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The Burden of Measles and Subnational Disparities among Under-Five Children in Ethiopia: A Systematic Analysis of the GBD 2021 Study

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Abstract

Ethiopia is among the countries with a high burden of measles outbreaks. Moreover, studies investigating the burden of measles in Ethiopia, particularly those that systematically analyze measles cases at the subnational level and their determinants, are scarce. Hence, thirty years of measles data were extracted and evaluated from the Global Burden of Disease 2021 database. Descriptive statistics were used to quantify the overall burden of measles, including incidence, prevalence, deaths, and disability-adjusted life years (DALYs), and temporal trends from 1990 onwards were analyzed. Subnational disparities in measles burden were assessed to identify high-burden areas requiring targeted interventions. Uncertainty in the estimates was quantified through 1,000 iterations of the model, producing 95% uncertainty intervals (2.5th and 97.5th percentiles) for all metrics. Measles incidence, prevalence, death, and disability-adjusted life years were 709/100,000 (95% UI: 461.66-1017.29), 19/100,000 (95% UI: 12.65-27.87), 8/100,000 (95% UI: 4.28-14.35), and 728/100,000 (95% UI: 377.52-1264) in Ethiopia in 2021.Moreover, the national measles incidence rate decreased by 96% in 2021 compared to that of 1990. The measles burden was higher in the Afar, Somali, and Benishangul Gumuz regions and lower in Addis Ababa. After the introduction of the second dose of measles, there was a notable decrease in the burden. However, the measles burden remains substantial in Ethiopia, despite a notable decline over the past three decades. Therefore, our results suggest that there is an urgent need to improve measles vaccination service in Ethiopia, especially in high-burden regions.

Keywords: *Disability-adjusted Life Years, Ethiopia, Global Burden of Diseases, Measles Burden, Measles Death, Measles Incidence.*

Introduction

Measles is a highly contagious disease caused by a morbillivirus and spread by droplets from an infected individual's mouth, throat, or nose. It is a human-only disease that spreads quickly among unvaccinated people [1]. Children who are malnourished or have other immune system weaknesses are most vulnerable to measles-related deaths [2]. The expected number of measles cases in 2023 was 10.3 million. Outbreaks of measles are currently occurring everywhere in the world [3]. Despite the availability of a safe and

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affordable vaccine, an estimated 107,500 measles deaths occurred worldwide in 2023, primarily among children under the age of five who were either unvaccinated or inadequately vaccinated [1]. High rates of malnutrition, limited access to healthcare in conflict-affected areas, displacement, and overcrowding, among other issues, are challenges countries face that could make matters worse. Access to and use of inadequate sanitation and hygiene practices raise the possibility of interpersonal transmission [4].

In several parts of Africa, the Middle East, and Asia, measles is still prevalent. Measles deaths are overwhelmingly more common in countries with poor per capita incomes or inadequate health systems that make it difficult to vaccinate every child [1]. Ethiopia is among the countries with a high burden of measles outbreaks, alongside Pakistan and Iraq, according to center for disease control and prevention (CDC) reports [5]. A systematic review also revealed that low routine immunization coverage and seasonality were factors that contribute to measles outbreaks in Ethiopia [6]. In 2023, 14.5 million children worldwide were considered "zero-dose children" because they had not received any vaccinations [7]. Next to Nigeria and India, Ethiopia has the third-highest number of zero-dose children worldwide [8]. Moreover, according to WUENIC estimates, the measles vaccination coverage of the country was 61% and 53% for the first dose and second dose, respectively [9]. Inadequate information from health workers, irregularities in service delivery, low staff motivation, high staff turnover, closed and inaccessible health facilities, a lack of operational health posts, and service provision restricted to certain days or hours were all linked to the high percentage of zero-dose children in Ethiopia [10]. As a result, there were 16,814 laboratory-confirmed measles cases and 182 deaths nationwide between August 12, 2021, and May 1, 2023, representing a Case Fatality Ratio (CFR) of 1.1% [4].

In response to measles and other vaccine-preventable diseases, Ethiopia endorsed the immunization agenda 2030 targets. The IA2030 is a global immunization and vaccine strategy for the years 2021–2030. It offers a framework for collaboration between immunization stakeholders at various levels, such as national, regional, and international. It aims to leave no one behind, regardless of age or circumstance, and to guarantee that everyone has access to vaccinations for overall health and wellbeing [11]. In accordance with IA2030, Ethiopia stepped up to the plate by developing a national catch-up vaccination policy in the face of persistent conflict, natural disasters, and a large proportion of children who have not received measles vaccination. Therefore, the country is implementing zero-dose vaccination to achieve a reduction of zero doses by 50% in 2025 and reduce measles and other vaccine-preventable diseases burden [12].

This effort needs analysis of high-quality data to assess whether progress is being made. However, studies on measles burden in Ethiopia are scarce that systematically investigate measles cases at the subnational level and its determinants. The design of effective preventative strategies was hampered by the paucity of solid evidence. In order to estimate the incidence, prevalence, mortality, and disability-adjusted life years (DALYs) of measles in Ethiopia, this study incorporated the best available data from the GBD 2021 on the national and subnational burden of measles in Ethiopia. The study's finding will guide policies and programs aimed at enhancing measles prevention strategies and the well-being of the community.

Methods

Setting

Ethiopia is the second most populous country in Africa after Nigeria, with a population of 128 million as of 2024 [13].

Twelve regional states and two city administrations make up the administrative division of the country. The United Nations (UN) World Population Prospects estimates that the median age of Ethiopians is 18.9 years in 2024. More than 78% of people live in rural areas with little access to healthcare [14]. The infant and under-five mortality rates are 34 and 46 deaths per 1,000 live births, respectively [13]. The ministry of health is in charge of measles vaccination, and the Public Health Emergency Management Team at the Ethiopian Public Health Institute oversees surveillance for measles and other vaccine-preventable diseases[15].

Data Sources

This study primarily utilized data from the Global Burden of Disease (GBD) 2021 Study, which offers comprehensive estimates of the burden of diseases, injuries, and risk factors across countries and subnational regions. The GBD dataset includes detailed, location-specific data on the incidence, prevalence, and mortality of measles, along with sociodemographic variables such as age, sex, and geographic region. Complementary data sources include: (i) the World Health Organization's (WHO) official reports on immunization coverage, disease incidence, and health policies, providing additional context and validation for the GBD estimates; (ii) Ethiopia's National Health Demographic Surveys and Reports, including data from the Ministry of Health and Demographic and Health Surveys (DHS), Multiple indicator survey, sample registry surveillance data for cross-referencing trends and ensuring consistency with national data; and (iii) peer-reviewed articles and public health reports on the burden of measles in Ethiopia, used for comparative analyses [16, 17].

Data Processing

Data extraction focused on measles incidence, prevalence, mortality, and DALYs, disaggregated by age, sex, and geographic region within Ethiopia. The GBD study employs standardized procedures to address missing or inconsistent data, relying on interpolation, established data standards, or exclusion based on predetermined criteria. The data were further standardized to account for population size, demographic structure, and regional variations, ensuring comparability across locations and time. Descriptive statistics were used to quantify the overall burden of measles, including cases, deaths, and disability-adjusted life years (DALYs), and temporal trends from 1990 onwards were analyzed. Subnational disparities in measles burden were assessed to identify high-burden areas requiring targeted interventions.

Analysis

The GBD 2021 methodology underpins the analysis, leveraging a hybrid modeling framework to estimate measles burden in Ethiopia. For locations with sparse mortality data, such as Ethiopia, a natural history model was employed, combining non-fatal case estimates with location- and year-specific case fatality rates (CFR). Mortality estimates for regions with robust vital registration systems were derived using the Cause of Death Ensemble Model (CODEm). The GBD 2021 study used key covariates, including rolling averages of measles-containing vaccine (MCV1) coverage, the Healthcare Access and Quality (HAQ) Index, and the Socio-demographic Index (SDI), were included to capture the multidimensional determinants of measles mortality in the estimation analytic framework. CFR estimates were derived using a mixed-effects negative binomial regression model, which accounted for country-level random effects and study-level variations such as hospital settings, outbreak conditions, and rurality.

Uncertainty in the estimates was quantified through 1,000 iterations of the model, producing 95% uncertainty intervals (2.5th and

97.5th percentiles) for all metrics. Measles deaths were estimated by multiplying modeled incidence with CFR, and results were disaggregated by age and sex to reflect demographic patterns. Adjustments were made to account for reductions in measles cases during the COVID-19 pandemic in 2020 and 2021, the details of methodology published elsewhere [17].

Ethical Considerations

We obtained an ethical approval certificate from the Institutional Review Board, Ethiopian Public Health Institute (IRB-EPHI).

Results

Table 1 shows that the estimated burden of measles by sex. Among male children, the incidence rate was 713 per 100,000 (95% UI: 463.77–1021.94) compared with 706 per 100,000 (95% UI: 459.43–1012.42) in female children. The DALY rate was 821 per 100,000 (95% UI: 431.84–1458.92) for males and 630 per 100,000 (95% UI: 271.24–1174.81) for females.

The measles incidence rate in Ethiopia in 2021 was significantly high at ages 12 to 23 months as compared to ages 24 to 59 months, recording 1,258 per 100,000 (95% UI: 818.72-1804.08) and 424 per 100,000 (95% UI: 276.02-608.28), respectively. Additionally, the DALY rate was similarly high at ages 12 to 23 months and low at ages 24 to 59 months, with figures of 1,162 per 100,000 (95% UI: 582.51-2051.82) and 488 per 100,000 (95% UI: 236.41-868.62), respectively. Similarly, the prevalence and death rates were higher at ages 12 to 23 months and lower for those older than 24 months.

The Afar regional state took the lead with a high measles incidence rate of 970/100,000 (95% UI: 632.67-1376.65), followed by the Somali regional state with a 908/100,000 (95% UI: 592.05-1289.24) incidence rate. The lowest incidence rate was from Addis Ababa, the capital city of Ethiopia, with 384/100,000 (95% UI: 237.59-558.96). Overall, the national measles incidence rate in Ethiopia in 2021 was 709/100,000 (95% UI: 461.66-1017.29). Figure 1 illustrates that the incidence of measles decreased between 1990 and 2021 at the subnational level. However, from 1990 to 2000, this decrease was not as pronounced as in the years following 2000. A sharp decrease in measles incidence was observed from 2000 to 2005. From 2005 to 2015, there was a decline, though not a steep one. Between 2015 and 2021, there was also a notable decline at both subnational and national levels.

Afar and Somali regions had low incidence of measles in 1990 but became the regions with the highest incidence rate from 2000 to 2021. In contrast, the Gambela region recorded the highest incidence rate in 1990; however, this rate decreased significantly over time, resulting in it becoming one of the regions with the lowest incidence by 2021. Addis Ababa, the capital city, consistently recorded the lowest incidence rate throughout the years. The measles incidence rate shows a decreasing trend over the years (1990-2021) nationally.

A high measles death rate was recorded in the Benishangul-Gumuz regional state, with 28/100,000 (95% UI: 8.96-65.8) deaths, followed by the Somali regional state with 17/100,000 (95% UI: 7.83-30.97) deaths. The lowest death rate was from Addis Ababa, the capital city of Ethiopia, with 0.6/100,000 (95% UI: 0.22-1.29). The national measles death rate in Ethiopia in 2021 was 8/100,000 (95% UI: 4.28-14.35).

Subnationally, the measles death rate declined between 1990 and 2021. The decline was less pronounced between 2005 and 2010 than it was before 2005, though. Between 1995 and 2005, there was a notable decrease in the number of measles deaths. From 2010 to 2015, there was a decline, though not a steep one. Between 2015 and 2021, there was also a notable decline at both subnational and national levels. Benishangul Gumuz and Amhara regions had a high measles death rate in 1990,

but Amhara region became the region with the lowest death rate from 2010 to 2021. In contrast, Benishangul Gumuz regional state remained with the highest death rate throughout the period (1990-2021). Somali, Afar and Benishangul regions were regions with the highest measles deaths from 2000 to 2021. Addis Ababa, the capital city, consistently recorded the lowest death rate throughout the years.

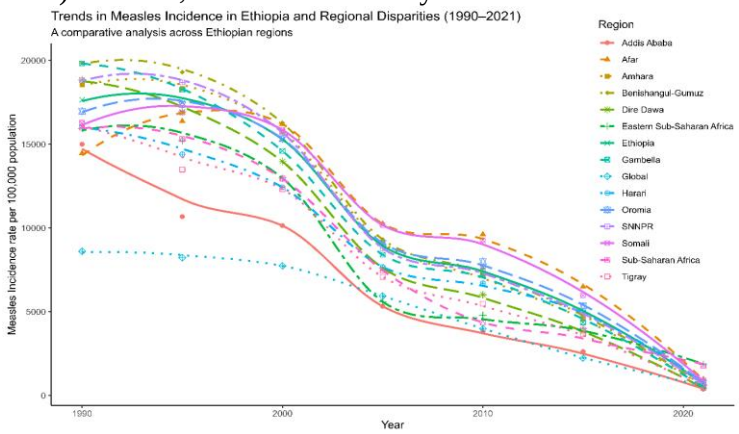

Figure 1. Measles Incidence Rate Trend among Under-five Children in Subnational Regional States, Ethiopia, 1990–2021

Figure 2 indicates that the Benishangul Gumuz regional state took the lead with a high measles DALYs rate of 2,432/100,000 (95% UI: 788.11-5786.66), followed by the Somali regional state with a 1,477/100,000 (95% UI: 692.11-2730.33) DALYs rate. The lowest DALYs rate was reported from Addis Ababa, the capital city of Ethiopia, which was 55/100,000 (95% UI: 20.93-115.49). Overall, the national measles DALYs rate in Ethiopia in 2021 was 728/100,000 (95% UI: 377.52-1264). The measles DALYs rate decreased through time from 1990 to 2021 at the subnational level. However, between 1990 and 2000, the decline rate was not as significant as it was between 2000 and 2005. Between 2000 and 2005, the measles DALYs rate dropped significantly. From 2005 to 2021, there was a decline, though not a steep one.

Somali, Afar, and Benishangul-Gumuz regions had the highest DALY rate throughout the period (1990-2021). In contrast, Addis Ababa, Harari, and Diredawa regions had the lowest DALYs rate from 1990 to 2021 consistently. After 2005, most of the region did not exhibit a discernible decrease in the DALYs rate.

The annual rate of change (ARC) in measles incidence, prevalence, mortality, and DALY rates in Ethiopia from 1990 to 2021 was -0.96 (95% CI: -0.98, -0.88), -0.96 (95% CI: -0.98, -0.88), -0.99 (95% CI: -0.99, -0.96), and -0.99 (95% CI: -0.99, -0.96), respectively.

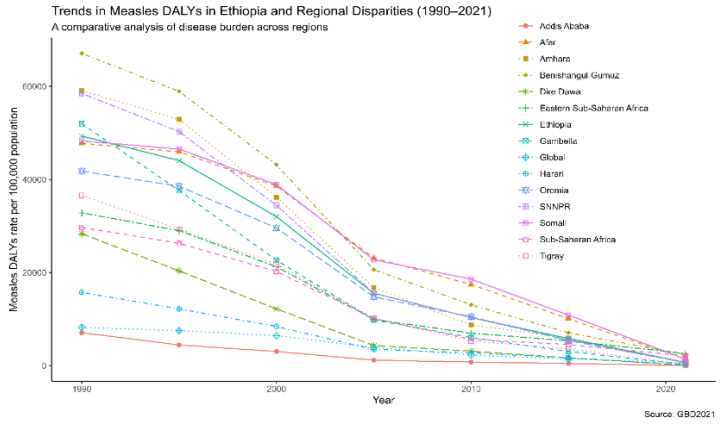

Figure 2. Trend of DALYs Rate of Measles among Under Five Children in Subnational Regional States, Ethiopia, 1990-2021

Table 1. Measles Incidence, Prevalence, Death and DALY Rates, and Annual Rate of Change among Under-Five Children, both Nationally and Subnationally, 1990–2021

By Country/Region	Incidence			Prevalence			Death			DALY		
	2021		1990–2021	2021		1990–2021	2021		1990–2021	2021		1990–2021
	Number (95% UI)	Rate/100,000 (95% UI)	ARC (95%CI)	Number (95% UI)	Rate/100,000 (95% UI)	ARC (95%CI)	Number (95% UI)	Rate/100,000 (95% UI)	ARC (95%CI)	Number (95%CI)	Rate/100,000 (95% UI)	ARC (95%CI)
Global	4080287.07 (3588879.66, 4612755.75)	619.94 (545.28, 700.84)	-0.93 (-0.97,-0.79)	111786.56 (98323.22,126374.63)	16.98 (14.94,19.2)	-0.93 (-0.97,-0.79)	48137.85 (27267.02,75009.04)	7.31 (4.14,11.4)	-0.92 (-0.97,-0.79)	4248999.31 (2411053.88, 6616240.96)	645.58 (366.33,1005.25)	-0.92 (-0.97,-0.79)
Sub-Saharan Africa	3062840.11 (2593999.79, 3542713.74)	1771.96 (1500.72, 2049.59)	-0.89 (-0.95,-0.67)	83911.32 (71066.44,97058.65)	48.55 (41.11,56.15)	-0.89 (-0.95,-0.67)	42414.06 (23137.69,67291.07)	24.54 (13.39,38.93)	-0.93 (-0.97,-0.8)	3742364.92 (2045983.99, 5933082.04)	2165.09 (1183.68,3432.5)	-0.93 (-0.97,-0.8)
Eastern Sub-Saharan Africa	1186309.89 (848543.9, 1638449.34)	1859.53 (1330.08, 2568.25)	8.24 (5.33,11.86)	32499.53 (23245.78,44887.02)	50.94 (36.44,70.36)	-0.88 (-0.95,-0.65)	19210.86 (9132.95,35541.05)	30.11 (14.32,55.71)	-0.92 (-0.97,-0.75)	1694258.6 (805805.11,3132270.44)	2655.73 (1263.09,4909.79)	-0.92 (-0.97,-0.75)
Ethiopia	**113239.65 (73704.18, 162412.31)**	**709.29 (461.66, 1017.29)**	**-0.96 (-0.98,-0.88)**	**3102.46 (2019.29,4449.65)**	**19.43 (12.65,27.87)**	**-0.96 (-0.98,-0.88)**	**1316.81 (682.55,2290.74)**	**8.25 (4.28,14.35)**	**-0.99 (-0.99,-0.96)**	**116156 (60271.15,201798.7)**	**727.56 (377.52,1264)**	**-0.99 (-0.99,-0.96)**
Addis Ababa	924.48 (572.51, 1346.94)	383.65 (237.59, 558.96)	-0.97 (-0.99,-0.92)	25.33 (15.69,36.9)	10.51 (6.51,15.31)	-0.97 (-0.99,-0.92)	1.48 (0.54,3.12)	0.62 (0.22,1.29)	-0.99 (-1,-0.98)	133.11 (50.43,278.3)	55.24 (20.93,115.49)	-0.99 (-1,-0.98)
Afar	2770.91 (1807.76, 3933.56)	969.75 (632.67, 1376.65)	-0.93 (-0.97,-0.8)	75.92 (49.53,107.77)	26.57 (17.33,37.72)	-0.93 (-0.97,-0.8)	47.07 (20.85,84.99)	16.47 (7.3,29.75)	-0.97 (-0.99,-0.92)	4149.97 (1832.43,7511.33)	1452.39 (641.31,2628.79)	-0.97 (-0.99,-0.92)
Amhara	16329.81 (10554.11, 23503.17)	569.66 (368.17, 819.89)	-0.97 (-0.99,-0.91)	447.39 (289.15,643.92)	15.61 (10.09,22.46)	-0.97 (-0.99,-0.91)	192.23 (86.5,361.95)	6.71 (3.02,12.63)	-0.99 (-1,-0.97)	16961.09 (7639.67,31897.42)	591.68 (266.51,1112.72)	-0.99 (-1,-0.97)

Benishangul-Gumuz	1079.97 (693.07, 1554.87)	606.46 (389.19, 873.14)	-0.97 (-0.99,-0.91)	29.59 (18.99,42.6)	16.62 (10.66,23.92)	-0.97 (-0.99,-0.91)	49.23 (15.95,117.18)	27.64 (8.96,65.8)	-0.96 (-0.98,-0.94)	4330.43 (1403.45,10304.77)	2431.76 (788.11,5786.66)	-0.96 (-0.98,-0.94)
Dire Dawa	238.57 (149.36, 344.27)	448.23 (280.63, 646.82)	-0.98 (-0.99,-0.93)	6.54 (4.09,9.43)	12.28 (7.69,17.72)	-0.98 (-0.99,-0.93)	0.86 (0.27,1.63)	1.62 (0.5,3.07)	-0.99 (-1,-0.98)	76.59 (23.83,144.76)	143.9 (44.78,271.97)	-0.99 (-1,-0.98)
Gambella	300.81 (194.54, 433.02)	528.61 (341.87, 760.95)	-0.97 (-0.99,-0.92)	8.24 (5.33,11.86)	14.48 (9.37,20.85)	-0.97 (-0.99,-0.92)	1.69 (0.66,3.4)	2.97 (1.17,5.97)	-0.99 (-1,-0.98)	149.64 (58.94,300.55)	262.96 (103.57,528.17)	-0.99 (-1,-0.98)
Harari	216.71 (141.36, 309.93)	716.19 (467.16, 1024.26)	-0.96 (-0.98,-0.87)	5.94 (3.87,8.49)	19.62 (12.8,28.06)	-0.96 (-0.98,-0.87)	0.68 (0.29,1.29)	2.24 (0.95,4.26)	-0.99 (-1,-0.96)	60.2 (25.69,114.22)	198.94 (84.89,377.49)	-0.99 (-1,-0.96)
Oromia	51344.99 (33597.02, 73234.93)	770.23 (503.99, 1098.61)	-0.95 (-0.98,-0.87)	1406.71 (920.47,2006.44)	21.1 (13.81,30.1)	-0.95 (-0.98,-0.87)	519.28 (234.75,953.38)	7.79 (3.52,14.3)	-0.98 (-0.99,-0.95)	45811.7 (20796.77,83927.4)	687.23 (311.97,1259.01)	-0.98 (-0.99,-0.95)
Somali	10790.11 (7037.67,15325.14)	907.72 (592.05, 1289.24)	-0.94 (-0.98,-0.84)	295.62 (192.81,419.87)	24.87 (16.22,35.32)	-0.94 (-0.98,-0.84)	199.21 (93.12,368.14)	16.76 (7.83,30.97)	-0.97 (-0.99,-0.92)	17557.77 (8227.07,32455.48)	1477.06 (692.11,2730.33)	-0.97 (-0.99,-0.92)
SNNPR*	25239.48 (16493.27, 36132.7)	700.72 (457.9, 1003.15)	-0.96 (-0.98,-0.89)	691.49 (451.87,989.94)	19.2 (12.55,27.48)	-0.96 (-0.98,-0.89)	271.99 (130.31,517.32)	7.55 (3.62,14.36)	-0.99 (-1,-0.97)	24003.26 (11499.23,45632.78)	666.4 (319.25,1266.9)	-0.99 (-1,-0.97)
Tigray	4003.82 (2532.69, 5769.11)	502.64 (317.96, 724.26)	-0.97 (-0.99,-0.91)	109.69 (69.39,158.06)	13.77 (8.71,19.84)	-0.97 (-0.99,-0.91)	33.08 (14.45,61.53)	4.15 (1.81,7.72)	-0.99 (-1,-0.97)	2922.25 (1276.23,5426.62)	366.86 (160.22,681.26)	-0.99 (-1,-0.97)
By Age group												
<12 months	32582.1 (21207.99 ,46731.45)	973.5 (633.66, 1396.27)	-0.96 (-0.98,-0.88)	892.66 (581.04,1280.31)	26.67 (17.36,38.25)	-0.96 (-0.98,-0.88)	364.26 (165.11,682.85)	10.88 (4.93,20.4)	-0.98 (-0.99,-0.96)	32615.99 (14818.86,61066.06)	974.52 (442.77,1824.56)	-0.98 (-0.99,-0.96)

12-23 months	40946.62 (26651.61, 58727.44)	1257.86 (818.72, 1804.08)	-0.96 (-0.98,-0.88)	1121.83 (730.18,1608.97)	34.46 (22.43,49.43)	-0.96 (-0.98,-0.88)	425.75 (213.2,752.57)	13.08 (6.55,23.12)	-0.98 (-0.99,-0.96)	37813.05 (18962.35,66791.9)	1161.6 (582.51,2051.82)	-0.98 (-0.99,-0.96)
24-59 months	39710.92 (25843.98, 56953.42)	424.13 (276.02, 608.28)	-0.96 (-0.98,-0.88)	1087.97 (708.05,1560.37)	11.62 (7.56,16.67)	-0.96 (-0.98,-0.88)	526.8 (254.57,937.59)	5.63 (2.72,10.01)	-0.99 (-0.99,-0.96)	45726.96 (22135.16,81328.93)	488.38 (236.41,868.62)	-0.99 (-0.99,-0.96)
<59 months	113239.65 (73704.18, 162412.31)	709.29 (461.66, 1017.29)	-0.96 (-0.98,-0.88)	3102.46 (2019.29,4449.65)	19.43 (12.65,27.87)	-0.96 (-0.98,-0.88)	1316.81 (682.55,2290.74)	8.25 (4.28,14.35)	-0.99 (-0.99,-0.96)	116156 (60271.15,201798.7)	727.56 (377.52,1264)	-0.99 (-0.99,-0.96)
By Sex												
Male	58244.68 (37911.23, 83538.2)	712.52 (463.77, 1021.94)	-0.96 (-0.98,-0.88)	1595.74 (1038.66,2288.72)	19.52 (12.71,28)	-0.96 (-0.98,-0.88)	761.14 (400.12,1356.46)	9.31 (4.89,16.59)	-0.98 (-0.99,-0.95)	67074.45 (35301.11,119259.1)	820.53 (431.84,1458.92)	-0.98 (-0.99,-0.95)
Female	54994.96 (35792.26, 78874.11)	705.91 (459.43, 1012.42)	-0.96 (-0.98,-0.88)	1506.71 (980.61,2160.93)	19.34 (12.59,27.74)	-0.96 (-0.98,-0.88)	555.67 (238.71,1038.48)	7.13 (3.06,13.33)	-0.99 (-1,-0.96)	49081.55 (21131.36,91525.2)	630.01 (271.24,1174.81)	-0.99 (-1,-0.96)

**SNNPR = Sidama, Central Ethiopia, South Ethiopia and South West Regions.*

Discussion

This study compiled the best available evidence on measles from the GBD study for Ethiopia and its sub-national regions from 1990 to 2021. The difference in incidence and DALY between males and females was not statistically significant. Among male children, the incidence rate was 713 per 100,000 (95% UI: 463.77–1021.94) compared with 706 per 100,000 (95% UI: 459.43–1012.42) in female children. The DALY rate was 821 per 100,000 (95% UI: 431.84–1458.92) for males and 630 per 100,000 (95% UI: 271.24–1174.81) for females. Our finding is consistent with the Gavi Gender and Immunization report [18]. In infants and early childhood, it is uncommon to observe sex differences in incidence and DALY rates. This may also be attributed to both male and female children having equal access to measles vaccination Our analysis revealed that the measles incidence rate in Ethiopia in 2021 was high at ages 12 to 23 months and low at ages 24 to 59 months, recording 1,258 per 100,000 (95% UI: 818.72-1804.08) and 424 per 100,000 (95% UI: 276.02-608.28), respectively. Additionally, the DALY rate was similarly high at ages 12 to 23 months and low at ages 24 to 59 months, with figures of 1,162 per 100,000 (95% UI: 582.51-2051.82) and 488 per 100,000 (95% UI: 236.41-868.62), respectively. This may be explained by the fact that infants are protected from measles by antibodies they receive from their mothers during pregnancy and breastfeeding. However, these maternal antibodies gradually decrease, making infants more susceptible to infection around 12 months of age [19].

Overall, the national measles incidence rate in Ethiopia in 2021 was 709/100,000 (95% UI: 461.66-1017.29), which was lower than eastern sub-Saharan Africa and sub-Saharan Africa measles incidence rates, 1,860/100,000 (95% UI: 1330.08-2568.25) and 1,772/100,000 (95% UI: 1500.72-2049.59), respectively. However, it was higher than the global incidence rate, which was 620/100,000 (95% UI: 545.28-700.84). The national measles incidence rate decreased by 96% in 2021 compared to that of 1990. However, Ethiopia recorded the highest incidence rate from 1990 to 2020 and the lowest in 2021, compared to the trends in measles incidence rates in eastern sub-Saharan Africa and sub-Saharan Africa as a whole. The lower incidence of measles in Ethiopia after 2020, compared to sub-Saharan Africa, may be attributed to the introduction of the second dose of the measles vaccine in Ethiopia in 2019 [20].

Subnationally, the Afar regional state took the lead with a high measles incidence rate of 970/100,000 (95% UI: 632.67-1376.65), followed by the Somali regional state with a 908/100,000 (95% UI: 592.05-1289.24) incidence rate. The lowest incidence rate was from Addis Ababa, the capital city of Ethiopia, with 384/100,000 (95% UI: 237.59-558.96). This finding is in line with a study of the prevalence and determinants of zero-dose children in Ethiopia, which evidenced a high number of unvaccinated and under-vaccinated children in the Afar and Somali regions and a lower number of unvaccinated children in Addis Ababa [21]. Therefore, the lower vaccination coverage in these regions may be the reason for the high incidence rate compared to other regions.

The national measles death rate in Ethiopia in 2021 was 8/100,000 (95% UI: 4.28-14.35), which was lower than eastern sub-Saharan Africa and sub-Saharan Africa measles death rates, 30/100,000 (95% UI: 14.32-55.71) and 25/100,000 (95% UI: 13.39-38.93), respectively. However, it was higher than the global death rate, which was 7/100,000 (95% UI: 4.14-11.4). A high measles death rate was recorded in the Benishangul-Gumuz regional state, with 28/100,000 (95% UI: 8.96-65.8) deaths, followed by the Somali regional state with 17/100,000 (95% UI: 7.83-30.97) deaths. The lowest death rate was from Addis Ababa, the capital city of Ethiopia, with 0.6/100,000 (95% UI: 0.22-1.29). The low death rate in

Addis Ababa may be attributed to improved access to healthcare services, as it is the capital city of the country.

Between 1990 and 2021, the country's measles death rate decreased by 98%. Moreover, between 2015 and 2021, there was a notable decrease at both subnational and national levels. Improved vitamin A supplementation might have reduced the severity of measles and prevented complications and deaths, especially in children [22].

The national measles DALY rate in Ethiopia in 2021 was 728/100,000 (95% UI: 377.52-1264), which was lower than eastern sub-Saharan Africa and sub-Saharan Africa measles DALYs rates of 2,656/100,000 (95% UI: 1263.09-4909.79) and 2,165/100,000 (95% UI: 1183.68-3432.5), respectively. However, it was higher than the global measles DALYs rate, which was 646/100,000 (95% UI: 366.33-1005.25). DALY rates for measles have been declining globally between 1990 and 2021. Ethiopia has the highest overall DALY rate when comparing the trajectory of DALY rates in eastern sub-Saharan Africa across time. It was, however, lower than the global and Sub-Saharan African DALY rates.

Between 2005 and 2021, there was no appreciable decrease in DALYs across the country. The Benishangul Gumuz regional state took the lead with a high measles DALYs rate followed by the Somali regional state. The lowest DALYs rate was reported from Addis Ababa, the capital city of Ethiopia, which was 55/100,000 (95% UI: 20.93-115.49). In 2021, the national measles DALY rate decreased by 98% from 1990. The notable decline in DALYs may be the result of expanding vaccination coverage, decreasing missed vaccination opportunities, and gradually removing immunization barriers [23].

Strengths and limitations of the study

The GBD study has a number of strengths, including comprehensiveness and representativeness at the sub-national level using all Ethiopian data sources that are readily available, which enhance the validity of estimates that cannot be seen in individual household surveys with varied data quality. However, the absence of a reliable measles surveillance and reporting system in the country may lead to wider uncertainty in determining the burden of measles.

Conclusion

The measles burden remains substantial in Ethiopia, despite a significant decline over the past three decades. After the introduction of the second dose of measles, there was a notable decrease in the burden. Our results suggest that there is an urgent need to improve measles vaccination service in Ethiopia, especially in high-burden regions. Moreover, coordinated efforts are required by researchers, politicians, and policymakers to ensure reducing the measles burden in Ethiopia becomes a priority.

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Conflict of Interest

The authors declare no conflict of interest.

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