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Under-five mortality and its associated factors in sub-Saharan Africa: a multilevel analysis of recent demographic and health surveys data based on Bayesian approach

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Abstract

Background An estimated 75.8 under-five deaths per 1000 live births occurred in sub-Saharan Africa. This study aimed to investigate the prevalence and factors associated with under-five mortality in Sub-Saharan Africa.

Methods This study was based on secondary data sources from 33 Sub-Saharan countries' recent Demography and Health surveys from 2010 to 2020. A weighted sample of 360,397 under-five children was included in the study. Bayesian multilevel binary logistic regression was fitted using the brms R package. Besides, leave one out information criteria was used for model comparison. The adjusted odds ratio (AOR) and its 95% credible interval (CrI) were reported for significant factors associated with under-five mortality. Clinical trial number: not applicable.

Results The prevalence of under-five mortality in sub Saharan Africa was 62 per 1000 live births (95%CI (56.29, 68.29). In sub region of SSA, it was 65 in central, 52 in eastern, 50 in southern and 73 in western region per 1000 live births. Multiple birth (AOR = 5.27; 95%CrI: 4.72, 5.87), number of under-five children 3 to 5 (AOR = 3.31; 95%CrI: 3.01, 3.60), caesarean section delivery (AOR = 1.64; 95%CrI: 1.47, 1.83), being unmarried (AOR = 1.16; 95%CrI 1.08, 1.26), using unimproved toilet (AOR = 1.08;95%CrI: 1.02, 1.16), birth order of 4th to 6th (AOR = 1.18; 95%CrI:1.1, 1.25),were risk factors of under-five mortality. Whereas, being female (AOR = 0.86; 95%CrI: 0.82, 0.91), preceding birth interval of 24–35 months (AOR = 0.61; 95%CrI: 0.57, 0.65) and above 36 months (AOR = 0.48; 95%CrI: 0.43, 0.49), ANC visit (AOR = 0.80; 95%CrI: 0.74 0.86), contraceptive use (AOR = 0.57; 95%CrI: 0.53, 0.61), were preventive factors of under-five mortality.

Conclusion Under-five mortality remains the highest in sub-Saharan Africa. Most of the risk factors of under-five mortality were found to be preventable. Policymakers and other stakeholders should enhance maternal education, lengthen birth interval, ANC visit, improved toilet facilities and, giving special attention to small size child and cesarean section delivery to reduce under-five mortality.

Keywords Under-five mortality, Associated factors, Bayesian, Sub-saharan Africa, DHS

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Background

The under-five mortality rate is defined as the probability of dying between birth and exactly five years of age, expressed per 1,000 live births [1]. Children are the most important future generation's resource for the development and growth of the country. Under-Five Mortality Rate (U5MR), Infant Mortality Rate (IMR), and Neonatal Mortality Rate (NMR) represent the quality of children's health care services in an area and are used to measure the level of medical and health care services in a country [2]. Attempts have been made with many resources to address this problem facing the world and reducing the U5MR is a long-term goal for all countries in the world [3]. Under-five mortality has decreased dramatically worldwide, but there are substantial variations across the world due to the inequality growth of economic and health care levels; in developing countries, under-five mortality rates are significantly higher than those in developed countries [4].

In sub-Saharan Africa, large numbers of children die before celebrating their fifth birth day by the most potentially preventable leading causes of childhood deaths [5]. This indicates the limited access that children have to basic health interventions such as vaccinations, primary medical treatment, adequate nutrition, and clean water and sanitation [6]. Under-five mortality represents the social, economic, and environmental conditions in which children and others in society live, and is a leading indicator of child health and the overall development of a country [7]. According to the World Health Organization(WHO), 9.2 million children under the age of five die every year, of which significant number of death was contributed by conditions that could be handled through efficient health care intervention [8]. Lack of access to healthcare facilities, improper hygiene and sanitation, unclean water and food, and low levels of education are the causes of the diseases that kill children under the age of five [8].

Globally, 5.4 million children under the age of five died in 2017. Of these, half died in sub-Saharan Africa and three tenths died in south Asia. Most of these fatalities were caused by preventable conditions such malaria, pneumonia, diarrhea, and birth problems [9]. Despite advancements over the past two decades, 2.5 million newborns, 1.5 million infants, and 1.3 million children aged 1–4 were died in 2018 alone [10]. Of the world's twenty countries estimated to have high under-five mortality, 19 are in sub-Saharan African and 20 countries with the highest risk of neonatal deaths worldwide, 15 are in Africa [11]. There has been significant progress in reducing child mortality worldwide, however; there are still millions of children that die every year in sub-Saharan Africa. Sub-Saharan Africa had the highest under-five mortality, 1 in 13 and in high-income countries,1 in 185 children died before their fifth birthday [12]. In 2019, an estimated 5.2 million under five children were died, of which 1.5 million, 1.3 million and 2.4 million were accounted for children aged 1 to 11 months, children aged 1 to 4 years and newborns (under 28 days) respectively [13].

Previous studies revealed that marital status [14], maternal education [15, 16], partner's education [17], sex of household head [18, 19], toilet facility [20], water source [20], number of under-five children in household [21], the wealth of household [16, 22], media exposure [23], age of mother at first birth [24], preceding birth interval [14, 15], birth order [25–27], ANC visit [26], contraceptive use [28], cesarean section delivery [14], place of delivery [15, 29], Sex of child [16, 30, 31], type of birth (multiple or single) [26, 32], size of the child [19], and breastfeeding [29, 33] were statistically significantly associated with of under- five mortality.

The Sustainable Development Goals (SDG) states that all countries seek to reduce under-five mortality to 25 per 1,000 live births by 2030 [34]. Despite this, in sub-Saharan Africa as evidences suggested there is high under-five mortality rate and needs tremendous effort to achieve the SDG within the stated time frame. To achieve these targets, generating comprehensive evidence for public health planners, implementers, and policymakers on individual and community-level factors is invaluable choice. Besides this, the previous studies done on the factors related to under-five mortality using the classic approach which has some relative drawbacks for large data set, since the Bayesian statistical approach for parameter estimation is better as compared to the classic method for hierarchical nature of the data. Therefore, this study aimed to determine the pooled prevalence and associated factors of under-five mortality in Sub-Saharan Africa using Bayesian statistical approach.

Methods

Data sources

This study was conducted based on the secondary data from the most recent Demography and Health Surveys in 33 Sub-Saharan Africa countries from 2010 to 2020. The DHS for each country is national representative survey gathering information on fundamental health factors such as mortality, morbidity, family planning, pregnancy, maternal and child health. The survey of each country consists of different datasets, including men, women, children, birth, and household characteristics. The data were extracted from Kid recorded dataset from each country and were appended together by coding each country (Fig. 1).

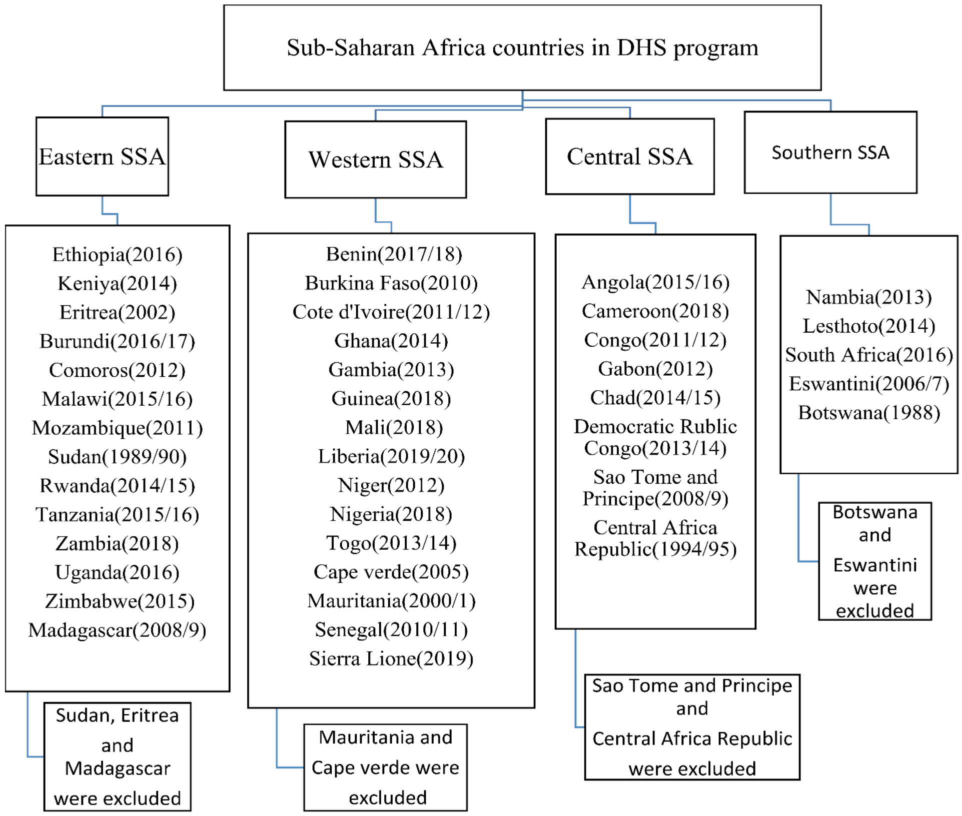

Fig. 1 Schematic presentation of eligibility from sub-Saharan Africa counties

Eligibility criteria

The study was done in 33 sub-Saharan Africa countries. Five Sub Saharan Africa countries Sudan, Central African Republic, Madagascar, Sao Tome Principe and Eswantini did not have a DHS survey report after 2010/2011 Survey year. Another four SSA countries Eritrea, Mauritania, Botswana and Cape Verde datasets are not openly accessible and did not have a report after 2010. Due the above reason nine SSA counties were excluded from this study. The sample size taken for each country is shown in (Table 1).

Study variables and measurements

Dependent variable

The outcome variable of this study was under-five children mortality. The outcome variable was declared and coded. The variable was binary and coded as 1 if the child below 59 months died and 0 if children below 59 months alive.

Independent variables

There are two types of variables considered for this study. The individual and community levelvariables. The individual-level variables were socio-demographic and household variables; marital status, maternal education, partner's education, sex of household head, toilet facility, water source number of under-five children in household, the wealth of household, and media exposure. Maternal and health care delivery variables were age of mother at first birth, preceding birth interval, birth order, ANC visit, contraceptive use, cesarean section delivery, and place of delivery. Child characteristic variables were sex of child, type of birth (multiple or single), size of the child, and breastfeeding status. Community-level variables; the community-level variables share the common thing that has a clustering effect. In this level residence and distance to health facility was obtained from the surveys, whereas region (East, West, Central, and South) and country income level were obtained by aggregating the countries were considered as community-level variables.

Data management and analysis

The independent variables were extracted, cleaned, recoded using the same command in each country using STATA version14 software. The data were weighted using sampling weight to restore the representativeness of the surveys for each country. Children nested within a cluster are more likely similar than children from other clusters implies that the clustering effect should be considered using a multilevel or hierarchical model. The DHS data violates the independence of observations and equal variance assumptions of the logistic regression

Table 1 Weighted and unweighted under-five children sample in Sub Saharan Africa countries using the recent DHS

Country	DHS year	Sample size	
		Weighted	Unweighted
Eastern Region			
Ethiopia	2016	11,023	10,641
Kenya	2014	19,564	20,940
Burundi	2016/17	13,611	13,192
Comoros	2012	3235	3149
Malawi	2015/16	17,395	17,286
Mozambique	2011	11,704	11,102
Rwanda	2014/15	8003	7856
Tanzania	2015/16	10,051	10,233
Zambia	2018	9840	9959
Uganda	2016	15,270	15,522
Zimbabwe	2015	6418	6132
Western Region			
Benin	2017/2018	13,643	13,589
Burkina Faso	2010	15,375	15,044
Côte d'Ivoire	2011/12	7492	7776
Ghana	2014	5695	5884
Gambia	2013	7906	8088
Guinea	2018	7884	7951
Mali	2018	10,304	9940
Liberia	2019/2020	5263	5704
Niger	2012	13,347	12,558
Nigeria	2018	34,192	33,924
Togo	2013/14	6706	6979
Senegal	2010/11	11,479	12,326
Sierra Leone	2019	9771	9899
Central Region			
Angola	2015/16	13,356	14,322
Cameroon	2018	10,061	9733
Congo	2011/12	8170	9329
Gabon	2012	5122	6067
Chad	2014/15	18,635	18,623
Democratic Republic Congo	2013/14	18,390	18,716
South Africa			
Namibia	2013	4803	5046
Lesotho	2014	3112	3138
South Africa	2016	3571	3548
Total		360,397	364,220

model since has a hierarchical structure. This indicates that there is a need to take into account the between cluster variability by using multilevel models. The multilevel Bayesian binary logistic regression was done using the brms R package in R software and presented with AOR using 95% credible intervals for both individual and community-level variables. Group level effects (a measure of variation) were estimated by intra-class correlation coefficient ICC, median odds ratio (MOR), and Proportional Change in Variance (PCV). The intra-class correlation coefficient (ICC) represents the proportion of the total that is attributable to between-group differences and it provides an assessment of whether or not the significance between-group variations exist [35]. The MOR is defined as the median value of the odds ratio between the area at highest risk and the area at lowest risk when randomly picking out two areas. The proportional change in variance (PCV) measures the total variance attributed by the individual's level factors and area level in the multilevel model [36].

Bayesian statistical approach

This study used a Bayesian statistical approach that assumes all unknown parameters are random. A Bayesian approach is a useful tool in statistics, where all form of uncertainty is expressed in terms of probability. All Bayesian inferential conclusions are based on the posterior distribution of the model generated which is a combination of the likelihood function and prior information. The likelihood function in Bayesian analysis reflects information about the parameters contained in the data. The likelihood distribution for this study was Bernoulli distribution. The Prior distribution is the probability distribution that represents the prior information associated with the parameter of research interest. This study used non-informative normal prior distribution with mean = 0 and precision = 0.001 for the population level fixed effect and uniform distribution for the variance of random effect with 10,000 iterations and 1000 warm-ups. In the Bayesian approach because of the difficulty in analytically determining the posterior distribution, simulation techniques are generally used to obtain posterior information [37]. The Hamiltonians Monte Carlo (HMC) method was used to simulate direct draws from the complex posterior distribution. Hamiltonians Monte Carlo (HMC) avoids sensitivity to correlated parameters that plaque, many MCMC methods by taking a series of steps informed by first-order gradient information [37, 38]. No-U-Turn Samplers (NUTS) are used for simulation techniques which are an extension of HMC that uses a recursive algorithm [39]. The Bayesian statistical inference was done based on samples drawn from the posterior distribution using the HMC algorithm. Therefore, monitoring the convergence of the algorithm is essential and the convergence was checked with Rhat value = 1, Bulk-ESS and Tail-ESS were greater than 1000, trace plots and density plot [35, 40].

Model comparison and selection

In this model, the four models were fitted; Empty model: analyzed without any independent variables to test the random effect of between-cluster variability. Individual-level factors model: done by including only individual variables. Community-level factors model: analyzed using only community levels variables. Then the combined model by including both individual and community levels variables simultaneously was fitted and compared to get the best-fitted model. Model comparison was done based on their LOOIC value and the smallest LOOIC value model was selected for the inference. The Leave-one-out information criteria (LOOIC) is particularly useful in Bayesian model selection where the posterior distributions of the models have been obtained by Hamiltonians Monte Carlo (HMC) algorithm using No–U-Turn Sampler(NUTS) simulations [41, 42].

Results

Socio-demographic characteristics of study participants

A total of weighted 360,397 under-five children born five years preceding the surveys in 33 sub-Saharan Africa countries were included in this study. The largest study participants 149,059(41.36%) were from the west of Sahara and the smallest 11,487(3.19%) were from the south of Sahara. More than half 245,756(68.19%) were residing in rural areas (Table 2).

Maternal and child characteristics

Of a total of under-five children, 182,638(50.68%) were males and 13,129 (3.64%) were multiple births. Around 67% 240,746(66.88%) of under-five children were delivered at health institution and 18,219(5.07%) of them were delivered by cesarean section (Table 3).

Prevalence of under-five mortality in Sub Saharan Africa

The prevalence of under-five mortality rate in Sub Saharan Africa countries was 62 with 95%CI (56.29, 68.29) per 1000 live births. Under-five mortality in six central Africa countries was 65 per 1000 live births with 95%CI of (51.62, 78.57). In the eastern region of SSA, the prevalence was 52 per 1000 live births across eleven countries with 95%CI of (46. 48, 57.26). In the southern region of sub-Saharan Africa across three countries it was 50 per 1000 live births with 95%CI (33.96, 65.39). In the western region, under-five mortality was 73 with 95% CI (63.29, 82.09) across thirteen countries (Fig. 2).

Multilevel analysis based on bayesian approach

Null model without covariates

In the null model R-hat value is one and all effective sample sizes values (both Bulk-ESS and Tail-ESS) are greater than 1000 that confirming the convergence of the model. The variance between the country's death statuses of under-five children is estimated as 0.34 which is found to be significant since the credible interval of the respective parameters was greater than zero. Here the null hypothesis tested is $\sigma\mu_0^2 = 0$, i.e. there is no countries variation in the under-five child mortality in sub-Saharan Africa. Based on the result the values of variables are significant at 95% credible interval, which means the interval does not include zero. Therefore, the null hypothesis had been rejected indicating strong evidence that between countries variance is non-zero. To get how much variation of under-five mortality was attributable to the country-level factors, it is useful to see the intra-class correlation coefficient. As the result displayed that the intra-class correlation coefficient (ICC) was 0.094, meaning that around 9.4%of the variance in under-five mortality is due to variation between countries. Whereas the remaining 90.6% is attributable to the individual level that means within-country difference. The MOR in the null model indicates the odd of under-five mortality was 1.73 times more likely when under-five children go from low risk to high-risk countries (Table 4).

Model two with individual variables only

In this model Rhat value is one and all effective sample sizes (both Bulk-ESS and Tail-ESS) are greater than 1000 for each estimated value. In this model, maternal education, marital status, partner education, toilet facility, maternal working status, contraceptive use, number of under-five children, birth order, sex of a child, preceding birth interval, ANC visit, breastfeeding, birth type, cesarean section delivery and size of the child were significantly associated with under-five mortality among under-five children in sub-Saharan Africa (Table 5).

Model three with community-level variables only

Model three that fitted with community-level only variables also have R-hat value is one and all effective sample sizes (both Bulk-ESS and Tail-ESS are greater than 1000. The variables region and residence were significantly associated with child mortality in Sub-Saharan Africa (Table 6).

Model four with both individual and community-level factors

In the full model R-hat value is one and all effective sample sizes (Bulk-ESS and Tail-ESS) are greater than 1000 implies that the model was converged. Besides this the density plot was unimodal (one peak) and they are centered on one value. Trace plot also shows both chain one and chains two were well mixed. The PCV in the full model shows that 14.7% of the country variance observed was explained by both individual and community-level variables.

Interpretation of the multilevel bayesian binary logistic regression

The final interpretation and report were based on the best-fitted model that has a small LOOIC value after a comparison of four models. The full model has the smallest (LOOIC = 53089) compared to the rest model, a model with individual variables is (LOOIC = 53138), community-level variable (LOOIC = 56727), and null model is LOOIC = 56743). This shows that the full model

Table 2 Socio-demographic and other characteristics of children aged less than 59 months in sub- Saharan Africa using recent DHS 2010 to 2020

Variables	Weighted frequency	Weighted Percent
Socio-demographic characteristics		
Maternal education		
No education	145,940	40.50
Primary	119,157	33.07
Secondary and above	95,270	26.44
Marital Status		
Married	256,876	71.28
Unmarried	103,519	28.72
Sex of Household head		
Male	288,668	80.10
Female	71,730	19.90
Water source		
Improved	241,532	67.04
Unimproved	118,772	32.96
Toilet facility		
Improved	152,166	42.24
Unimproved	208,107	57.76
Maternal education		
No education	145,940	40.50
Primary	119,157	33.07
Secondary and above	95,270	26.44
Mother Working status		
Not working	131,471	37.59
Working	218,287	62.41
Wealth index		
Poor	159,910	44.37
Middle	72,299	20.06
Rich	128,188	35.57
Media exposure		
Yes	231,506	64.40
No	128,000	35.60
Partner education		
No education	124,801	39.55
Primary	86,586	27.44
Secondary and above	104,149	33.01
Community-level Variables		
Residence		
Urban	114,629	31.81
Rural	245,769	68.19
Region		
Eastern	126,117	34.99
Western	149.059	41.36
Central	73,734	20.46
South	11,487	3.19
Distance to the health facility		
Not big problem	197,508	58.74
Big problem	138,760	41.26
Country Income level		
Low	171.954	47.71
Low middle	174,946	48.54
Upper middle	13,498	3.75

Table 3 Maternal and child characteristics of children aged less than 59 months in sub- Saharan Africa using recent DHS 2010 to 2020

Maternal and Child characteristics		
Sex of child		
Male	182,638	50.68
Female	177,760	49.32
Type of Birth		
Single	347,269	96.36
Multiple	13,129	3.64
Size of Child		
Large	122,664	35.11
Average	164,219	47.00
Small	62,520	17.89
Number of under 5 children in the household		
Less than 2	264,261	73.32
3 to 5	87,882	24.38
Greater than 5	8,255	2.29
Birth order		
1st to 3rd	205,516	57.02
4th to 5th	107,904	29.94
Above 6th	46,978	13.04
Preceding birth interval(Months)		
Less than 24	54,526	19.46
24 to 35	97,667	34.85
Greater or equal 36	128,020	45.69
Breastfeeding status		
No	15,366	4.41
Yes	332,963	95.59
ANC visit status		
No	29,528	11.98
Yes	216,913	88.02
Place of delivery		
Home	119,199	33.12
Institutional	240,746	66.88
Cesarean section delivery		
No	341,135	94.93
Yes	18,219	5.07
Age at 1st birth		
< 15	46,079	12.79
15–24	282,132	78.28
> 24	32,187	8.93
Contraceptive use		
No	258,477	71.72
Yes	101,921	28.28

is the winning model for interpretation. In the full model multilevel Bayesian analysis results in sex of the child, birth type, the number of under-five children, birth order, preceding birth interval, maternal education, marital status, partner education, toilet facility, maternal working status, contraceptive use, ANC visit, place of delivery, cesarean section delivery, size of a child, region, and country income levels were significantly associated with under-five mortality in sub-Saharan Africa.

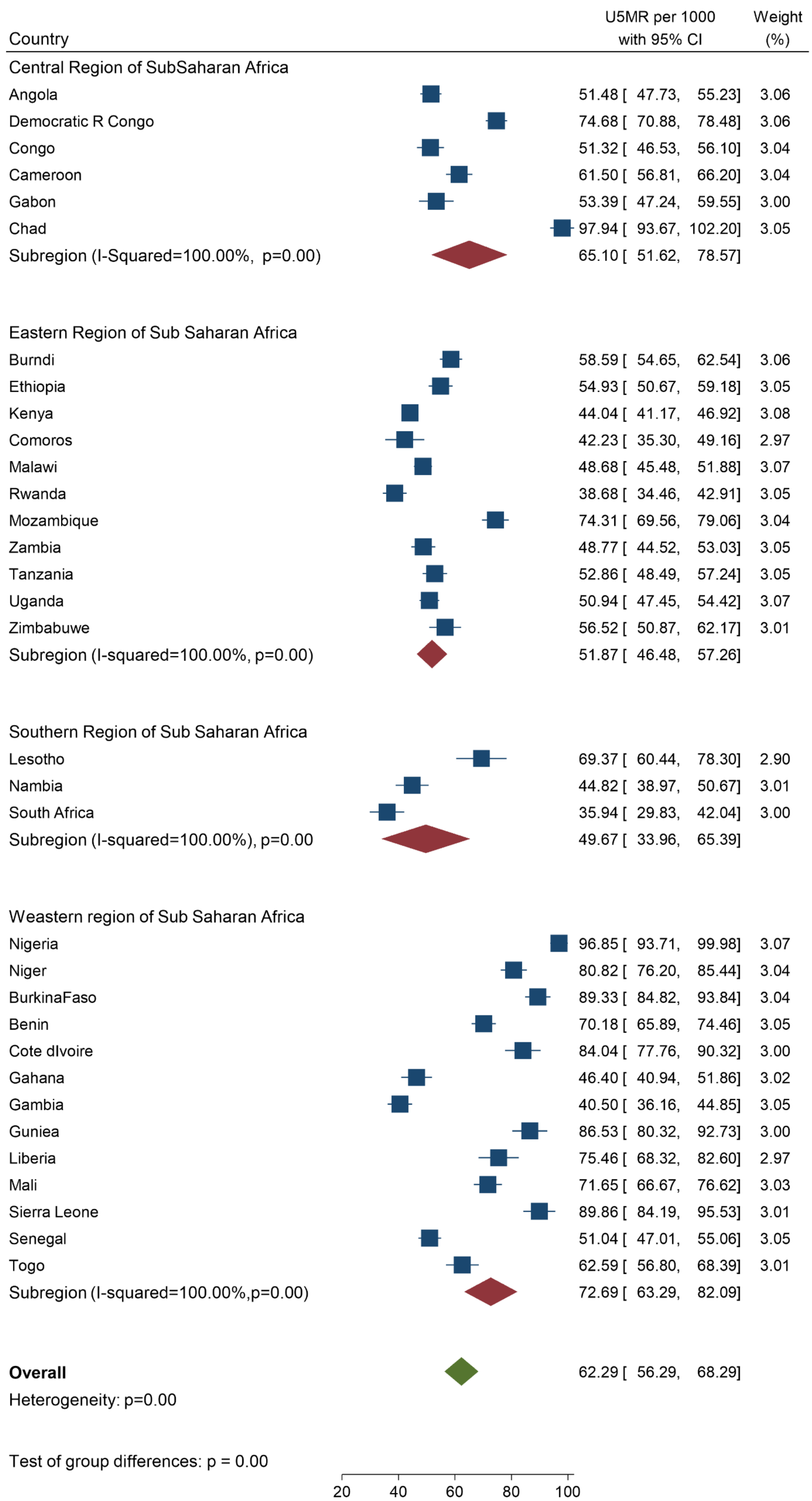

Fig. 2 Prevalence of under-five mortality per 1000 live births in sub-Saharan Africa using recent DHS 2010 to 2020

Table 4 Model 1 null model without variables result of bayesian multilevel binary logistic regression in Sub-saharan Africa using recent DHS 2010 to 2020

Fixed effect	Estimates	SE	AOR	95%CrI		Rhat	Bulk-ESS	Tail-ESS
				L-CrI	U-CrI			
β0 (intercept)	-3.23	0.06	0.0393	0.0347	0.0442	1.00	1497	2577
Random effect								
Variance	0.34	0.05		0.26	0.45	1.00	2053	3813
ICC	0.094							
MOR(%)	1.73							
PCV(%)	1							
LOOIC	56743.6							

The odds of death among female children were decreased by 14% as compared to its counterpart 0.86(AOR = 0.86; 95%CrI: 0.82, 0.91). The odd of death among multiple births was 5.27 times higher as compared to singletons (AOR = 5.27; 95%CrI: 4.72, 5.87). The odds of child death among small size child were 1.42 times higher than average children (AOR = 1.42; 95%CrI: 1.32, 1.52). The odds of child death among children born on the birth order of 4th to 6th and above 6th was 1.18 and 1.84 (AOR = 1.18; 95%CrI 1.1, 1.25) and (AOR = 1.84; 95%CrI 1.72, 1.99) respectively times more likely to die as compared to a child born from1st to 3rd birth order.

The odds of child death among children born with mother's education level secondary and above is 0.83 less likely as compared to children born from mothers of uneducated mothers. The odds of child death born from unmarried 16%, 1.16 (AOR = 1.16; 95%CrI: 1.08, 1.26) times more likely to die as compared to child born from a married. The odds of child death from households accessed with unimproved toilet used was 1.08(AOR = 1.08 95%CrI; 1.02, 1.16 more likely to die as compared to those from used improved toilet. Children born from mothers who are working was 1.14 times more likely to die as compared to their counterpart (AOR = 1.07; 95%CrI: 1.07, 1.21).

The odds of child death among children born from preceding birth interval of 24–35 and above 36 months were (AOR = 0.61; 95%CrI: 0.57, 0.65) and (AOR = 0.48; 95%CrI: 0.43, 0.49) less likely to die as compared to a children born from preceding birth interval of less than 24 months. The odds of child death among breastfeeding children lowered by 50% as compared to their counterparts (AOR = 0.50; 95%CrI: 0.40, 0.60). The odds of child death born those from mothers who have ANC visit were (AOR = 0.80; 95%CrI: 0.74 0.86) as compared to those born never visit one ANC. The odds of child death among children born using cesarean section were 1.64(AOR = 1.64; 95%CrI: 1.47, 1.83) times higher than children delivered by non-cesarean section delivery (Table 7).

Discussion

Under-five mortality is a crucial sign of both children's survival and the wellbeing of the population [43]. This study revealed that the prevalence of under-five mortality across 33 Sub- Saharan Africa countries was 62.29 per 1000 live births. It was higher than the SDGs targets to reduce under-five mortality in to 25 per 1000 live births by 2030 [44]. This could be attributed to countries in SSA lack of access to healthcare facilities, poor hygiene and sanitation, unclean water and continued to high risk of malnutrition contributes to high burden of under-five mortality [45].The prevalence of under-five mortality rate variation was observed across the four sub-regions of SSA. Under-five mortality was highest in the western region of Sub-Saharan Africa 73 per 1000 live birth with 95% CI (63.29 to 82.9) and the lowest was in the southern region of sub-Saharan Africa 50 per 1000 live birth with 95% CI (33.96, 65.39). In the eastern region of SSA also the prevalence was 52 per 1000 live births and 65 per 1000 live births in was central region of SSA. This variation could be due to in adoption and implementation of policies and programs in addition to socio-economic and geographical difference [46].

In this study we tried to assess both individual and community-level factors of under-five mortality using the Bayesian approach. From multilevel Bayesian binary logistic regression result; sex of the child, birth type, the number of under-five children, birth order, preceding birth interval, maternal education, marital status, partner education, toilet facility, maternal working status, contraceptive use, ANC visit, place of delivery, cesarean section delivery, size of child, region, and country income levels were significantly associated with under-five mortality.

This study revealed that the level of maternal education was found to be significantly associated with under-five mortality. Educated mothers (secondary and above) reduce the risk of child mortality; which is supported by different kinds of literatures [16, 17, 24, 47]. The possible justification might be educated mothers will have better socioeconomic status, good knowledge of child feeding practices, hygiene, and follow their child's health status closely [48]. Educated mothers might have greater

Table 5 Model two with individual-level variables result of bayesian multilevel binary logistic regression in Sub-saharan Africa using recent DHS of 2010 to 2020

Fixed effect	Category	Estimates	SE	AOR	95%CrI		Rhat	Bulk-ESS	Tail-ESS
					L-CrI	U-CrI			
β0 intercept)		-1.23	0.11	0.29	0.23	0.37	1.00	3390	8006
Sex of child	Male	Ref							
	Female*	-0.15	0.03	0.86	0.82	0.91	1.00	21,065	13,549
Birth type	Single	Ref							
	Multiple*	1.66	0.06	5.27	4.73	5.88	1.00	21,392	13,570
Size of child	Average	Ref							
	Small*	0.35	0.03	1.41	1.32	1.51	1.00	17,784	14,135
	Large	-0.04	0.03	0.96	0.91	1.02	1.00	17,783	14,587
Birth order	1st -3rd	Ref							
	4th – 6th*	0.16	0.03	1.18	1.10	1.25	1.00	18,812	14,217
	Above 6*	0.61	0.04	1.84	1.71	1.98	1.00	16,392	14,366
Breastfeeding	No	Ref							
	Yes*	-0.70	0.04	0.50	0.40	0.62	1.00	19,649	14,272
Household head sex	Male	Ref							
	Female	-0.03	0.04	0.97	0.90	1.04	1.00	23,301	14,371
Age at first birth	< 15	Ref							
	15–24	0.01	0.04	1.09	0.93	1.08	1.00	14,662	13,282
	> 24	-0.07	0.06	0.93	0.82	1.04	1.00	14,495	14,217
Media exposure	No	Ref							
	Yes	0.22	0.03	1.24	1.16	1.31	1.00	20,321	13,970
Water source	Improved	Ref							
	Unimproved	-0.01	0.03	0.99	0.93	1.05	1.00	20,944	14,674
Toilet facility	Improved	Ref							
	unimproved*	0.09	0.03	1.09	1.02	1.16	1.00	17,537	14,018
Maternal working status	Not working	Ref							
	Working*	0.13	0.03	1.14	1.07	1.21	1.00	40,973	13,521
Contraceptive use	No	Ref							
	Yes*	-0.56	0.04	0.57	0.53	0.61	1.00	22,391	17,714
Number of under-five	<=2								
	3–5 < = 2*	1.20	0.04	3.3	3.04	3.60	1.00	21,296	14,810
	>=6	0.05	0.13	1.05	0.82	1.35	1.00	21,350	13,353
Maternal education	Uneducated	Ref							
	Primary	0.05	0.04	1.05	0.98	1.13	1.00	12,179	13,521
	Secondary and above*	-0.2	0.05	0.82	0.74	0.91	1.00	11,482	12,917
Marital status	Married	Ref							
	Unmarried*	0.15	0.04	1.15	1.07	1.27	1.00	18,464	15,039
Wealth index	Middle	Ref							
	Poor	0.04	0.04	1.04	0.97	1.22	1.00	16,879	14,000
	Rich	-0.06	0.04	0.94	0.86	1.02	1.00	16,237	13,753
Preceding birth interval	< 24	Ref					1.00		
	24–35*	-0.49	0.04	0.61	0.57	0.65	1.00	13,174	13,473
	> 36*	-0.78	0.03	0.45	0.42	0.48	1.00	11,787	13,308
ANC visit	No	Ref							
	Yes*	-0.22	0.04	0.80	0.74	0.86	1.00	17,371	14,299
Place of delivery	Home	Ref							
	Institutional	-0.05	0.03	0.95	0.89	1.02	1.00	16,613	13,979
Caesarian section delivery	No	Ref							
	Yes*	0.49	0.06	1.63	1.45	1.81	1.00	19,531	14,053
Partner education	No education	Ref							
	primary*	-0.11	0.04	0.89	0.83	0.97	1.00	15,723	14,026
	Secondary and above*	-0.10	0.04	0.91	0.83	0.99	1.00	13,266	13,521

Table 5 (continued)

Fixed effect	Category	Estimates	SE	AOR	95%Crl		Rhat	Bulk-ESS	Tail-ESS
					L-Crl	U-Crl			
Random effect									
Variance*	0.30	0.05			0.22	0.40	1.00	3930	7184
ICC	0.083								
MOR(%)	1.68								
PCV(%)	11.7								
LOOIC	53138.6								

*= significant, ref = reference

Table 6 Model three with community-level variables result of bayesian multilevel binary logistic regression in Sub-saharan Africa using recent DHS 2010 to 2020

Fixed Effect	Category	Estimates	SE	AOR	95%Crl		Rhat	Bulk-ESS	Tail-ESS
					L-Crl	U-Crl			
β0 (intercept)		-3.32	0.11	0.03	0.02	0.04	1.00	8574	11,008
Region	Eastern	Ref							
	Western*	0.40	0.12	1.49	1.17	1.90	1.00	8859	11,207
	Central*	0.41	0.17	1.51	1.08	2.09	1.00	9291	10,801
	South*	0.66	0.27	1.92	1.11	3.30	1.00	11,988	11,109
Residence	Rural	Ref							
	Urban*	-0.15	0.03	0.86	0.81	0.91	1.00	23,223	13,845
Country income level	Low	Ref							
	Low middle	-0.10	0.12	0.90	0.71	1.13	1.00	9078	10,837
	Upper middle	-0.49	0.28	0.61	0.35	1.06	1.00	11,895	11,947
Distance to health facility	No big problem	Ref							
	Big Problem	-0.03	0.03	0.97	0.91	1.01	1.00	22,615	13,782
Random effect									
Variance*	0.32	0.05			0.26	0.43	1.00	3711	7079
ICC	0.088								
MOR(%)	1.71								
PCV(%)	5.9								
LOOIC	56727.4								

*= significant, ref = reference

health-seeking behavior for childhood illnesses, knowledge of family planning and use of child health care services like immunization [49, 50]. Additionally, partner education is an important factor of under-five mortality, which is children born from primary, secondary, and above educated fathers are benefited for their life. That means educating fathers reduce child mortality, supported by the previous similar study [27], which shares a possible explanation with mother education. Children born from unmarried women had a high risk of mortality as compared to married. This finding was supported by the studies done in [14, 21]. This could be unmarried mothers may be stretched between care of their children and securing an adequate income to support themselves and their children that may less ability to seek medical care when children fall sick. These children are also likely to lack critical financial and emotional inputs from their fathers early in life [51]. Children with working mothers were experienced a higher risk of under-five mortality, was supported by studies [16, 52, 53].The reason could be because working women would only breastfeed seldom [54] and would delay visiting medical facilities when their children were ill because of their heavier workloads [23].

Under five children born from a household of accessed unimproved toilet facilities have high risk of mortality; which is supported by the studies [55–57]. It is known, children become more affected by environmental contamination when they are walking, exploring, and taking objects to their mouth, that which increases the risk of child health [58]. Also due to unsafe disposal of stool and use of open defecation leads to poor sanitation and child disease like diarrhea that will further increases the risk of child death. The number of under-five children in the household has a direct relationship with under-five mortality. Children born from having high number of under-five children in household have a high risk of death [21, 33]. The possible reason be due to sharing household materials may leads to family poverty and more vulnerability to disease and consequently exposed to high risk of under-five mortality [59].

Table 7 Model 4 with both individual and community level variables result of bayesian multilevel binary logistic regression in Sub-saharan Africa using recent DHS 2010 to 2020

Fixed Effect	Category	Estimates	SE	AOR	95%CrI		Rhat	Bulk-ESS	Tail-ESS
					L-CrI	U-CrI			
β0 (intercept)		-1.35	0.17	0.26	0.19	0.36	1.00	7971	10,821
Sex of child	Male	Ref							
	Female*	-0.15	0.03	0.86	0.82	0.91	1.00	42,613	13,085
Birth type	Single	Ref							
	Multiple*	1.66	0.06	5.27	4.72	5.87	1.00	37,090	13,245
Size of child	Average	Ref							
	Small*	0.35	0.03	1.42	1.32	1.52	1.00	33,688	14,764
	Large	-0.04	0.03	0.96	0.91	1.02	1.00	33,756	13,965
Birth order	1st -3rd	Ref							
	4th – 6th*	0.16	0.03	1.18	1.1	1.25	1.00	27,207	14,800
	Above 6*	0.61	0.04	1.84	1.72	1.99	1.00	26,477	14,574
Media exposure	No	Ref							
	Yes	0.22	0.03	1.24	1.17	1.31	1.00	35,157	13,299
Water source	Improved	Ref							
	Unimproved	-0.01	0.03	0.99	0.93	1.04	1.00	39,305	12,512
Toilet facility	Improved	Ref							
	unimproved*	0.08	0.03	1.08	1.02	1.16	1.00	34,678	12,640
Maternal working status	Not working	Ref							
	Working*	0.13	0.03	1.14	1.07	1.21	1.00	40,973	13,211
Age at first birth	< 15	Ref							
	15–24	0.01	0.04	1.01	0.94	1.08	1.00	26,810	14,744
	> 24	-0.07	0.06	0.93	0.82	1.04	1.00	27,238	15,101
Breastfeeding	No	Ref							
	Yes*	-0.70	0.04	0.50	0.40	0.60	1.00	35,081	12,543
Household head sex	Male	Ref							
	Female	-0.03	0.04	0.97	0.90	1.04	1.00	39,017	12,358
Contraceptive use	No	Ref							
	Yes*	-0.56	0.04	0.57	0.53	0.61	1.00	38,225	12,206
Number of under five	<=2	Ref							
	3–5	1.20	0.04	3.31	3.05	3.60	1.00	33,946	13,342
	>=6	0.05	0.12	1.05	0.82	1.33	1.00	38,527	13,069
Maternal education	No education	Ref							
	Primary	0.06	0.04	1.06	0.98	1.14	1.00	28,307	15,299
	Secondary and above*	-0.19	0.05	0.83	0.77	0.91	1.00	25,266	14,488
Marital status	Married	Ref							
	Unmarried*	0.15	0.04	1.16	1.08	1.26	1.00	38,686	13,647
Partner education	No education	Ref							
	primary*	-0.10	0.04	0.90	0.84	0.97	1.00	27,453	14,762
	Secondary and above*	-0.09	0.04	0.91	0.84	0.95	1.00	24,902	15,194
Preceding birth interval	< 24	Ref					1.00		
	24–35*	-0.50	0.04	0.61	0.57	0.65	1.00	22,714	13,702
	> 36*	-0.78	0.03	0.48	0.43	0.49	1.00	24,200	14,728
ANC visit	No	Ref							
	Yes*	-0.23	0.04	0.80	0.74	0.86	1.00	40,033	13,270
Place of delivery	Home	Ref							
	Institutional	-0.04	0.03	0.96	0.90	1.02	1.00	35,285	11,752
Caesarian section delivery	No	Ref							
	Yes*	0.49	0.06	1.64	1.47	1.83	1.00	41,007	13,186
Wealth index	Middle	Ref							
	Poor	0.04	0.04	1.04	0.97	1.12	1.00	31,550	14,338
	Rich	-0.05	0.04	0.95	0.88	1.03	1.00	29,511	13,692

Table 7 (continued)

Fixed Effect	Category	Estimates	SE	AOR	95%CrI		Rhat	Bulk-ESS	Tail-ESS
					L-CrI	U-CrI			
Distance to the health facility	No problem	Ref							
	Problem	0.03	0.03	1.02	0.97	1.08	1.00	37,237	12,916
Region	Eastern	Ref							
	Western*	0.30	0.16	1.35	1.01	1.84	1.00	5979	8775
	Central	0.12	0.20	1.13	0.76	1.70	1.00	7883	10,778
	South	0.57	0.34	1.78	0.92	3.46	1.00	10,793	11,913
Residence	Rural	Ref							
	Urban	-0.07	0.04	0.94	0.87	1.01	1.00	36,295	12,748
Country income level	Low	Ref							
	Low middle	-0.14	0.15	0.87	0.65	1.16	1.00	6219	9003
	Upper middle*	-0.88	0.34	0.41	0.21	0.82	1.00	10,289	12,118
Random effect(Group level effect)									
Variance*	0.29	0.05			0.21	0.39	1.00	3637	5818
ICC	0.081								
MOR(%)	1.67								
PCV(%)	14.7								
LOOIC	53088.9								

* = significant, ref– reference

We also found evidence that the lower risk of child death were found among female's under-five children as compared to male children. The finding was supported by the studies [16, 24, 52]. The possible reason might be females have a biological advantage against many causes of death over males [60]. Due to genetic and biological difference female are less vulnerable to infectious diseases, perinatal conditions, and congenital anomalies [61]. Children from multiple births had high risk of mortality. The result was supported by studies done [14, 19, 26, 32]. This might be during pregnancy multi-fetal causes sharing nutrition may leads to malnutrition and an adverse birth outcome during birth [62]. In addition, parents of multiples pay less attention to their children and have higher levels of worry, stress, and depression in the first year following delivery than do parents of singletons [63]. As well as children from multiple births may have limited access to breastfeeding and other health care due to increase their family size that leads to an increase risk of death [64]. This study also showed that children with small size had a high risk of under-five mortality. Children with small size had a higher risk of death by 42% as compared to average size. The finding was supported by the studies [14, 19]. This could be small size child may be more vulnerable to preterm birth and birth complication that leads to more risk of death than average size children [65].

Finding from this study indicated that the length of preceding birth interval has an inverse relationship with under-five mortality. Children born after 24–35 months [53] and greater or equal to 36 months of the preceding birth interval had a lower risk of mortality compared to children born from less than 24 months. This finding was consistent with the study conducted in [19, 24, 26, 28, 66]. This might be shorter birth interval may affect maternal health and reduction of nutrition during pregnancy that leads the child would prone to malnutrition during intrauterine life, low birth weight, premature birth [23, 67]. Additionally, the recovery time for the uterus will short, and lactation will deplete maternal nutrient that it will further increase the risk of child death [68]. On the other hand, the study also found that children with high birth order had a high risk of under-five mortality. This finding is in line with the studies done [25, 26, 32]. This may be due to high birth order indicates with many pregnancies lead to more complications to both mother and child health problems which shares a possible explanation with birth intervals.

This study also showed that breastfeeding significantly decreases under-five mortality. The finding was supported by studies [16, 33]. The reason may be due the first milk colostrum's abundance in antibodies that strengthen the immune system and protect against digestive tract infections, which are required for better survival after delivery and breastfeeding it is crucial for children's immunity development [69]. Breastfeeding for mothers also used as a contraceptive method that prolongs the birth interval will improve the overall child health [70]. Children born from whose mothers did not use any of contraceptive methods was more likely to die as compared to their counterparts. The finding was supported by the studies done [15, 18, 26, 28]. Women's use of contraceptive methods indicates that these women have better access to healthcare and have better knowledge and access to maternal and child health programs [71]. Moreover, usage of contraceptives prevents unwanted pregnancies, some of which may have resulted in child death [71]. On the other hand, a high risk of child death was found among children born by cesarean section delivery. This in line with the study [14]. The reason could be because children born via cesarean delivery are exposed to different bacteria at birth than those born via vaginal delivery, making them more likely to develop immune-related illnesses throughout their lifetimes [72].

Children born from mothers who had at least one ANC visit had a low risk of under-five mortality. The finding was supported by the studies [18, 26]. The reason may be because women who received ANC services have prenatal checkup, access to health promotion and disease prevention programs like tetanus immunization and iron/folic acid supplementation, as well as health education and counseling from qualified health professionals [73]. Children from high-income countries had a low risk of mortality as compared to low-income countries. The possible reason might be due to having good infrastructure like modern use of health facility and education that has an influence on the household food security.

Strength and limitations

The strength of the study; this study was conducted on nationally representative multi-country data that could enhance the generalizability of the estimated under-five mortality in sub-Saharan Africa. Besides this using Bayesian statistical analysis, which has high power and that computes the posterior distribution by combing the prior information with current data, and inference is based on the posterior distribution. Additionally, a cross-nationally representative population-based study is employed to draw the conclusion, as well as the use of multilevel logistic regression analysis, which could detect factors other than those at the individual -level. On the other hand, the study did not address the cause-effect conclusion, since the study was based on data from a cross-sectional survey is the limitation of the study.

Conclusion and recommendation

In conclusion, Even though the mortality rate for under-five has decreased in Sub-Saharan Africa, still a significant number of under-five children were dying. Multiple birth types, number of under-five children 3–5, birth order 4th -6th and above 6th, being unmarried, maternal working, used unimproved toilet, cesarean section delivery, and being small size were factors that increase the odds of under-five mortality. On the other hand, being female, maternal education level secondary and above, contraceptive use, ANC visit, preceding birth interval 24–36 and above 36 were the factors that reduce the odds of under-five mortality rate in Sub Saharan Africa. To achieve the SDG targets regarding under-five mortality in Sub-Saharan Africa, Ministry of education, policymakers and health planners and health institutions should give prior attention to preventable factors for under-five mortality accordingly such us strengthen maternal education, lengthen the preceding birth interval, ANC and give special attention to multiple births, small size child and cesarean section delivery.

Abbreviations

ANC	Antenatal care
AOR	Adjusted Odd Ratio
Bulk ESS	Bulk Effective Sample Size
CrI	Credible Interval
DHS	Demography and Health Survey
ICC	Intra-class Correlation Coefficient
IMR	Infant Mortality Rate
KR	Kids Record
HMC	Hamiltonians Monte Carlo
LOOIC	Leave- One- Out-information criteria
NMR	Neonatal Mortality Rate
SSA	Sub-Saharan Africa
SDG	Sustainable Development Goal
Tail ESS	Tail Effective Sample Size
U5MR	Under- Five Mortality Rate
WHO	World Health Organization

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Author contributions
AL, ZT, and KS were involved for this study from inception to design, acquisition of data, data cleaning, data analysis, drafting the manuscript, and critically revising the manuscript. Atalay Liknaw wrote the manuscript and Bekalu Endalew edited the grammar of background and discussion part of this manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets are available from the measure DHS program accessed from the measure DHS website (http://www.dhsprogram.com) through an online request by explaining the objective of the study. We used the Kid recorded file to the extract variables based on literature. Then we kept the same variable from each country and appended together by coding each country.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from Research Ethical Committee of School of public health, College Medicine and Health Sciences, university of Gondar, with Ref No/ IPH/1505/2021. Hierarchically, all administrator bodies were communicated and permission was secured. Permission was requested from a measure of DHS program through their website (http://www.dhsprogram.com) by explaining the objective of the study. Then After, waiver of written informed consent was obtained from the International Review Board of Demographic and Health Surveys (DHS) program data archivists to download the dataset for this study. The datasets were not shared or not passed on to other bodies. Lastly, we confirm that the study was conducted in accordance with the declaration of Helsinki.

Consent for publication
Not applicable as there are no image or other confidentiality-related issues.

Competing interests
The authors declare no competing interests.

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