000 children (6,895.1–10,789.8). In adults older than 70 years, there were 725,273.3 (640,315.4–837,746.3) new cases of LRIs with an annual incidence of 38,394.4 per 100,000 people (33,896.9–44,348.5) (Figure 2; Supplemental Table 1 and Table 2).

Compared to national estimates, a significantly lower age-standardized incidence rate of LRIs per 100,000 people was observed in the chartered cities (6,788.1 [6,285.1–7,339.1] in Addis Ababa, 7,148.8 [6,634.6–7,750.7] in Dire Dawa), and in Harari region (7,190.5 [6,684.1–7,718.6]). The highest rates of age-standardized incidence per 100,000 people were observed in Afar (9,350.2 [8,648.8–10,157.4]), Somali (9,220.0 [8,515.9–10,046.4]), and Benishangul-Gumuz (9,054.6 [8,394.2–9,766.0]) although not significant compared to the national estimate (Figure 2; Supplemental Figure 1 and Table 2).

In children younger than 5 years, the lowest incidence rates were observed in Addis Ababa (4,927.2 [3,812.5–6,231.8]), Harari (6,821.6 [5,373.5–8,607.3]), and Gambella (6,791.1 [5,370.4–8460.1]) per 100,000 people, substantially below the national estimate. The highest incidence of LRIs per 100,000 children were recorded in Benishangul-Gumuz (10,481.8 [8,269.5–13,219.0]), Somali (10,062.7 [7,949.6–12,802.8]), Afar (9,365.5 [7,421.7–11,714.7]), and Oromia (9,039.4 [7,080.5–11,277.7]).

The age-standardized decline rate between 1990 and 2019 was 39% for both sexes, and it was 56% in under-five children and 13% in adults older than 70. The lowest decline in age-

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standardized incidence rate was in Somali (19%); while it was between 38% and 44% for the remaining regions (Supplemental Table 2).

In children younger than 5, the incidence rates increased slightly between 1990 and 1995, except in Addis Ababa and Amhara region. The highest decline rates were found between the years 2005 and 2015 across all regions (Supplemental Figure 2).

Mortality due to LRIs

In 2019, LRIs caused 46,300.7 (95% UI: 39,515–54,642) deaths in Ethiopia, giving the age-standardized mortality rate of 86.4 (75.3-97.6) per 100,000 people. Under-five mortality accounted for 42% (19,591.8 [14,018.4–26,899.0]) of all deaths due to LRIs which resulted in a mortality rate of 117.4 (84.0–161.2) per 100,000 children. Of the under-five deaths, 71% (13,919.0 [9,946.0–18,860.0]) occurred in the first year of life. In adults older than 70 years, LRIs caused 14,627.6 (12,393.7–16,892.8) deaths, which was a mortality rate of 774.3 (656–894.2) deaths per 100,000 adults (Table 1; Supplemental Table 3).

In 2019, the number of deaths in all age groups by region were highest in Oromia (18,206 [15,193–21,745]), Amhara (9525 [7,530–11872]), SNNP (9,494 [7,713–11,649]), and Somali (3,907.5 [3,007.4–4,959.4]), followed by Tigray (2,551.4 [2,090.3–3,028.6]), Afar (706.2 [567.7–869.6]), Benishangul-Gumuz (619 [470.7–803.0]), Dire Dawa (154.6 [120.6–193.8]) and Gambella (123.2 [98.2–151.9]). Harari (93.1 [73.8–116.0) had the lowest number of deaths. (Supplemental Table 3).

Between 1990 and 2019, the age-standardized mortality rate declined by 61%, and the decline in under-five children and adults over 70 years was 86% and 30%, respectively (Table 1 and Supplemental Figure 3).

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Table 1: Lower Respiratory Infections mortality rates and percentage changes between 1990 and 2019 in Ethiopia, both sexes, with different age groups

	Age standardized		Children younger than 5			People older than 70		
Location	Deaths per 100 000 people [95% UI], 1990	Deaths per 100 000 people [95% UI], 2019	Deaths per 100 000 children [95% UI], 1990	Deaths per 100 000 children [95% UI], 2019	Cha-Nge,%	Deaths per 100 000 people [95% UI], 1990	Deaths per 100 000 people [95% UI], 2019	Cha-nge,%
Addis Ababa	163.4[134.6-206.9]	59.4[49.8-71.4]	441.5[320.4-602.7]	23.4[14.1-36.4]	95	909.2[669.5-1264.6]	503.6[410.5-633.7]	45
Oromia	241.3[188.5-292.8]	89.3[75.9-103.1]	920.7[629.5-1264.1]	122.3[84.8-171]	87	1174.1[842.8-1543]	849.5[687.3-1009]	28
Amhara	197.7[163.5-236.5]	74.3[59.4-91]	691.3[531.7-883.4]	94.9[55.6-146.1]	87	1017.9[755.4-1324]	682.7[537.4-857.9]	33
SNNPs	243.7[196.4-296.9]	98.9[83.8-116.6]	971.9[697.2-1273.2]	118.4[79-168.5]	88	1161.3[584.7-822.3]	845.4[685.6-018.1]	28
Tigray	242.7[200.5-292]	84.6[69.2-100.1]	780.4[593.5-1009.1]	67.2[43.5-98.3]	92	1166.7[838.2-1586]	788.6[637.9-956.8]	33
Harari	240.2[182.6-303.1]	77[63-92.5]	1146.7[730-1604.1]	89.9[51.1-138]	93	762.3[412-1223.7]	694.3[551.9-849]	9
Afar	244.8[186.5-316.9]	103.7[86.6-122.6]	723.7[481.5-1023.7]	101.7[65-152.4]	86	1010[658-1541.7]	917.6[720.6-146.8]	10
Somali	147.6[113.8-192.6]	97.5[79.2-118.6]	455.9[313-628.5]	197.3[135-279.8]	57	798.8[519.2-1177.6]	765.1[588.8-972.4]	5
BG	284.1[221.8-358.1]	101.8[84-121.7]	1266.4[846.7-790.9]	215.1[141.4-311]	84	975.3[656.5-1379.3]	671.9[532.7-848.7]	32
Dire Dawa	220.1[171.6-270.9]	69.9[56.5-84]	1084.2[689.1-503.2]	83.7[44.7-135.9]	93	868.7[604.5-1205.5]	621.3[496.4-766.1]	29
Gambella	231.5[176.8-297.4]	82.4[68.3-97.1]	1265.5[805.4-764.3]	57[32.4-89.6]	96	739.6[477.7-1074.9]	678.3[540.4-835.3]	9
Ethiopia*	223[184.7-264.3]	86.4[75.3-97.6]	822.2[635-1051.2]	117.4[84-161.2]	86	1092.3[844-1391.5]	774.3[656-894.2]	30

N.B: all changes are in decreasing percent. SNNPs: Southern Nations, Nationalities, and Peoples; BG: Benishangul-Gumuz; *national estimate

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In Ethiopia, the age-standardized mortality rate was higher among males (100.6 [84.1-121.4]) than females (71.8 [60.2–82.9]) (Supplemental Table 4).

In 1990, the age-standardized mortality rate per 100,000 people was the highest in Benishangul-Gumuz (284.1 [221.8–358.1]), Afar (244.8 [186.5–316.9]) and SNNP (243.7 [196.4–296.9]), although it is not significantly different from the national estimate. On the other hand, the lowest age standardized mortality rate was exhibited in Somali (147.6 [113.8–192.6]). Although the value was not significantly different from the national value in 1990, Addis Ababa showed the second lowest age-standardized mortality rate (163.4 [134.6–206.9]) (Table 1).

In 2019, the age-standardized mortality rate per 100,000 people was significantly lower in Addis Ababa (59.4 [49.8–71.4]) when compared to other regions, although not significantly lower than Gambella and other urban areas (Harari and Dire Dawa). Dire Dawa showed a significantly lower age-standardized mortality rate when compared to Benishangul-Gumuz, Afar, and SNNP. Compared to the national estimate, the regions of Afar (103.7 [86.6–122.6]) and Benishangul-Gumuz (101.8 [84.0–121.7]) recorded the highest age-standardized mortality rates per 100,000 people, although the difference is not statistically significant (Table 1). Compared to the 1990s, there was a 58% to 68% decrease in the age-standardized mortality rates across all regions. However, the Somali region recorded a 34% reduction in mortality rates (Supplemental Figure 3).

Among children below the age of five, the mortality rate per 100,000 people was significantly lower in Addis Ababa (23.4 ([14.1–36.4]) than other regions, although it was not significantly less than Gambella in 2019. The mortality rate was the highest in Benishangul-Gumuz (215.1 [141.4–311.0]), Somali (197.3 [135.2–279.8]), and Oromia (122.3 [84.8–171.0]) despite being not significantly higher than the national estimate (Table 1). Dire Dawa showed a significantly

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lower mortality rate than Benishangul-Gumuz and Somali. Harari had a significantly lower mortality rate than Benishangul-Gumuz. For all regions, the mortality rate declined for children younger than 5-years between 1990 and 2019 by between 84% (in Benishangul-Gumuz) and 96% (in Gambella), except in Somali, which showed a 57% decline (Table 1). The mortality rate increased slightly between 1990 and 1995 and between 2010 and 2015 in Somali region (Supplemental Figure 4).

The mortality rate in adults older than 70 was the lowest in Addis Ababa (503.6 [410.5–633.7]). Other regions and cities have not shown a statistically significant difference from the national estimate. The decline in mortality rates between 1990 and 2019 is below 50% across all regions (Table 1). The mortality rate increased in Afar and Somali between 2005 and 2019 and in Gambella between 1990 and 2005 (Supplemental Figure 5).

Premature Mortality due to LRIs

In 2019, premature death due to LRIs was 2,445,093.7 (95% UI: 1,934,420.8–3,119,838.6) YLLs, yielding an age-standardized rate of 2404.5 per 100,000 people (2059.4–2833.3). Compared to 1990, the age-standardized YLL rate declined by 76% in 2019. In parallel, 70% of all premature mortality occurred in children younger than five, which accounted for 1,721,122.3 (1,231,032.1–2,362,958.7) YLLs. The YLL rate of 72,055.4 (55,718.5–92,064) per 100,000 under-five children in 2019 declined by 86% compared to the YLL rate in 1990. Adults over 70 years contributed 8% of all YLLs due to LRIs (194,756.2 [165,462.0–225,502.1]), yielding a rate of 10,309.9 (8759.2–11,937.6) YLLs per 100,000 people (Table 2; Supplemental Table 5 and Table 6).

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Compared to 1990, the number of YLLs has decreased by 70% in all age groups and by 76% in children younger than five in 2019. However, the number of YLLs has increased by 45% in adults older than 70 (Supplemental Table 5).

The age-standardized YLL rate was significantly lower in Addis Ababa (1,285.6 [1,065–1,561.8]) in 2019 compared to the national average. The highest age standardized YLL rate were in Benishangul-Gumuz (3,571.1 [2,772.4–4,510.7]), Somali (3,236.4 [2,537.4–4,006]), and Afar (2,824.6 [2,323–3,414]), although not statistically significant compared to the national estimate (Table 2).

In children younger than five years, Addis Ababa (2,069 [1,253–3,217.5]) had a significantly lower YLL rate than the national estimate. The YLL rate was observed to be the lowest in Gambella (5,031.8 [2,867.2–7,885.7]), although not significantly lower than the national estimate (Table 2).

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Table 2: Lower Respiratory Infections YLL rates and percentage changes between 1990 and 2019 in Ethiopia, both sexes, with different age groups

	Age-standardized		**Children younger than 5 years**			People older than 70		
Location	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change, %	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change, %
Addis Ababa	6362.2(5161.9-7847.9)	1285.6(1065-1561.8)	38824.7(28230.1-53092.4)	2069(1253-3217.5)	95	13587(9985.4-18978.3)	6857.1(5545.8-8721.2)	50
Oromia	11217.6(8517-14318)	2433.8(2042.2-2879.5)	80610.7(55103.7-110696)	10742.8(7456.7-15039.6)	87	18754.2(13297.1-24843)	11119.7(8939.1-13305)	41
Amhara	8690.4(7146.3-10453.8)	2016.4(1551.4-2541.8)	60663.3(46712.5-77511.5)	8355(4898.9-12845)	87	15950.4(11723.4-21059.7)	9059.7(7063.2-11529.2)	44
SNNPs	11633(9119.4-14477.9)	2698.1(2243.5-3250.2)	85114.7(61203.2-111502.1)	10409.3(6968.1-14819.3)	88	18842.6(13166.1-26081)	11736.6(9426.7-14238.6)	38
Tigray	10346.4(8522.9-12340.3)	1977.1(1593.9-2395)	68509.3(52185.7-88712.2)	5927.9(3839.4-8676.8)	92	19502.8(13914.1-26751.2)	10486.8(8439.5-12765.3)	47
Harari	12826.5(9336.5-16985.4)	2060.4(1595.6-2623.1)	100421.7(63898.7-140467.8)	7922.5(4518.7-12117.2)	93	11782.6(6360.4-19341.1)	9260.4(7338.7-11340.3)	22
Afar	10993.5(8520.8-14193.6)	2824.6(2323-3414)	63570.5(42296.6-89769)	8943.7(5734.6-13390.2)	86	16925.5(10923.7-26001.7)	11867.1(9346-14716.9)	30
Somali	6286.9(4860.5-7970)	3236.4(2537.4-4006)	40088.1(27543.7-55109)	17314.3(11890.7-24530)	57	11953.6(7599.2-17885.5)	10246(7797.8-13150.6)	15
BG	14965.1(11197.4-19998.6)	3571.1(2772.4-4510.7)	110847.2(74368-156588.4)	18868.3(12442.9-27281.8)	83	16397.3(10917-23228.5)	9541.9(7476.9-12112.3)	42
Dire Dawa	11749.7(8605.4-15249.5)	1832.8(1407.3-2363.1)	94905.3(60458.5-131584.5)	7371.3(3953-11962.1)	93	13207.9(9219.6-18328.2)	8371(6616.3-10408.2)	37
Gambella	13175.8(9291-17411)	1937.4(1567.6-2344.6)	110783.8(70576-154304.1)	5031.8(2867.2-7885.7)	96	11811.4(7673.5-17012.5)	10030.9(7730.2-12664.9)	16
Ethiopia *	10189.1(8347.5-12201.8)	2404.5(2059.4-2833.3)	72055.4(55718.5-92064)	10318.6(7380.4-14166.6)	86	17415.9(13362.7-22228.5)	10309.9(8759.2-11937.6)	41

SNNPs: Southern Nations, Nationalities, and Peoples; BG: Benishangul-Gumuz; *national estimate

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The age-standardized premature mortality rate between 1990 and 2019 showed a continuous decline in all regions, except Somali. Benishangul-Gumuz showed the highest burden between 1990 and 2019 (Figure 3).

The change in premature mortality in children younger than five was significant throughout the years. However, the reduction in premature mortality among adults older than 70 was not as significant (Supplemental Figure 6 and Figure 7).

Risk Factors

Across all population groups, about half (48%) of the mortalities (measured in rates) due to LRIs in Ethiopia were attributed to household air pollution from solid fuel. In addition, lack of access to a hand-washing facility (23%), childhood wasting (23%), low birth weight (9%), short gestation period (7%), and ambient particulate matter pollution (6%) were also risk factors for mortality due to LRIs. The contribution of the risk factors to death due to LRIs in all regions was similar to the national estimate, except in Addis Ababa, where lack of access to hand-washing facilities, ambient particulate matter pollution, and low temperature were the main contributing factors. Ambient particulate matter pollution was also relatively higher in Dire Dawa, Harari, and Tigray regions (Supplemental Figure 8).

In children younger than five, more than three-fourths of deaths due to LRIs were attributed to childhood wasting (54%) stunting (12%), and child underweight (10%) in Ethiopia. In addition, 50% of the LRIs mortalities were attributed to household air pollution from solid fuel. Lack of access to hand-washing facilities (23%), low birth weight (23%), short gestation period (17%), high (4%) or low temperature (4%), absence of exclusive breastfeeding (4%) were also the risk factors with evident contribution. The distribution of risk factors varied among the regions. Child

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wasting, low birth weight, and pre-term birth were the contributing factors of mortality in Addis Ababa. In Harari and Dire Dawa, child wasting, lack of access to hand-washing facilities, pre-term birth, and household air pollution from solid fuels contributed more to the death from LRIs than the other risk factors in 2019. All the risk factors except for ambient particulate air matter and low temperature were the highest in Somali and Benishangul-Gumuz (Supplemental Figure 9). When we examine the trend from 1990 to 2019, there is no significant reduction in the risk factors (Supplemental Figure 10).

Discussion

The findings from this study indicate that although the burden of LRIs, measured in incidence or mortality rates, have shown a significant decline, they are still the third leading cause of death after neonatal disorders and diarrheal diseases in 2019 in Ethiopia. Cities and predominantly urban areas had lower mortality rates than predominantly pastoralist regions of the country. The rate of decline in mortality between 1990 and 2019 varied slightly across regions and chartered cities. The mortality rate decreased by more than three-fourths among children under the age of five and only by one-third among adults older than 70 between 1990 and 2019. Half of LRIs mortalities are attributed to household air pollution from solid fuels in all age groups. About three-fourths of LRIs in children were attributed to malnutrition.

The mortality rate of LRIs among children below the age of five has declined by 86% between 1990 and 2019. This decline could be attributed to improvements in living conditions, access to healthcare, and immunization. The national health delivery infrastructure has grown from 2,600 health facilities in 1997 to 21,154 facilities, including 314 hospitals, 3,678 health centers, and 17,162 health posts and private health facilities in 2019. As a result, the health workforce has

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increased from 46,000 in 2007 to 159,545 in 2019 (16). The introduction of HEP since 2004 to provide preventive, health promotion, and curative treatment for pneumonia, malaria and diarrhoea had improved health outcomes for children (14). Moreover, Ethiopia has been implementing holistic child health improvement programs like IMCI since 1997 (15) and ICCM (5). Vaccination against Streptococcus pneumonia, which is responsible for about half of the LRIs mortality in African countries, with the PCV 10 vaccine since 2011 helped reduce the burden of LRIs (4). In addition, improved socioeconomic conditions have supported the reduction of the burden of LRIs in the country (29).

Despite the achievements reached in improving child health outcomes in Ethiopia, children are still disproportionately affected by LRIs. Out of the total burden of LRIs, 42% of all the deaths were among children younger than five. In that regard, this study has shown that one out of ten child deaths are due to LRIs. However, another study estimated that pneumonia alone shared about 17% of all deaths in children younger than five years (30)**.** Among children under five, children younger than one carry the highest burden of LRIs. Furthermore, the mortality rate among children younger than one (397.7 per 100,000 people) was more than nine times higher than that of children between one and four years old (43 per 100,000 people). Although most studies on the high burden of LRIs corroborate our findings, the findings from Global Health Observatory (GHO) estimated a much higher mortality rate than the estimates of this study (i.e. 481.9 in children less than one year and 51.1 per 1000,000 population in children between one and four years) (8). Although we could not explain why this variation occurs, the estimates from GBD are also less than the estimate from findings of the Child Health Epidemiology Reference Group (CHERG), which is primarily due to the difference in the types of data used (31).

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Urban areas of the country, mainly Addis Ababa and Dire Dawa, had significantly lower mortality rates than pastoralist areas such as Benishangul-Gumuz and Somali. These regional variations could be attributed to gaps in availability and access to healthcare and socioeconomic status differences among the subnational states. A previously conducted study indicated that disease burden is high among people in the poorest wealth quintile and people located mainly in Afar, Somali, Oromia, SNNP, and Benishangul-Gumuz and also have the lowest level of health service utilization (32). The rural area of the country has less healthcare coverage and utilization than the urban areas. The coverage of all basic vaccination is 43% in the country. Across the regions, the coverage of all basic vaccination is lowest in Afar (20%) and highest in Addis Ababa (83%). Coverage of pentavalent vaccines in children is 72% among the urban population while it is 56% among the rural population (15, 30). There is a variation in the performance of immunization across regions. Addis Ababa, Ethiopia's capital has PCV3 coverage of 93% among 1-year-olds in 2019, whereas this coverage is only 23% in Afar and Somali. The wasting rate in Somali was 21% in children under five, while it was just 2% in Addis Ababa in 2019 (33)

In addition to children, LRIs affects people older than 70 years. The number of people dying from LRIs increased over the years in people older than 70 years, partly due to the increase in the aging population. However, the mortality rate declined by 30% between 1990 and 2019 (3, 34). The incidence rate did not show a significant improvement across the study years, showing only 15% reductions between 1990 and 2019. Among the regions, Somali and Afar have recorded an increased incidence rate between 1990 and 2019. This could partly be explained by poor accessibility and availability of health facilities in the regions (33).

Wasting, stunting, and underweight were major risk factors contributing to the death of children younger than five years due to LRIs (35-37). More than 37% of children under five are stunted,

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with a higher percentage in rural areas (41%) than in urban areas (26%). Similarly, the prevalence of child underweight and wasting is 21% in the rural and 7% in the urban parts of Ethiopia (38). This indicates that more investment is needed to reduce the burden on malnutrition among children and in the rural parts of the country to attain better health outcomes, protecting against LRIs. Although the prevalence of stunting, wasting, and underweight has decreased markedly over time, they are still major risk factors for death caused by LRIs. In the Millennium Development Goals (MDG) era, between 1990 and 2015, about half of the deaths averted due to LRIs were attributed to improvement in the nutritional status of children (reduction in wasting and stunting) (15).

Ambient particulate matter and household air pollution from solid fuel use were the two essential components of air pollution. Household air pollution from solid fuel use the was the second leading risk factor for LRIs, and ambient particulate matter is the eight leading risk factor among the top ten risk factors for LRIs (39-41). Our analysis also showed that there is a poor progress in the reductions of risk factors across the year, which shows there is a weak attempt in reducing the risk factors to prevent the population from LRIs. This indicates that improved use of electricity and natural gas for cooking and also appropriate investment in interventions that helps to reduce these risk factors will contribute to the reduction in the burden of the LRIs. (3).

To reduce the burden of LRIs, both national and global efforts are underway. The Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea (GAPPD), established by the World Health Organization, set goals in 2013 to reduce child LRI mortality rates to below 3 in 1,000 live births and to reduce severe LRI incidence by 75% of the 2010 baseline by 2025. To achieve these goals, reaching 90% of children with full-dose vaccine coverage, 90% access to pneumonia treatment, 50% coverage of exclusive breastfeeding in the first six months, and

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exclusive breastfeeding promotion were set as prerequisites (17). However, a 6% average annual mortality reduction was recorded between 2000 and 2018 in Ethiopia. With this, the country can only reach the 2025 GAPPD target in 2035, ten years behind the target, according to the Maternal and Child Epidemiology Estimation Group (MICE) estimation (30).

Ethiopia's major health sector strategic plan, the Health Sector Transformation Plan-2 (HSTP-2) for the year 2021-2024, aims to reduce the infant mortality rate to 35, the neonatal mortality rate to 21 and the children under-5 mortality rate to 43 per 1,000 live births. Similarly, the 2030 Sustainable Development Goals (SDG) has set targets to reduce childhood mortality significantly. These targets can be achieved if the country implements high-impact priority curative and preventive interventions against LRIs (42). To achieve this, concerted action to improve policies, increase investment, foster innovations, and scale-up evidence-based interventions has paramount importance. Parallel to this, an estimated $274 billion for health is required to achieve the health-related SDGs by 2030 in 67 low and middle-income countries, including Ethiopia. One of the strategies to mobilize the needed resources is to increase government expenditure by 15% and share the population's costs through taxes or insurances (43).

This study is not without limitations; limitations in the GBD methods also apply to this study and limitations on Ethiopia subnational burden of disease that includes scarcity of quality data is published elsewhere (28).. When data on causes of death, morbidity or risk factors were not available for a particular regional state such as Afar or Somali, GBD modelled estimates use data from other locations and predictive covariates. Data sources such as household surveys have both sampling and non-sampling errors that account and led a wider 95% uncertainty intervals which might compromise the accuracy of the findings and reduce the use of these findings for policy

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decision-making (1). Causes of mortality data sources used were mainly from verbal autopsy and sibling history having recall bias, broader category of causes of death report or poor generalizability to regional states (44). We used the best available data identified through an extensive collaboration effort and involving more than 700 leading researchers and policy makers from Ethiopia. The generation of estimates and their interpretation have benefited from intensive subnational review workshops and consultative meetings with domain experts.

Conclusion

Despite the substantial reduction in morbidity and mortality at national and regional states, LRIs still remain one of the leading causes of the burden of disease in Ethiopia. Children and elders are still disproportionately affected by LRIs. The burden of illness and death due to LRIs varies across regional states in Ethiopia, with lower rates in cities and predominantly urban areas while predominantly pastoralist areas of the country have higher rates. Efforts should be made to tackle the major risk factors contributing to death by LRIs. Improving child nutrition, access to immunization and curative health services, as well as universal electrification to reduce indoor air pollution will be very useful strategies to reduce deaths due to LRIs in Ethiopia. Furthermore, improvement in socioeconomic factors will also help to reduce LRI burden at national and regional levels. To reach the targets set at the national and international level, mobilizing resources to health and improving the provision of health services to the community according to the needs of the regions is of paramount importance.

List of abbreviations

EPHI: Ethiopian Public Health Institute; GAPPD: Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea GBD: Global Burden of Disease; GHO: Global Health

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Observatory; HSTP: Health Sector Transformation Plan; ICCM: integrated community case management; IHME: Institute of Health and Metric Evaluation; LRIs: Lower Respiratory Infections; NDMC: National Data Management Center for health; PCV: Pneumococcal Conjugate Vaccine; SDG: Sustainable Development Goals; SNNPs: Southern Nations, Nationalities and Peoples; UI: Uncertainty Interval; WHO: World Health Organization; YLL: Years of Life Lost.

Ethics approval and consent to participate

This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

Consent for publication

Not applicable.

Availability of data and material

All relevant data are submitted with this manuscript.

Competing interests

The authors declare that they have no competing interests.

Funding

Bill and Melinda Gates Foundation has funded Ethiopia subnational burden of disease EPHI-IHME collaborative initiative. The funder of this study had no role in study design, data collection, data analysis, data interpretation, or the writing of the report.

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Declarations

M A Gebremichael reports support for the present manuscript from the Bill and Melinda Gates Foundation.

Acknowledgements

The authors have no acknowledgements to declare

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Figure 1: Socio-demographic index, Ethiopia, 2019

Figure 2: Incidence of lower respiratory infections per 100,000 people in Ethiopia and its regions in 2019.

Figure 3: Trend in LRIs age standardized years of life lost rates per 100,000 people in Ethiopia, 1990-2019

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Figure 1: Socio-demographic index, Ethiopia, 2019

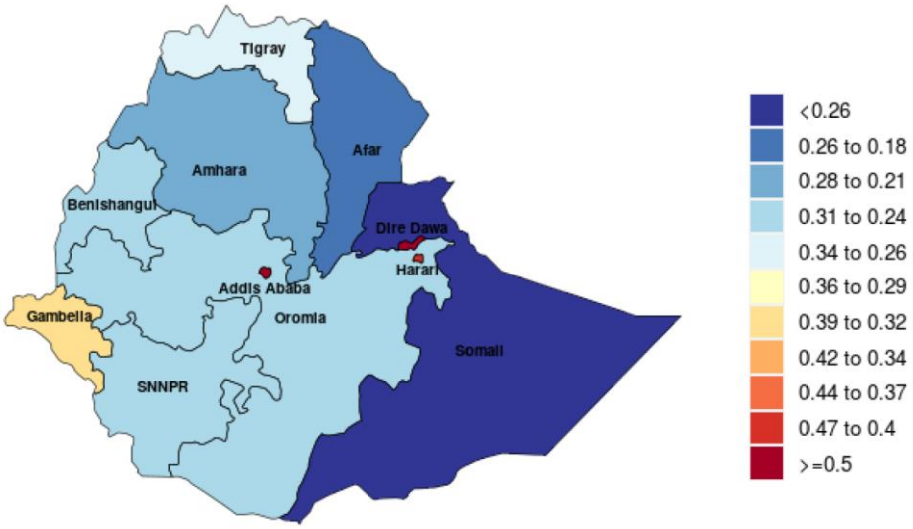

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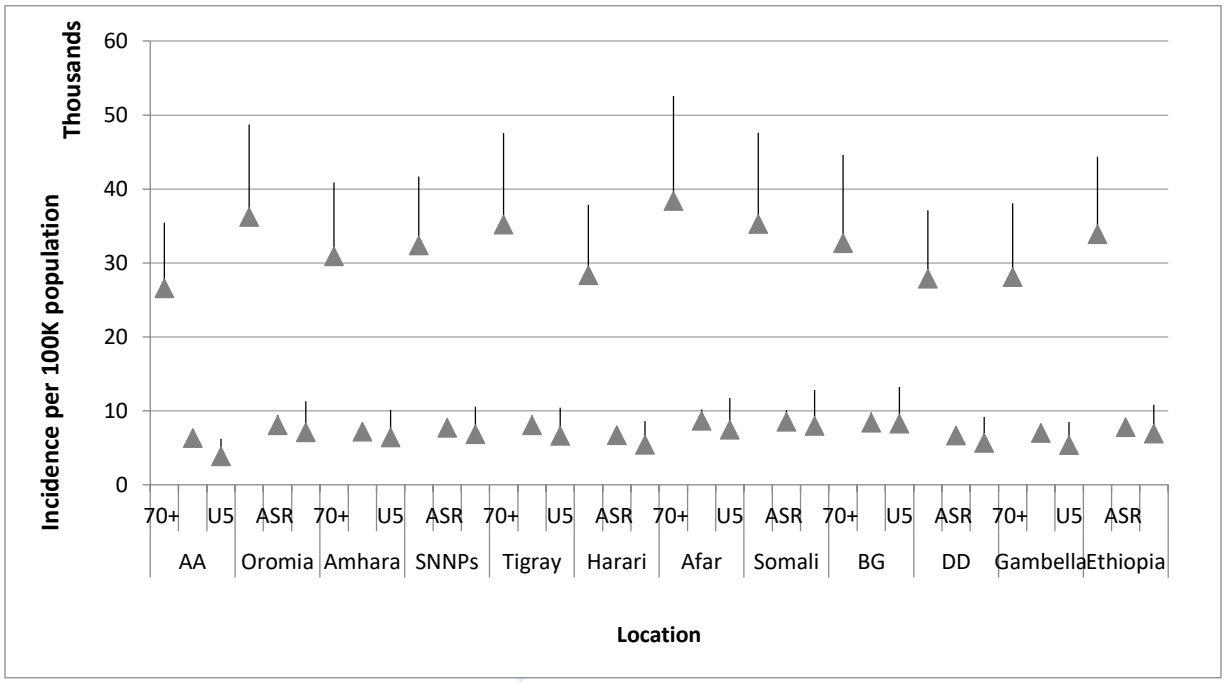
Figure 2: Incidence of lower respiratory infections per 100,000 people in Ethiopia and its regions in 2019.



Key: U5: children younger than 5 years; 70+: adults older than 70 years; ASR: Age-standardized rates; AA: Addis Ababa; DD: Dire Dawa; SNNPs: Southern Nations and Nationalities and Peoples; BG: Benishangul Gumuz

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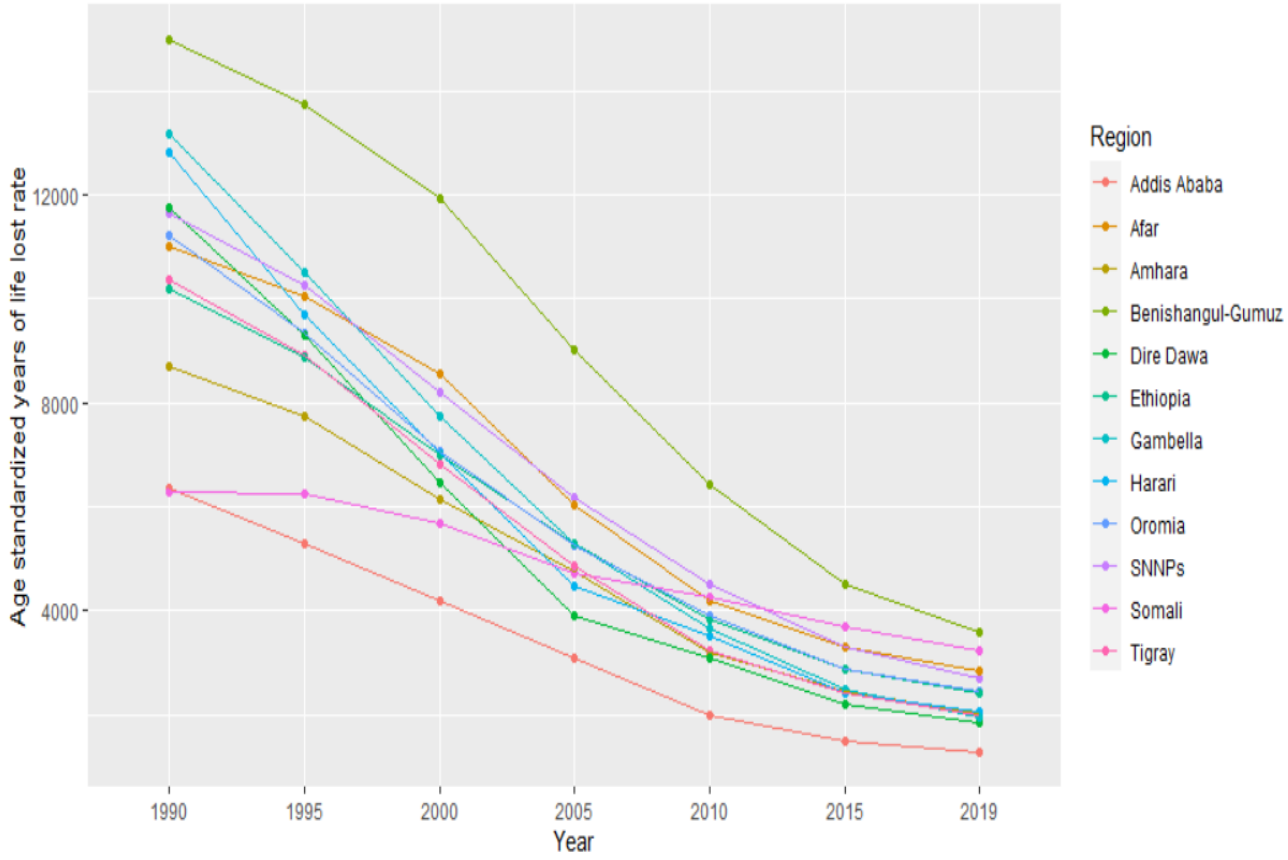
Figure 3: Trend in LRIs age standardized years of life lost rates per 100,000 people in Ethiopia, 1990-2019



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Supplementary material to "The burden of lower respiratory infections and associated risk factors across regions in Ethiopia: A subnational analysis of the Global Burden of Diseases 2019 Study"

This supplementary material provides supplemental figures and tables more detailed results for ""The burden of lower respiratory infections and associated risk factors across regions in Ethiopia: A subnational analysis of the Global Burden of Diseases 2019 Study"

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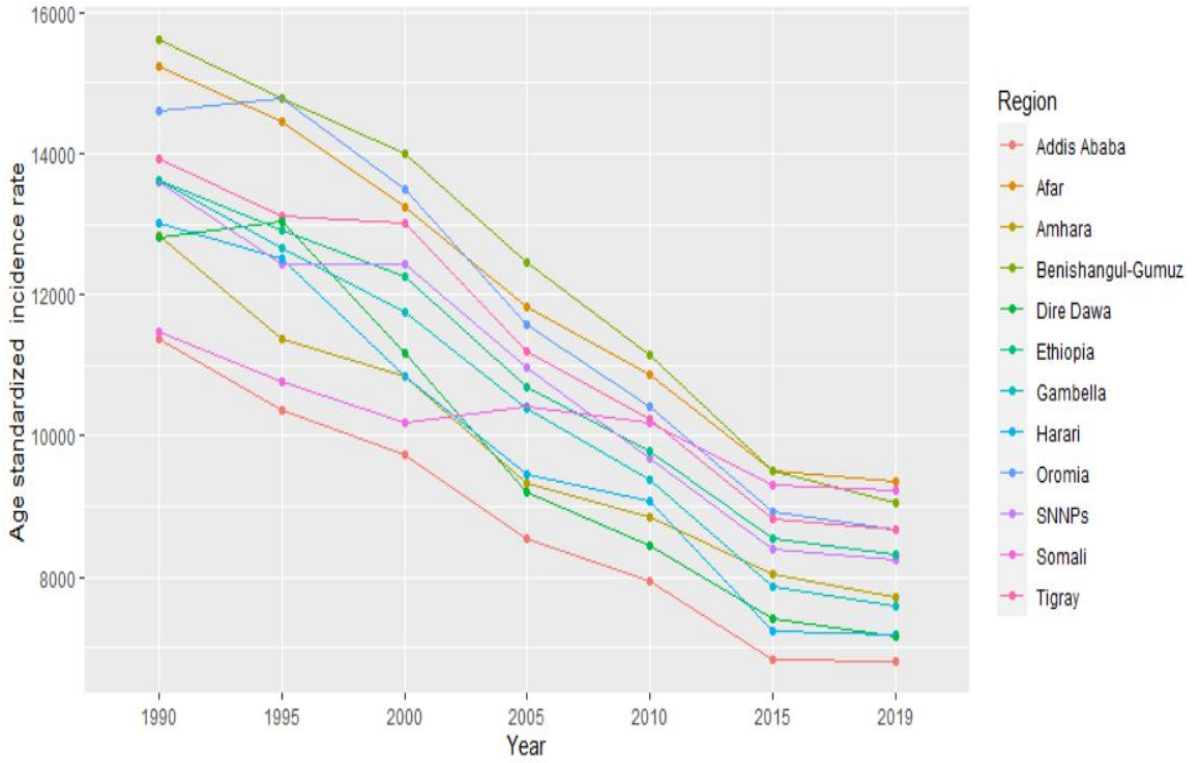

Supplemental Figure 1: Trend in age-standardized incidence rate of LRIs per 100,000 people in Ethiopia, 1990-2019

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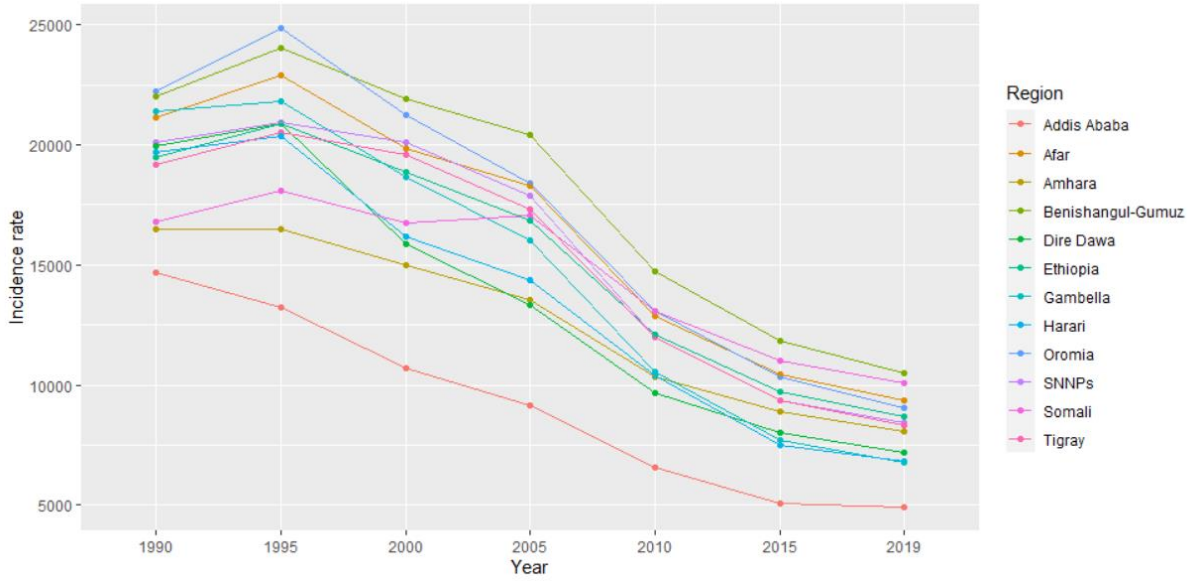
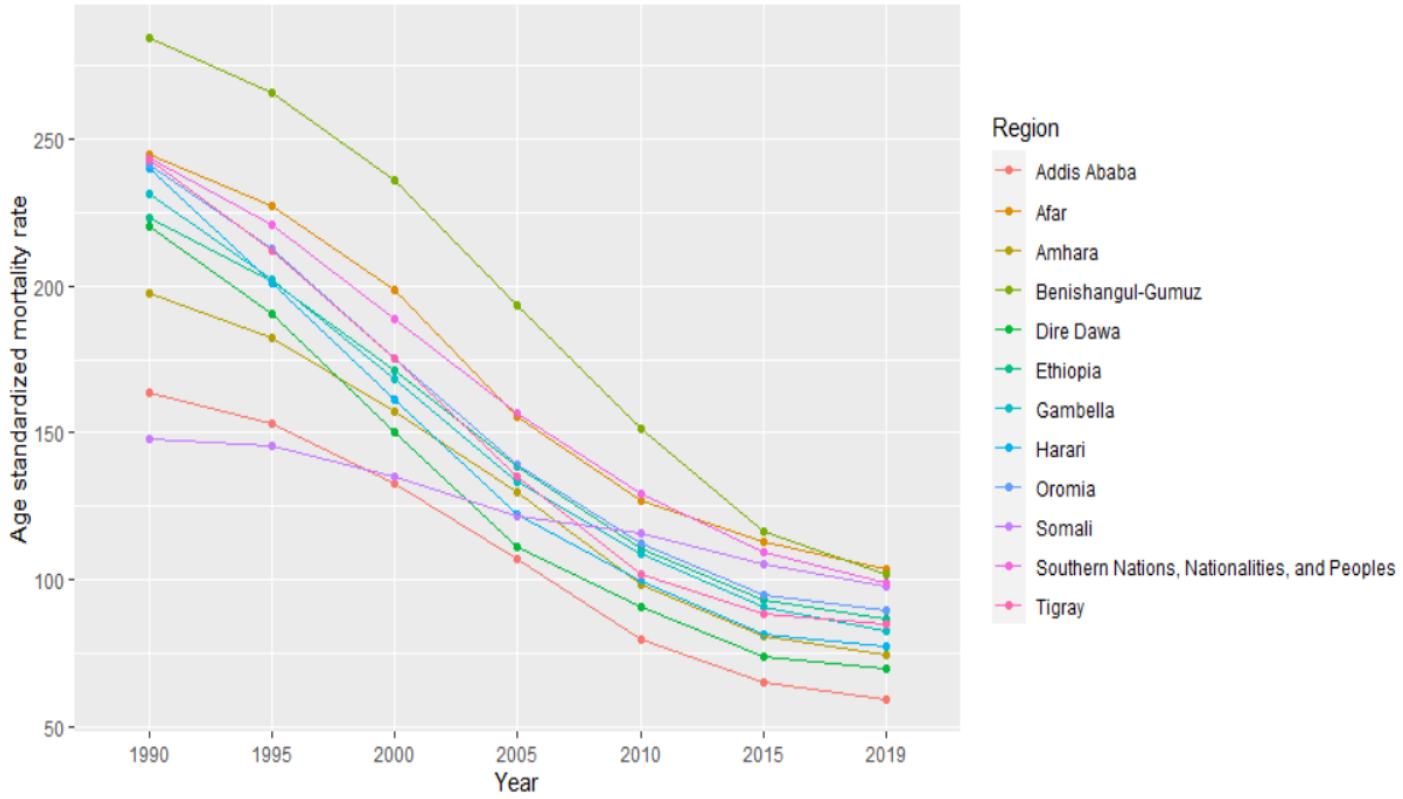
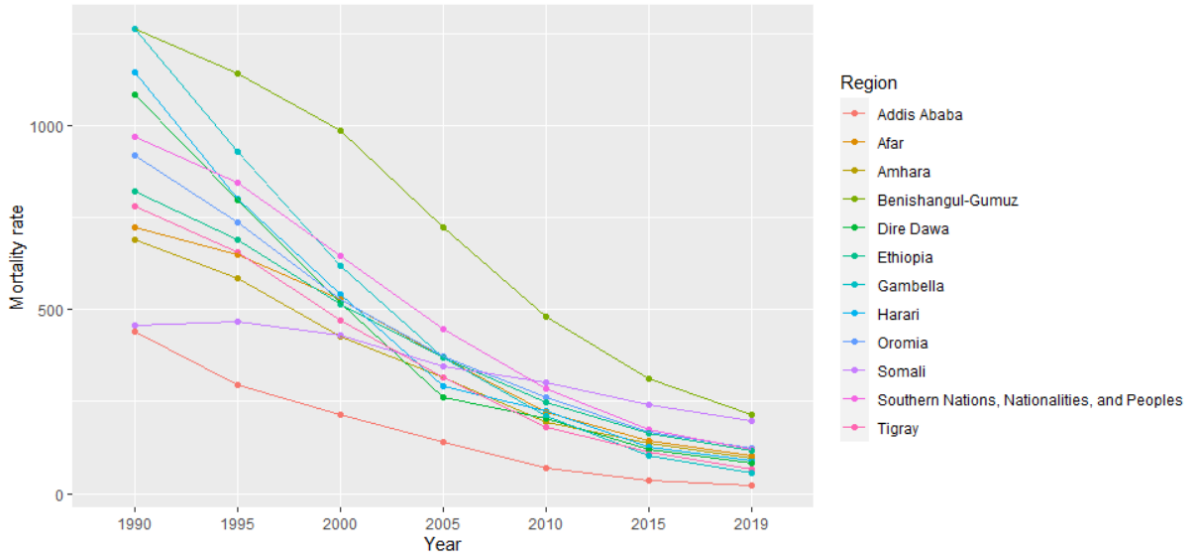


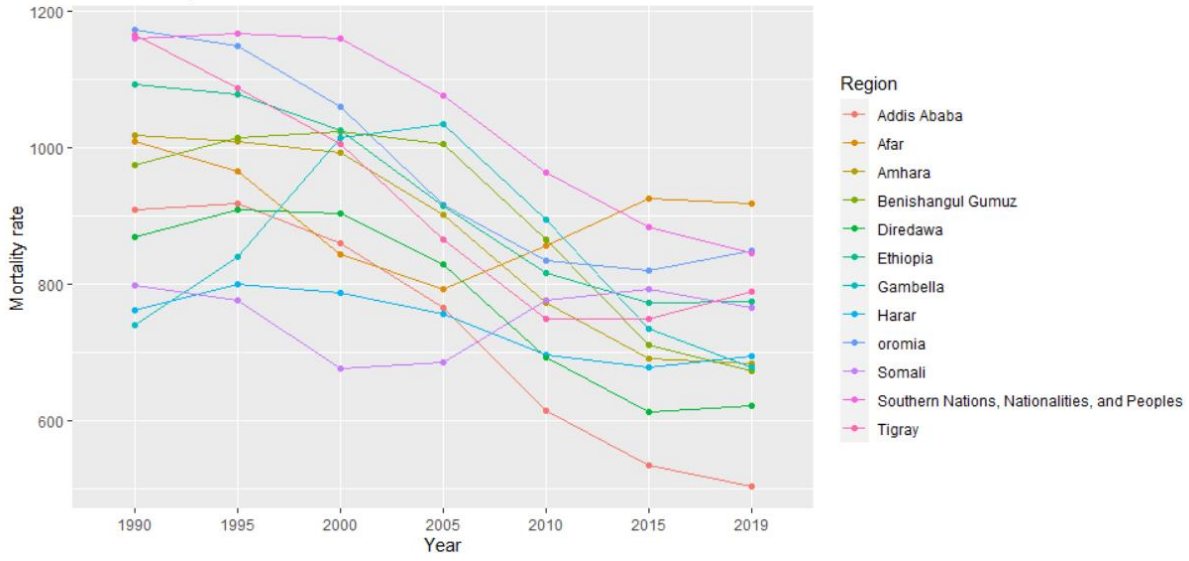
Supplemental Figure 2: Children under 5 years of age incidence rate per 100,000 populations due to LRI in Ethiopia, 1990- 2019



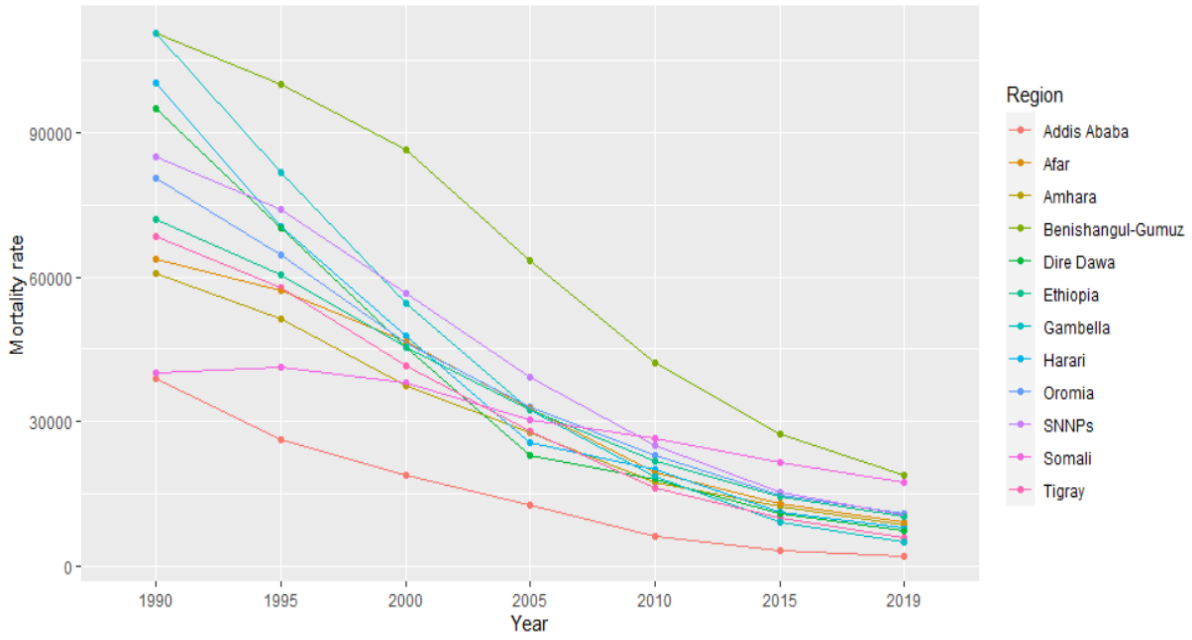
Supplemental Figure 3: Trend in LRIs age-standardized mortality rates per 100,000 people in Ethiopia, 1990-2019



Supplemental Figure 4: Children younger than 5 years mortality rate per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019



Supplemental Figure 5: Adults older than 70 years mortality rate per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019



Supplemental Figure 6: Children younger than 5 years YLL per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019

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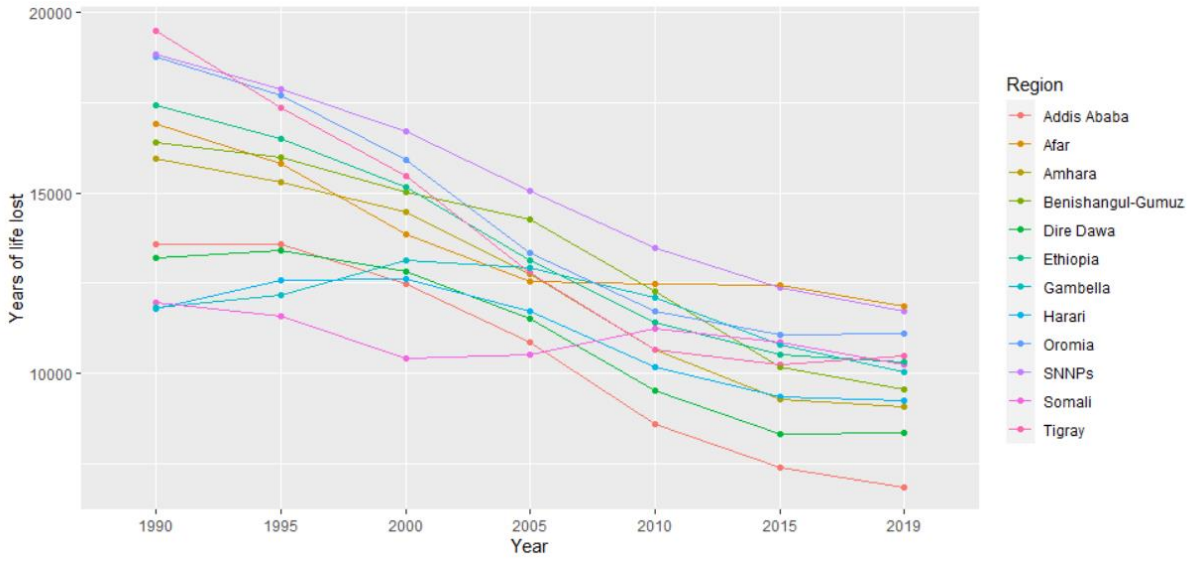

Supplemental Figure 7: Adults older than 70 years YLL per 100,000 populations for lower respiratory infections in Ethiopia, 1990-2019

Location	Alcohol use	Ambient particulate matter pollution	Child stunting	Child underweight	child wasting	High temperature	Household air pollution from solid fuel-	Low birth weight	Low temperature	No access to handwashing facility	Non-exclusive breastfeeding	Secondhand smoke	Short gestation	Smoking
Addis Ababa	1.4	4	0.1	0.1	0.7	0	1.7	0.7	3.7	4.8	0.1	0.4	0.7	1
Oromia	0.6	2.5	2.5	1.9	11.2	0.9	21.6	4.3	2.2	10.3	0.9	0.6	3.5	1.3
Amhara	0.4	2.5	1.8	1.4	6.7	0.9	19.8	3.3	2.4	9.5	0.4	0.6	2.6	0.4
SNNPs	0.8	2.4	2.7	2.2	10.2	1.8	19.9	3.5	1.4	9.6	0.8	0.5	2.9	0.9
Tigray	0.7	3.3	0.8	0.8	4	1.1	17.7	2.8	1.2	9.4	0.3	0.5	2.4	0.4
Harari	1	3.8	0.9	0.7	5.3	0	9.6	2.4	1.1	7.6	0.6	0.6	2.1	3.2
Afar	0.4	2.1	1.8	1.9	8.5	6.3	21	4.5	0.1	9.4	0.9	0.6	3.6	1.4
Somali	0.3	1.6	3.3	3.8	22.2	4.8	31.6	7.2	0.4	13.3	2.5	0.9	5.7	1.8
Benishangul-Gumuz	0.4	3.4	4.5	3.5	20	4.7	27.7	4.9	0.6	13.3	1.3	0.7	4	0.8
Dire Dawa	0.9	3.6	0.7	0.7	5.1	0.4	8.3	2.4	0.5	6.9	0.4	0.5	2	2.1
Gambella	0.8	2.2	0.4	0.4	3.2	2.5	9.3	2.2	0.1	5.4	0.4	0.3	1.9	2.1
Ethiopia	0.6	2.5	2.2	1.8	9.9	1.4	20.5	3.9	1.9	9.9	0.8	0.6	3.2	1

Supplemental Figure 8: Attribution of the risk factors to LRIs death rate per 100,000 population in all age groups between 1990 and 2019 for Ethiopia and its regions, both sexes, number of death, 2019. SNNPs: Southern Nations, Nationalities, and Peoples.

	Ambient particulate matter pollution	child stunting	Child under weight	child wasting	high temperature	Household air pollution from solid fuels	Low birth weight	Low temperature	No access to handwashing facility	Non-exclusive breastfeeding	Secondhand smoke	Short gestation
Addis Ababa	3.63	0.82	0.64	8.35	0.00	1.75	8.86	3.29	4.27	1.32	0.31	7.98
Oromia	6.41	14.75	11.45	67.14	2.34	60.08	25.95	6.05	28.32	5.25	1.66	21.03
Amhara	5.40	13.01	9.84	48.10	2.02	46.86	23.47	5.46	21.99	2.81	1.36	18.88
SNNPs	6.36	16.67	13.77	63.88	5.03	57.68	21.95	4.12	27.49	5.28	1.38	18.31
Tigray	5.03	6.15	5.75	29.88	1.87	29.89	20.59	2.00	15.32	1.91	0.79	17.45
Harari	9.12	7.21	5.80	43.66	0.01	25.51	19.63	2.74	19.30	5.00	1.62	17.18
Afar	4.88	11.42	11.57	52.76	15.77	53.12	28.03	0.26	23.50	5.49	1.33	22.31
Somali	5.40	18.08	20.92	121.83	16.76	110.21	39.76	1.46	46.07	13.99	3.18	31.30
Benishangul-Gumuz	12.63	28.22	22.25	125.72	17.81	105.51	30.75	2.22	50.23	8.05	2.61	24.89
Dire Dawa	9.38	5.50	5.64	42.47	1.11	23.88	19.72	1.42	18.88	3.67	1.50	16.71
Gambella	4.75	3.13	3.08	25.92	6.16	23.51	18.20	0.18	13.02	2.86	0.60	15.31
Ethiopia	6.06	14.39	11.93	64.00	4.28	58.22	25.08	4.73	27.20	5.22	1.58	20.40

Supplemental Figure 9: Attribution of the risk factors to LRIs death rate per 100,000 population in children younger than 5 years between 1990 and 2019 for Ethiopia and its regions, both sexes, number of death, 2019. SNNPs: Southern Nations, Nationalities, and Peoples.

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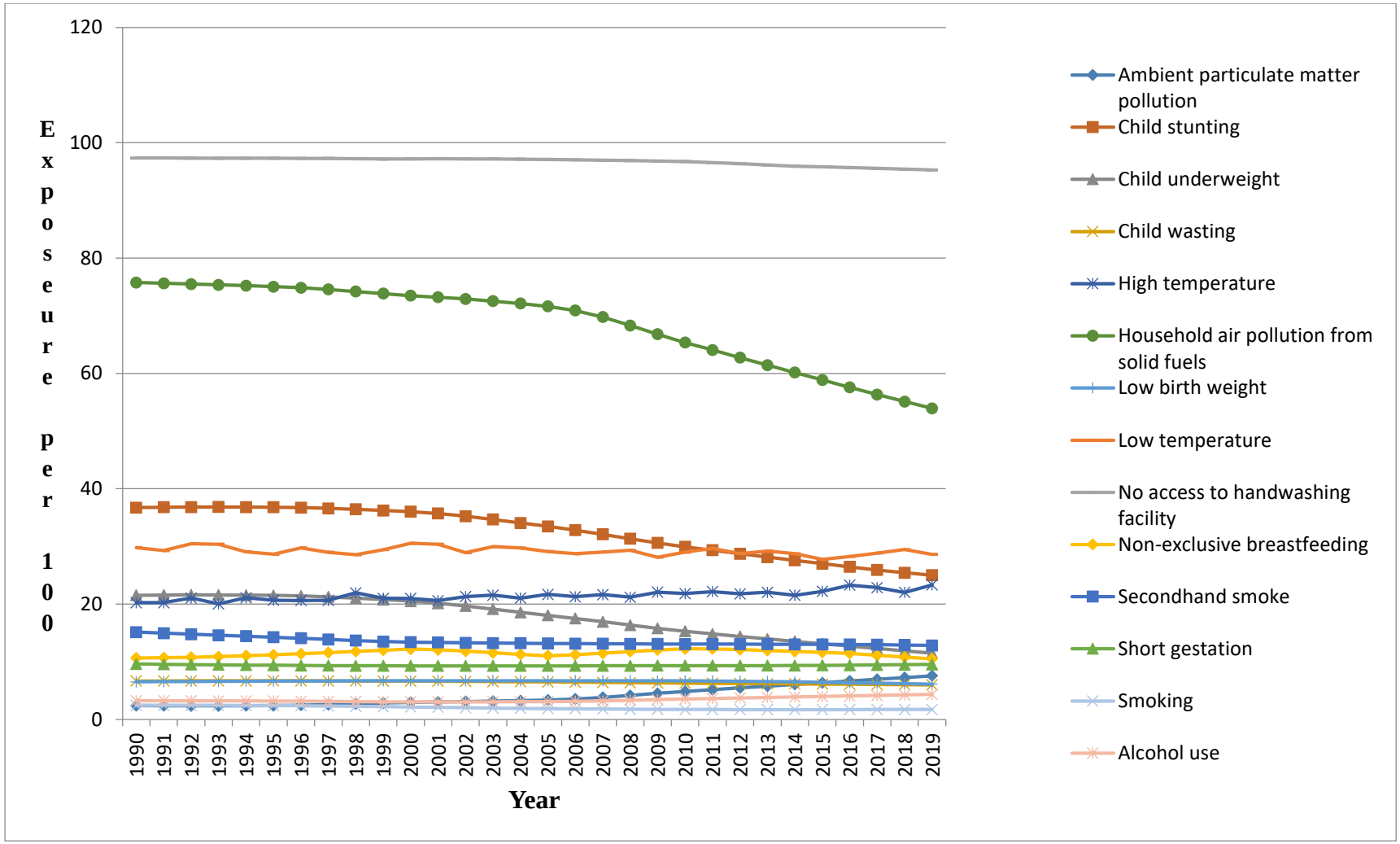

Supplemental Figure 10: Trends in the risk factors between 1990 and 2019 for all ages for Ethiopia

Tables

Supplemental Table 1: Number and percentage changes of episode attributable to LRIs in 1990 and 2019 for Ethiopia, its regions, both sexes

	All ages			Children younger than 5 years			People above 70		
Location	Episode, (95%UI),1990	Episode, (95%UI),2019	Change, %	Episode, (95%UI),1990	Episode, (95%UI),2019	Change, %	Episode, (95%UI),1990	Episode, (95%UI),2019	Change,%
Addis Ababa	194122.9(175403.8-213856.2)	176027.6(162152.3-190557.8)	10	44940.6(35673.3-56859.6)	14522.3(11237-18367.5)	68	8099.5(6891.6-9463.2)	24034.2(20749.5-27702.3)	196**
Oromia	2164243.7(1957719.5-2397957.9)	2597863.9(2372089.2-2859925.6)	20	739239.6(578477-935022.8)	613676.6(480687.2-765626.5)	17	110627.2(95303.7-129579.9)	292179.4(254670.4-342438.5)	164**
Amhara	1508431.4(1368059.8-1671550.1)	1400682.4(1285323-1530939.8)	8	423999.3(334700.8-538426.8)	261397.4(206754.7-327889.7)	39	116332.8(98774.4-137194.5)	198977.5(173809.4-229925.5)	71**
SNNPs	1235554.9(1108317.9-1368520.3)	1330491.5(1217176.7-1452694.1)	7	421825.6(335087.1-526155.2)	307771.3(248326.4-385053.7)	28	68084.5(57450-79640.8)	99723(88168.3-113438)	46**
Tigray	360795.1(328276.3-400714.9)	409829.8(376290.4-445030.2)	13	109047.9(86435.2-137691.1)	69958.2(55210.7-87468.6)	36	20653.3(17469.9-24256.6)	62677.2(53933.1-72927.6)	203**
Harari	15145.9(13618.9-16851.9)	13765.3(12657-15054.7)	10	4693.6(3691.4-5990.1)	2188.4(1723.8-2761.3)	54	307.2(259.6-357)	1614.8(1396-1863.6)	425**
Afar	113506.8(102317-126084.3)	113210.3(102987.9-124578)	1	32991.6(25672.4-42147.6)	26177.2(20744.1-32743.3)	21	2640.2(2212.5-3150.9)	7222.5(6246.8-8559.1)	173**
Somali	300306.3(268988-336331.8)	463220.4(420429.8-516009.4)	54	103526.3(81391.3-131352.8)	126089.6(99611.9-160423.3)	21**	6182.3(5316-7370.4)	30203.2(25942.8-35038.5)	388**
BG	68501.6(61804.9-75736.4)	71675.7(64972.1-79105.8)	4	20970.5(16626.7-26454.5)	18175.6(14339.5-22922.1)	14	3288.9(2784.8-3911.4)	4311.3(3743.8-5113.9)	31**
Dire Dawa	30607.1(27359.8-34252.2)	26221.1(24010.1-28647.8)	15	9547.4(7523-12185)	4387.7(3439.6-5583.9)	55	1274.8(1090.1-1483.5)	2840.1(2469-3289.5)	122**
Gambella	19687.9(17723.9-21945.7)	25685.2(23516.6-28093.2)	30**	6747.7(5338.7-8613.7)	4335.4(3428.4-5400.9)	36	1568.1(1316.6-1825.8)	1489.6(1281.4-1737.3)	6
Ethiopia*	6010904.2(5467801.6-6648644.3)	6628673.6(6108786.2-7230986.3)	10**	1917530.8(1518850.1-2400978.5)	1448680.4(1150089.8-1799704.4)	25	339059.4(293491.9-387514.2)	725273.3(640315.4-837746.3)	**113****

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 1990 and 2019*

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Supplemental Table 2: Rate and percentage changes of episodes attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes

	Age standardized			Children younger than 5 years			People above70		
Location	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%	Episode per 100,000 people (95%UI),1990	Episode per 100,000 people (95%UI),2019	Change,%
Addis Ababa	11373(10484.2-12197.4)	6788.1(6285.1-7339.1)	40	14666.9(11642.4-18556.9)	4927.2(3812.5-6231.8)	67	35138(29897.7-41054.2)	30748.4(26546-35441.2)	13
Oromia	14613.1(13525.9-15725.8)	8659.9(8040.1-9411.6)	41	22232(17397.2-28120)	9039.4(7080.5-11277.7)	60	46498.3(40057.6-54464.4)	41564.6(36228.7-48714.4)	11
Amhara	12826.4(11830-13882.8)	7716.9(7162.3-8321.3)	40	16487.1(13014.7-20936.6)	8061.7(6376.4-10112.3)	52	43580(37002.4-51395.2)	35377.7(30902.9-40880.2)	19
SNNPs	13591.9(12538.6-14646.8)	8235.5(7670.5-8846.4)	39	20106.4(15972-25079.3)	8427.1(6799.4-10543.2)	59	44628.1(37657.5-52203.1)	36616.1(32373.5-41652)	18
Tigray	13927.2(12858.2-15100.7)	8663.8(8034-9382.3)	38	19185.4(15207-24224.8)	8342.1(6583.5-10430.1)	57	43748.4(37005.1-51381)	40859(35158.8-47541.2)	7
Harari	13014.6(11941-14066.7)	7190.5(6684.1-7718.6)	45	19672.6(15471.9-25106.9)	6821.6(5373.5-8607.3)	66	33916.7(28665.1-39416.7)	32797.4(28354-37850.7)	4
Afar	15245.7(14050.8-16525.6)	9350.1(8648.8-10157.4)	39	21151.6(16459.1-27021.7)	9365.5(7421.7-11714.7)	56	39849(33393.8-47557.2)	44368.7(38375.2-52580.1)	11**
Somali	11482.7(10638.1-12368.7)	9220(8515.8-10046.3)	20	16792.9(13202.4-21306.6)	10062.7(7949.6-12802.8)	41	32748.3(28159.7-39042.1)	41031.2(35243.4-47600)	25**
BG	15628.1(14481-16809.3)	9054.6(8394.2-9766)	42	22041.1(17475.5-27805)	10481.8(8269.5-13219)	53	42911.6(36334.5-51032.5)	37592.7(32643.9-44591.2)	13
Dire Dawa	12806.6(11807.9-13871.4)	7148.8(6634.6-7750.7)	44	19968.2(15734.3-25484.7)	7191.5(5637.6-9152.1)	64	38333(32779.4-44607)	32033.6(27847.4-37101.4)	17
Gambella	13623.1(12637.4-14572.4)	7575.8(7002.3-8128.2)	44	21419.8(16947.2-27343.2)	6791.1(5370.4-8460.1)	69	40197.8(33751.8-46803.7)	32657.1(28093.9-38087.2)	19
Ethiopia*	13619.7(12640.8-14588.6)	8313.7(7757.6-8918)	39	19486.4(15434.9-24399.3)	8685.3(6895.1-10789.8)	56	44092.2(38166.5-50393.4)	38394.4(33896.9-44348.5)	13

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate*; **percentage increase between 2019 and 1990*

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Supplemental Table 3: Number and percentage changes of death attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes.

	All age			Children younger than 5			People above 70 years		
Location	death, (95%UI),1990	death, (95%UI),2019	Change,%	death, (95%UI), 1990	Death, (95%UI),2019	Change, %	Death , (95%UI),1990	Death, (95%UI),2019	Change,%
Addis Ababa	2159.3(1731.9-2690.7)	918.8(767.4-1116.9)	58	1353(981.9-1846.7)	69.1(41.7-107.4)	95	209.5(154.3-291.5)	393.6(320.9-495.3)	87**
Oromia	40004.4(29432.4-51942.2)	18206.1(15193.3-21745.4)	55	30614.3(20932.5-42033.5)	8306.2(5763.5-11611.8)	73	2793.5(2005.1-3673)	5971.6(4831.7-7093.4)	113**
Amhara	25449.3(20869.5-30724.8)	9525.5(7530.5-11872.2)	63	17780.1(13674.3-22720.1)	3079.5(1805.3-4737.3)	83	2717.2(2016.4-3535.8)	3839.9(3022.6-4825.6)	41**
SNNPs	26044.7(20108-33017)	9494.7(7713.5-11649)	-64	20390.6(14627.6-26712.9)	4326.6(2891.3-6157.2)	79	1771.7(1254.5-2417.6)	2302.6(1867.3-2772.8)	29**
Tigray	6463.8(5272.1-7762.9)	2551.4(2090.3-3028.6)	61	4436(3373.5-5736)	564.2(364.9-825)	88	550.8(395.7-749.1)	1209.7(978.5-1467.8)	119**
Harari	336(233.3-448.8)	93.1(73.8-116)	73	273.5(174.1-382.7)	28.8(16.4-44.3)	90	6.9(3.7-11)	34.1(27.1-41.8)	395**
Afar	1717.5(1300.7-2243.4)	706.2(567.7-869.6)	-59	1128.9(751.1-1596.7)	284.2(182.5-426)	75	66.9(43.5-102.1)	149.3(117.3-186.6)	123**
Somali	3603.8(2620-4713.6)	3907.5(3007.4-4959.4)	#N/A	2811.1(1929.6-3874.8)	2472.2(1695.2-3506.8)	13	150.8(98-222.3)	563.1(433.4-715.8)	273**
BG	1549.2(1131.1-2097)	619(470.7-803)	61	1204.8(805.6-1703.9)	373(245.3-539.3)	70	74.7(50.3-105.7)	77(61.1-97.3)	3**
Dire Dawa	632.3(445.5-830.9)	154.6(120.6-193.8)	76	518.4(329.5-718.7)	51(27.3-82.9)	91	28.8(20.1-40)	55(44-67.9)	90**
Gambella	475.9(328.5-635.7)	123.2(98.2-151.9)	75	398.6(253.7-555.7)	36.4(20.7-57.2)	91	28.8(18.6-41.9)	30.9(24.6-38.1)	7**
Ethiopia*	108436.6(87669-132758.3)	46300.7(39515.8-54642.2)	58	80909.9(62491.6-103448.8)	19591.8(14018.4-26899)	76	8400.1(6490.3-10700.9)	14627.6(12393.7-16892.8)	74**

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 2019 and 1990*

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Supplemental Table 4: Age standardized mortality rate, Ethiopia and its regions, by sex, 2019.

Age standardized mortality rate per 100,000 people, 2019		
Location	Female	Male
Addis Ababa	47(35.5-62.5)	73.6(55-98.3)
Oromia	77.3(62-92.4)	100.3(79.9-123.5)
Amhara	57.9(44.1-73.7)	92.5(70.5-122.1)
SNNPs	79.2(63.5-95.2)	118.8(94.3-146.3)
Tigray	73.2(55.9-93.5)	96.9(74.8-122.3)
Harari	63(49-79.9)	95.7(72.5-123.4)
Afar	112.4(87.3-142.3)	98.7(76.9-127.3)
Somali	88.3(69-111.4)	101.7(77.2-130.7)
Benishangul-Gumuz	109.2(82.6-138.8)	95.8(74.6-124.1)
Dire Dawa	56.2(42.5-71.3)	85.4(67.3-109.5)
Gambella	47.9(34.6-60.1)	120.2(95.6-149.5)
Ethiopia	71.8(60.2-82.9)	100.6(84-121.4)

SNNP: Southern Nations, Nationalities, and Peoples

Supplemental Table 5: Number and percentage changes of YLL attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes

	all age			**Children younger than 5 years**			**People above 70**		
	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%	YLL, (95%UI),1990	YLL, (95%UI),2019	Change,%
Addis Ababa	149543.9(115542.6-195437)	29703.1(23833.4-36855.7)	81	118961.7(86499.1-162678.7)	6098.2(3693.1-9483.3)	95	3131.8(2301.7-4374.6)	5359.8(4334.8-6816.8)	71**
Oromia	3019031.9(2144916.2-4057496.3)	981808.4(748459.2-1278135)	68	2680397.2(1832260.4-3680767.1)	729313.8(506226.4-1021016.9)	73	44619.5(31636-59105.6)	78166.1(62837.5-93527.9)	75**
Amhara	1813522.3(1445106.4-2246142.2)	428277.8(309674.7-583000.2)	77	1560078.3(1201305.4-1993362.8)	270909.2(158846-416496.1)	83	42578.2(31294.7-56216.9)	50955.1(39726.1-64844.6)	19**
SNNPs	1993643.3(1489598.4-2577052.3)	543135.8(405565.6-711397.4)	73	1785675.1(1284021-2339272.5)	380166.4(254486.8-541224.9)	79	28746.2(20086.2-39789.1)	31964.4(25673.6-38778.5)	11**
Tigray	455613.4(364406.1-569702.1)	96429.9(74139.8-122350.5)	79	389399.3(296618.1-504230.2)	49712.6(32198.3-72764.9)	88	9207.1(6568.7-12629.1)	16086.6(12946.2-19581.8)	74**
Harari	26755.3(17866.5-36380.3)	4273.6(2999.1-5798.4)	85	23959.3(15245.4-33513.8)	2541.6(1449.6-3887.3)	90	106.7(57.6-175.1)	455.9(361.3-558.3)	327**

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Afar	124052(89386.4-166880.5)	39507.6(29535.5-52178.5)	69	99155.3(65972.9-140018.8)	24998.1(16028.5-37426.3)	75	1121.4(723.7-1722.7)	1931.7(1521.3-2395.6)	72**
Somali	281532.2(201275.3-374880.8)	266379.4(193669.7-357880.7)	6	247138.5(169803.8-339740.3)	216954(148995.2-307369.5)	13	2256.6(1434.6-3376.4)	7542.1(5740-9680.2)	234**
BG	119211.2(83517.3-165095.7)	42245.6(30388.8-57591.8)	-65	105463.5(70756-148983.1)	32718.1(21576.4-47307.2)	69	1256.7(836.7-1780.3)	1094.3(857.5-1389.1)	13
Dire Dawa	50024.5(33464.5-67580.6)	7267.7(5038-10264.7)	86	45377.4(28907.2-62914.9)	4497.4(2411.8-7298.3)	91	439.2(306.6-609.5)	742.1(586.6-922.8)	68**
Gambella	37680.8(24783.6-51516.1)	6064.4(4389.3-7853.6)	84	34899.5(22233.1-48609.4)	3212.2(1830.4-5034.1)	91	460.7(299.3-663.6)	457.5(352.6-577.6)	1
Ethiopia*	8070611.3(6356905.2-10091563.7)	2445093.7(1934420.8-3119838.6)	70	7090505.4(5482895.7-9059421.2)	1721122.3(1231032.1-2362958.7)	76	133924.6(102756.8-170932.9)	194756.2(165462-225502.1)	45**

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate; ***percentage increase between 2019 and 1990*

Supplemental Table 6: Rate and percentage changes of YLL attributable to LRIs in 1990 and 2019 for Ethiopia and its regions, both sexes.

	all age			**Children younger than 5 years**			**People above 70**		
Location	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%	YLL per 100,000 people,1990	YLL per 100,000 people, 2019	Change,%
Addis Ababa	6362.2(5161.9-7847.9)	1285.6(1065-1561.8)	80	38824.7(28230.1-53092.4)	6857.1(5545.8-8721.2)	95	13587(9985.4-18978.3)	6857.1(5545.8-8721.2)	50
Oromia	11217.6(8517-14318)	2433.8(2042.2-2879.5)	78	80610.7(55103.7-110696)	11119.7(8939.1-13305)	87	18754.2(13297.1-24843)	11119.7(8939.1-13305)	41
Amhara	8690.4(7146.3-10453.8)	2016.4(1551.4-2541.8)	77	60663.3(46712.5-77511.5)	9059.7(7063.2-11529.2)	87	15950.4(11723.4-21059.7)	9059.7(7063.2-11529.2)	44
SNNPs	11633(9119.4-14477.9)	2698.1(2243.5-3250.2)	77	85114.7(61203.2-111502.1)	11736.6(9426.7-14238.6)	88	18842.6(13166.1-26081)	11736.6(9426.7-14238.6)	38
Tigray	10346.4(8522.9-12340.3)	1977.1(1593.9-2395)	81	68509.3(52185.7-88712.2)	10486.8(8439.5-12765.3)	92	19502.8(13914.1-26751.2)	10486.8(8439.5-12765.3)	47
Harari	12826.5(9336.5-16985.4)	2060.4(1595.6-2623.1)	84	100421.7(63898.7-140467.8)	9260.4(7338.7-11340.3)	93	11782.6(6360.4-19341.1)	9260.4(7338.7-11340.3)	22
Afar	10993.5(8520.8-14193.6)	2824.6(2323-3414)	74	63570.5(42296.6-89769)	11867.1(9346-14716.9)	86	16925.5(10923.7-26001.7)	11867.1(9346-14716.9)	30
Somali	6286.9(4860.5-7970)	3236.4(2537.4-4006)	49	40088.1(27543.7-55109)	10246(7797.8-13150.6)	57	11953.6(7599.2-17885.5)	10246(7797.8-13150.6)	15
BG	14965.1(11197.4-19998.6)	3571.1(2772.4-4510.7)	76	110847.2(74368-156588.4)	9541.9(7476.9-12112.3)	83	16397.3(10917-23228.5)	9541.9(7476.9-12112.3)	42

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Dire Dawa	11749.7(8605.4-15249.5)	1832.8(1407.3-2363.1)	84	94905.3(60458.5-131584.5)	8371(6616.3-10408.2)	93	13207.9(9219.6-18328.2)	8371(6616.3-10408.2)	37
Gambella	13175.8(9291-17411)	1937.4(1567.6-2344.6)	85	110783.8(70576-154304.1)	10030.9(7730.2-12664.9)	96	11811.4(7673.5-17012.5)	10030.9(7730.2-12664.9)	16
Ethiopia*	10189.1(8347.5-12201.8)	2404.5(2059.4-2833.3)	76	72055.4(55718.5-92064)	10309.9(8759.2-11937.6)	86	17415.9(13362.7-22228.5)	10309.9(8759.2-11937.6)	41

SNNP: Southern Nations, Nationalities, and Peoples; BG: Benishangul Gumuz; *country's estimate*; ***percentage increase between 2019 and 1990*

This table indicate the rates of the years of life lost due to lower respiratory infection per 100,000 population for the year 1990 and 2019 and the percentage changes between the two years for three age categories (for all age groups, children younger than 5 years and people above 70 years).

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Authors contributions

Providing data or critical feedback on data sources

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Semagn Mekonnen Abate, Tezera Moshago Berheto, Alemayehu Hailu, Mohsen Naghavi, Negussie Boti Sidamo, and Amanuel Yigezu.

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Managing the estimation or publications process

Semagn Mekonnen Abate, Awoke Misganaw, Mohsen Naghavi, Negussie Boti Sidamo, and Amanuel Yigezu.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No. (Line No.)
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1 (1-2)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4 and 5 (73-89)
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	7 (140-147)
Objectives	3	State specific objectives, including any prespecified hypotheses	7 (148-153)
Methods			
Study design	4	Present key elements of study design early in the paper	10 (194-214)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	8 and 9 (175-192)
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	8 and 9 (175-192)
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	9 and 10 (194-214)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8 and 9 (175-192)
Bias	9	Describe any efforts to address potential sources of bias	10 (211-214)
Study size	10	Explain how the study size was arrived at	8 (175-184)

Continued on next page

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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9 (200-206)	
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9 (200-206)	
		(*b*) Describe any methods used to examine subgroups and interactions	10 (211-214)	
		(*c*) Explain how missing data were addressed	9 and 10 (194-214)	
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		
		(*e*) Describe any sensitivity analyses	10 (211-214)	
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10 (216-221)	
		(b) Give reasons for non-participation at each stage		This is a population level study
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7 and 8 (156-168)	Described in the method section
		(b) Indicate number of participants with missing data for each variable of interest		This is a population level study
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	12-19 (255-361	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time		
		Case-control study—Report numbers in each exposure category, or summary measures of exposure		
		Cross-sectional study—Report numbers of outcome events or summary measures	12-19 (255-361	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12-19 (255-361	
		(*b*) Report category boundaries when continuous variables were categorized	12-19 (255-361	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time		

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	period

Continued on next page

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Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12-19 (255-361
Discussion			
Key results	18	Summarise key results with reference to study objectives	19 (363-371)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23 and 24 (461-471)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19-23 (373-460)
Generalisability	21	Discuss the generalisability (external validity) of the study results	24 (475-486)
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	25 (506-508)

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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