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Spatial heterogeneities in acute lower respiratory infections prevalence and determinants across Ethiopian administrative zones

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Abstract

Background: Acute lower respiratory infections (ALRI) are a major cause of mortality among children under five. This study aimed to investigate the spatiotemporal pattern of ALRI in Ethiopian administrative zones.

Methods: In this study, a total of 29,599 under-five children from 2299 geographical units in 2000, 2005, 2011, and 2016 Ethiopian Demographic and Health Surveys (EDHSs) were involved. The generalized multilevel mixed model to analyze the effect of child-household level characteristics on ALRI was adopted.

Results: Overall prevalence of ALRI among Ethiopian under-five children is found to be 15%, with 2000, recording the highest prevalence of 24.44% while 2016 had the lowest prevalence of 11.07%. Being in the higher age group of children and having no experience of undernutrition status showed significantly lower ALRI prevalence than their counterparts. Among the household characteristics children from uneducated parents, unimproved household sanitation, lower wealth index, and rural residents were more likely to have ALRI than their counterparts. Based on the best linear unbiased prediction (BLUP) for the zonal-level random effect, the performance of Zones was ranked.

Conclusions: Between and within the Ethiopian administrative Zones disparities in ALRI were observed. The ranking of the performance of the Zones may help to target the worst performing Zones for immediate intervention strategy and the best performing Zones as a role model to adopt their best practice in the Ethiopian strategy to achieve the Sustainable Development Goal by the year 2030.

Keywords: Acute lower respiratory infection, Administrative zones, Best unbiased predictor, Children aged under five, Generalized linear mixed model

Background

Acute respiratory infection (ALRI) is typically a cough followed by short, rapid breathing that is chest-related and is often associated with death through comorbidities of other childhood illnesses. Acute respiratory infections (ALRIs) are a major cause of mortality among children under five [1–3]. Pneumonia and bronchiolitis are the most common ALRIs in children [4]. It is the third-largest singular cause of mortality in both developed and developing countries [4, 5], resulting in about 1.6 million deaths among those under five annually [6, 7]. Studies showed that nearly 97% of all ALRI [8, 9] cases occur in low- and middle-income countries, with more than 70% occurring in South Asia and Sub-Saharan Africa. According to reports from the global burden of disease in 2000, ALRI is the leading cause of death among under-five children in developing countries. Compared to the developed world, children in low-middle income countries were 10–15 times more likely to die from ALRI [1, 2]. In low-middle-income countries, 6.9 million children died in 2011 and about one in five of these deaths were caused by an ALRI [10]. Research indicates that improper treatment of ALRI cause such as; sore throat, ear infection, breathing difficulties, pink eyes, and associated disabilities including deafness [2, 3, 11, 12].

In Ethiopia, acute respiratory infections are one of the leading causes of morbidity and mortality in children under 5 years. According to the 2016 Ethiopian Demographic and Health Survey, the prevalence of ALRI was 11.7% [13], one of the highest in sub-Saharan Africa [14, 15]. More recently, health service utilization promotions and better management of childhood illness brought positive changes in both child and mother health outcomes [16]. Despite the improvements, Ethiopia is still among the few countries with high childhood mortality; 37.39% of the under-five children had chronic malnutrition, 51.5% lacked access to improved drinking water, 40% were without toilet facilities, and nearly 97% had no clean cooking fuel [13].

According to numerous cross-sectional studies [2, 7] several socioeconomic, demographic, biological, and behavioral determinants are contributed to acute respiratory infections. The income index of countries affected the risks of different covariates on acute respiratory infections. Hence, in low- and middle-income countries, factors such as the child's age [17, 18], sex [19], and immunization status [20] varied with ALRIs while parental factors such as age [17, 21], employment [17, 21], and levels of education associated with the vulnerability of these under-five children to ALRIs [19, 22]. Other studies found that wealth index, place of residence, household size, toilet, and cooking fuel type predicted the risk of ALRIs [17–19, 23, 24]. The nutritional status of under-five children is also strongly associated with ALRIs [4, 25, 26].

Various studies are conducted on ALRIs in Sub-Saharan Africa [17, 18, 21, 23, 24, 27], on samples of smaller size. As a result, they do not represent the situation of under-five children in the countries studied. Besides, these studies gave little attention to spatial heterogeneities in acute lower respiratory infections prevalence and its trajectories over time in subsequent surveys data for different administrative zones. Despite the number of studies conducted on risk factors of ALRI in Ethiopia over the past two decades [21, 28, 29], the challenges and achievements of different administrative Zones toward ALRI were not yet studied. Most of the previous studies had focused on the first administrative areas at regional levels and countries [21, 28–33], but this study focused on the zonal level as these are the administrative zones where political decisions and other administrative tasks are made [34]. In this study, Best Linear Unbiased Prediction (BLUP) ranks the performance of each Zone for the ALRI of under-five children in Ethiopia which made this paper more advantageous than other previous studies. Therefore, the main objective of this study was to explore the prevalence and risk factors of childhood ALRIs by accounting for the administrative Zones effect in 2000, 2005, 2011, and 2016 Ethiopian Demographic and Health surveys (EDHSs). In total, over twenty-five thousand children were involved in these four consecutive surveys period which indicates the manuscript is more advantageous over other previous studies as it consists of big data.

Detecting the problem of ALRI and its variation among administrative Zones provides deeper insight into the country's health priorities for under-five children since Zone's health departments have the mandate to plan, follow up, monitor, and evaluation of health activities at the lower level [30–33]. As a result, the findings of this study will be helpful for policymakers such as governmental and non-governmental health institutions at each Zonal administrative department to build a concrete long-run strategic plan based on information collected from four consecutive surveys in administrative Zones of Ethiopia. Thus, this could be an input for future researchers and a substantial contribution to reducing the prevalence of acute lower respiratory infections in Ethiopia.

This paper is structured as follows: first, in the Methods section study area, data source, study variables, and specific statistical analysis method implemented for this study were discussed. Second, in the Results section description of socio-demographic characteristics, factors associated with ALRI, and model diagnosis were elaborated. Finally, a Discussion and Conclusions of the main findings were included.

Methods

Study area

Settings

Ethiopia (3°–14° N and 33°–48 E°) is one of the East African countries, with a surface area of 1.1 million km^2 (kilometer square). The country is divided into 9 regional states, and two administrative cities (Addis Ababa and Dire-Dawa). Each of the 11 administrative units has its regional health bureau (RHB). The states are further divided into Zones, each with a zonal health department [35]. The bold blue text in the map shows the regional boundaries, while the thin black texts are the zonal boundaries (Fig. 1).

Data sources

In this study, we used birth history recorded data of EDHS collected in 2000, 2005, 2011, and 2016. This study was conducted based on 29,599 children which are comprised 8139 from 2016, 9238 from 2011, 3767 from 2005, and 8455 children were from the 2000 EDHS respectively. For the sampling frame classification, both the 1994 and 2007 population and housing censuses were used [36, 37].

Study variables

The outcome variable for this study was ALRI, a reply to the question on whether the child had experienced a cough followed by short, rapid breath in the two weeks preceding the survey. Mothers were asked whether their under-five child had a cough in the two weeks preceding the survey. If the child suffered from cough, they were also asked if the child had short, and rapid breathing and/or a fever during the 2 weeks before the survey. Children about whom the responses were 'yes' to the three questions were regarded as having ALRI

Fig. 1 Map of Ethiopia with administrative regions and zones

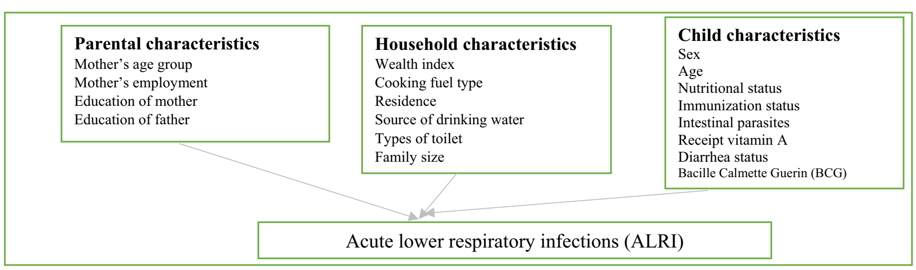

Fig. 2 Conceptual framework of risks factors for acute lower respiratory infection

and coded with a value of 1; otherwise, they were coded with a value of 0. A review of prior works revealed child-household level covariates were included [20–22, 38–41] (Fig. 2).

Statistical analysis

Suppose that our data is clustered and the response variable denoted by y_{ij}, the j^{th} response of subject i, with $i = 1, ..., m$ and $j = 1, ..., m_i$. Conditonal on a vector of individual random effectsu_i, the outcome variables are assumed to be independent, with density functions belonging to the exponential family [42–47].

$$f\left(y_{ij}|\theta_{ij}, \phi\right) = \exp[\phi^{-1}\left\{y_{ij}\theta_{ij} - \psi\left(\theta_{ij}\right)\right\} + c\left(y_{ij}, \varphi\right),$$

where φ is a scale parameter, $c(.)$ is a function only depending on y_{ij} and φ, and $\psi(.)$ is a function satisfying $E\left(y_{ij}|u_i\right) = \psi^{'}\left(\theta_{ij}\right) = v(x_{ij}^T\beta + z_{ij}^T u_i)$ and Var $\left(y_{ij}|u_i\right) = \phi\psi''(\theta_{ij})$, for which $\nu(.)$ denotes a known link function, x_{ij} and z_{ij} are vectors of covariates, β is a vector of unknown fixed effect parameters.

Hence, in this study, we adopted the generalized linear mixed model (GLMM) [48–52] to examine the effect of a child, woman, and household characteristics on ALRI measures for under-five children in Ethiopia. The adopted GLMM model is:

$g(\mu_{ij}) = logit(\mu_{ij}) = \log\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \log\left(\frac{P(y_{ij}=1)}{P(y_{ij}=0)}\right) = \eta_{ij}$, an alternative link function is probit link $\phi^{-1}(\mu_{ij})$, the inverse standard normal cumulative distribution function.

Where, $\eta_{ij} = \beta_0 + \beta_1 x_{1ij} + \cdots + \beta_k x_{kij} + u_{0j} X_{1ij}$, through X_{kij} denote the k explanatory variables measured on children, women, and households. μ_{ij} and 1-μ_{ij} are respectively the probability of a child getting ALRI and not having ALRI (j = 1,...,72, Zones, i = 1,...,n_j children within each Zone).

β_0 is the log odds of intercept.

$\beta_1 \ldots \beta_k$ are effect sizes of children and household-level covariates.

u_{0j} are random errors at Zone level.

The distribution of $u_{0j} \sim N(0, \sigma_{u0}^2)$. The intra-class correlation (ICC) was computed using between-Zone variance and within the Zone, variance (ICC = $(\sigma u^2/\sigma_u^2 + \sigma_e^2)$[43–45, 53].

The mixed model approach permits the estimation of the fixed effects using the Best Linear Unbiased Estimation (BLUE), as well as the prediction of the random effects using the Best Linear Unbiased Prediction (BLUP) procedure by solving a generalized form of mixed equations [49, 54–56]. The BLUP is a realized value of the random effects [34, 57–59], which provides an unbiased method by adjusting the known sources of variation [55]. BLUP is the commonly used method to predict genetic and breeding values in both animals and plants. It is used to rank and select the best plants [60–63] and has been used for selecting and ranking animals for breeding [64, 65]. It is also used to rank the performance of employees in a certain organization [58]. In our study, the BLUP estimates of Zones for each survey year, which then merged with the shapefiles of the country to display the performances of each Zone using maps. For the analysis, first, a bivariate binary logistic regression was fitted and a p-value of less than 0.25 in the bivariate analysis was considered candidates for inclusion in the multivariable logistic regression analysis [66, 67]. Finally, a multivariable logistic regression model was fitted for the combined data with a 95% confidence interval, and statistical significance was considered at a p-value < 0.05. The analyses were made with Stata, GIS, and R statistical software.

Results

Socio-demographic characteristics

Descriptive results on the background characteristics of child-household level characteristics and the prevalence of ALRIs for each and combined years of the survey have been presented in Table 1. The combined dataset revealed that about half of the proportion of the respondents comprised women aged 20–29 (49.80%). Around 75% of the mother and 55% of the fathers had no formal education. About 22.78% and 15.03% of the children were from the poorest and richest households, respectively. About 66%, 61%, and 99% of the children were raised in a family without (improved water, improved toilet, and clean fuel) respectively.

Table 1 Proportion of covariates and the prevalence of ALRIs (in parenthesis) within each covariate: 2000–2016

Characteristics	2000 (%)	2005(%)	2011 (%)	2016(%)	All years (%) (combined mean)
	N = 8139	N = 9238	N = 3767	N = 8455	N = 29599
Child characteristics					
Sex of child Male	50.78 (24.69)	50.74 (12.60)	51.41 (11.60)	51.28 (10.98)	51.06 (14.99)
Female	49.22 (24.18)	49.26 (12.50)	48.59 (11.82)	48.72 (11.17)	48.94 (14.98)
Age of child (months) 0–11	1.04 (8.670)	21.99 (15.70)	0.95 (5.99)	21.80 (13.37)	11.20 (14.20)
12–23	2.04 (18.48)	18.56 (14.61)	2.56 (6.66)	19.24 (13.91)	10.41 (13.98)
24–59	96.92 (24.73)	59.45 (10.74)	96.48 (12.12)	58.96 (9.30)	78.39 (15.33)
Child received BCG No	56.27 (23.71)	48.55 (11.86)	39.56 (11.78)	35.98 (11.94)	46.07 (15.93)
Yes	43.73 (25.37)	51.45 (13.21)	60.44 (11.66)	64.01 (13.28)	53.93 (15.50)
The child received No	44.11 (24.24)	56.22 (12.24)	52.09 (11.21)	59.68 (11.19)	52.92 (14.22)
Vitamin A Yes	55.89 (24.63)	43.78 (12.95)	47.91 (12.24)	40.32 (10.91)	47.08 (15.85)
The child received medicine No		95.87 (13.96)	81.34 (11.42)	88.52 (10.91)	87.49 (11.90)
Yes		4.13 (24.44)	18.66 (12.95)	11.48 (12.35)	12.51 (13.66)
Parental characteristics					
Mother' Educational level No education	81.57 (25.06)	78.65 (12.53)	68.92 (11.72)	65.83 (11.02)	73.70 (15.53)
Primary education	13.26 (22.65)	16.90 (13.52)	27.27 (11.95)	26.94 (12.37)	21.15 (14.08)
Secondary education	4.94 (19.49)	4.03 (9.94)	2.28 (11.14)	4.73 (7.87)	3.98 (12.53)
Higher	0.22 (14.06)	0.42 (2.15)	1.52 (7.41)	0.25 (4.44)	1.17 (5.72)
Father' Educational level No education	63.71 (24.92)	58.40 (11.97)	49.96 (12.27)	48.54 (10.64)	55.20 (15.60)
Primary education	25.11 (25.06)	30.46 (13.81)	41.61 (11.54)	39.18 (12.99)	34.10 (14.98)
Secondary education	9.87 (21.11)	10.04 (13.54)	5.10 (10.23)	7.81 (9.66)	8.16 (14.46)
Higher	1.31 (15.32)	1.11 (3.13)	3.34 (9.00)	4.47 (3.40)	2.55 (6.88)
Age of mother 15–19	4.42 (30.34)	4.87 (12.80)	4.01 (14.37)	3.45 (13.74)	4.18 (18.09)
20–29	49.23 (24.33)	48.65 (12.96)	52.05 (11.61)	49.13 (10.94)	49.80 (14.96)
30–39	35.41 (23.16)	36.32 (12.12)	35.17 (11.27)	38.73 (11.16)	36.38 (14.38)
40–49	10.94 (26.68)	10.16 (10.04)	8.76 (12.80)	8.69 (10.39)	9.63 (16.08)
Employment status Working	44.15 (24.25)	76.74 (11.98)	65.77 (11.87)	27.12 (12.60)	53.39 (14.46)
Status of the mother Not working	55.85 (24.61)	23.26 (14.44)	34.23 (11.39)	72.88 (10.51)	46.61 (15.43)
Household factors					
Wealth index Poorest	12.57 (25.89)	21.94 (12.27)	22.43 (13.03)	23.99 (9.10)	22.78 (11.43)
Poorer	26.87 (23.45)	20.99 (11.37)	22.14 (9.61)	22.91 (12.81)	22.02 (11.03)
Middle	20.25 (27.79)	21.86 (14.63)	20.62 (13.69)	20.72 (12.68)	21.05 (13.67)
Richer	19.08 (24.13)	19.93 (13.14)	19.54 (12.60)	17.85 (13.03)	19.11 (12.91)
Richest	21.24 (25.79)	15.28 (10.84)	15.28 (8.98)	14.53 (7.90)	15.03 (9.24)
Residence Urban	10.61 (16.31)	7.44 (8.52)	13.00 (8.98)	11.16 (6.64)	10.61 (10.15)
Rural	89.39 (25.40)	92.56 (12.88)	87.00 (12.12)	88.84 (11.63)	89.39 (15.56)
Household size Less than 5	24.92 (25.85)	22.35 (13.92)	24.02 (11.67)	26.09 (11.41)	24.36 (15.78)
5 or more	75.08 (23.97)	77.65 (12.16)	75.98 (11.71)	73.91 (10.96)	75.64 (14.73)
Source of drinking water Unimproved	87.05 (25.31)	65.37 (13.37)	59.59 (12.28)	51.50 (11.12)	65.96 (16.68)
Improve	12.95 (18.55)	34.63 (11.02)	40.41 (10.86)	48.50 (11.03)	34.04 (11.70)
Type of toilet facility Unimproved	86.10 (24.94)	70.79 (12.30)	49.12 (12.57)	39.13 (11.36)	61.23 (16.72)
Improve	13.90 (21.30)	29.21 (13.17)	50.88 (10.87)	60.57 (10.89)	38.77 (12.24)
Type of cooking fuel Not cleaned	99.99 (24.45)	99.99 (12.55)	99.58 (11.72)	97.15 (11.18)	99.15 (15.05)
Cleaned	0.01(0.00)	0.01 (0.00)	0.42 (7.29)	2.85 (7.45)	0.85 (7.13)
Stunting status Stunted	49.51 (26.37)	40.82 (11.63)	41.36 (12.32)	37.39 (12.22)	57.36 (16.58)

Table 1 (continued)

Characteristics	2000 (%)	2005(%)	2011 (%)	2016(%)	All years (%) (combined mean)
	N = 8139	N = 9238	N = 3767	N = 8455	N = 29599
Normal	50.49 (24.04)	59.18 (12.70)	58.64 (11.36)	62.21 (10.83)	42.64 (14.88)
Wasting Wasted	10.37 (27.76)	9.27 (13.82)	9.19 (11.47)	9.93 (14.74)	9.74 (19.08)
Normal	89.63 (24.81)	90.73 (12.10)	90.81 (16.36)	90.07 (10.98)	90.26 (15.23)
Underweight status Underweighted	45.52 (27.89)	33.84 (11.86)	26.87 (13.81)	23.69 (12.92)	32.28 (19.01)
Normal	54.48 (22.94)	66.16 (12.47)	7313 (11.23)	76.31 (10.86)	97.72 (13.97)
Diarrhea No	76.34 (18.74)	81.88 (8.66)	86.57 (8.86)	88.22 (8.56)	83.26 (11.03)
Yes	23.66 (42.96)	18.12 (30.13)	13.43 (30.09)	11.78 (29.91)	1674 (34.68)
Regions of Ethiopia Tigray	6.59 (29.17)	6.46 (14.41)	6.36 (18.34)	6.59 (15.09)	6.50 (19.39)
Afar	1.00 (21.91)	0.95 (5.26)	1.01 (7.97)	1.00 (7.95)	0.99 (10.91)
Amhara	26.02 (21.66)	22.87 (9.32)	22.44 (12.71)	18.88 (10.41)	22.58 (14.04)
Oromia	40.51 (27.39)	39.74 (14.24)	42.25 (11.56)	43.88 (13.15)	41.61(16.50)
Somali	1.18 (21.18)	4.28 (6.98)	3.07 (14.59)	4.57 (4.12)	3.25 (9.18)
Benshangul	1.00 (29.61)	0.94 (9.61)	3.07 (15.73)	1.09 (2.49)	1.05 (14.40)
SNNP	21.37 (22.13)	22.49 (14.44)	1.15 (9.18)	20.82 (9.05)	21.37 (13.76)
Gembela	0.23 (20.77)	0.29 (10.42)	20.87 (13.82)	0.24 (5.30)	0.28 (12.62)
Hareri	0.21 (16.550	0.21 (9.33)	0.34 (1.91)	0.23 (2.54)	0.22 (7.230
Addis Ababa	1.56(10.36)	1.44 (6.09)	1.94 (5.030	2.26 (5.31)	1.80 (6.48)
Dire Dawa	0.33 (13.81)	0.34 (2.45)	0.34 (9.27)	0.42 (5.98)	0.36 (7.81)
Total	24.44	12.55	11.70	11.07	14.99

The prevalence of ALRI among under-five children in the two weeks preceding the survey in the years 2000, 2005, 2011, and 2016 were 22.26, 12.55, 11.70, and 11.07 respectively. Although there were disparities over the study period, the overall prevalence of ALRI for all the EDHS datasets was 14.99%. Among children aged 24–59 months, the ALRI was lower (15.33%). Compared with mothers who have higher educational status (5.72%) children with uneducated mothers (15.53%) have a higher prevalence of ALRI. Similarly, compared with children whose fathers had a higher educational level (6.88%), children whose fathers had no education (15.60%) have a higher prevalence of ALRI. Compared with their normal counterparts, underweighted children (19.01%) had a higher prevalence of ALRI Overall, compared with urban children (15.56%), rural children (10%) were more likely to have ALRI symptoms. Children from families drinking unimproved water, unimproved toilets, and using unclean cooking fuel had a higher prevalence of ALRI than children who had better qualities of the facilities mentioned. The highest prevalence of ALRI was recorded in Tigray (19.39%) while the lowest was in Addis Ababa, Ethiopia (6.48%) (Table 1).

Factors associated with ALRI

The result derived from the generalized multilevel mixed model for assessing the association between the ALRI and child-household covariates was presented in Table 2. After adjusting all the covariates in the multivariable logistic regression model, we found that the odds of ALRI were less likely among older children (24–59 months) with (AOR: 0.81, 95% CI 0.73–0.90). The result revealed that compared to their counterparts who

Table 2 Generalized multilevel mixed model parameter estimates of CIAF among under-five children in Ethiopia over time, 2000–2016

	COR (95% CI)	p-value	AOR (95% CI)	p-value
Sex of child (Male@)	1			
Female	0.95 (0.79, 1.336)	0.552		
Age of child (0–11 months@)	1			
12–23	0.97 (0.79, 1.20)	0.782	0.90 (0.81, 1.01)	0.079
24–59	1.12 (0.96, 1.31)	0.156	0.81 (0.73, 0.90)	< 0.001*
The child received BCG (Yes@)				
No	1.07 (0.97, 1.18)	0.258		
The child received vitamin A (Yes)	1			
No	1.01 (0.92, 1.10)	0.982		
The child received medicine for intestine worms (Yes@)	1			
No	1.09 (0.93, 1.28)	0.313		
Stunting status (Normal@)				
Stunted	1.18 (1.08, 1.32)	< 0.001***	1.17 (1.01, 1.37)	0.041
Wasting status (Normal@)				
Wasted	1.21 (1.04, 1.40)	0.012*	1.51 (1.24, 1.84)	< 0.001***
Underweight status (Normal@)				
Underweighted	1.33(1.21, 1.48)	< 0.001***	1.14 (1.35, 1.54)	0.004**
Diarrhea status (No@)				
Yes	4.43(4.16, 4.73)	< 0.001***	9.73 (8.57, 11.05)	< 0.001**
Parental characteristics				
Mother' Educational level (No Education@)	1			
Primary education	0.76 (0.68, 0.85)	< 0.001***	0.64 (0.50, 0.81)	< 0.001***
Secondary education	0.51 (0.42, 0.63)	< 0.001***	0.21 (0.11, 0.38)	< 0.001***
Higher	0.38 (0.24, 0.58)	< 0.001***	0.37 (0.12, 1.08)	0.069
Father' Educational level (No Education@)	1			
Primary education	0.89 (0.80, 0.99)	0.025**	0.65 (0.53, 0.81)	< 0.001***
Secondary education	0.75 (0.64, 0.88)	,0.001***	0.37 (0.24, 0.57)	< 0.001***
Higher	0.42 (0.32, 0.55)	< 0.001***	0.31 (0.16, 0.59)	< 0.001***
Age of mother (15–19 years@)	1			
20–29	0.62 (0.42, 0.94)	0.024*	0.75 (0.49, 1.15)	0.185
30–39	0.73 (0.48, 1.12)	0.151	0.89 (0.57,1.39)	0.612
40–49	1.15 (0.68, 1.93)	0.598	0.97 (0.57, 1.66)	0.923
Employment status of the mother (Working@)	1			
Not working	1.43 (0.03,0.04)	< 0.001***	1.08 (1.01, 1.14)	0.015*
Household factors				
Wealth index (Poorest@)	1			
Poorer	0.70 (0.47, 1.04)	0.080	0.55(0.46, 0.67)	< 0.001***
Middle	1.11 (0.73, 1.68)	0.628	0.77 (0.64, 0.93)	0.007**
Richer	0.61 (0.40,0.93)	0.021*	0.74 (0.61, 0.89)	0.002***
Richest	0.36 (0.22, 0.59)	< 0.001***	0.20 (0.15, 0.27)	< 0.001***
Residence (Urban@)	1			
Rural	1.72 (1.51, 1.95)	< 0.001***	4.08 (3.10, 5.35)	< 0.001***
Household size (Less than 5@)				
5 or more	1.17 (1.06, 1.30)	0.002**	1.14 (0.94 (1.38)	0.178
Source of drinking water (Improved@)				
Unimproved	1.66 (1.51, 1.82)	< 0.001***	1.19 (1.05, 1.36)	0.007**
Type of toilet facility (Improved@)	1			

Table 2 (continued)

	COR (95% CI)	p-value	AOR (95% CI)	p-value
Unimproved	1.29 (1.17, 1.42)	< 0.001***	2.59 (2.08, 3.22)	< 0.001***
Type of cooking fuel (Cleand@)				
Not cleaned	3.57 (2.30, 5.55)	< 0.001***	2.84 (1.97, 4.11)	< 0.001***
States (regions) of Ethiopia				
Regions of Ethiopia (Addis Ababa@)	1			
Tigray	3.47 (2.82, 4.29)	< 0.001***	2.83 (2.11, 3.81))	< 0.001***
Afar	1.46 (1.16, 1.84)	< 0.001***	1.77 (1.24, 2.51)	< 0.001***
Amhara	2.37 (1.92,2.9)	< 0.001***	2.35 (1.75, 3.170	< 0.001***
Oromia	2.99 (2.44, 3.70)	< 0.001***	2.85 (2.13, 3.81)	< 0.001***
Somali	1.58 (1.27, 1.98)	< 0.001***	1.46 (1.04, 2.05)	0.029**
Benshangul	2.30 (1.85, 2.87)	< 0.001***	2.43 (1.71, 3.43)	< 0.001***
SNNP	2.31 (1.87, 2.84)	< 0.001***	2.30 (1.70, 3.11)	< 0.001***
Gembela	2.05 (1.63, 2.58)	< 0.001***	2.08 (1.46, 2.94)	< 0.001***
Hareri	1.08 (0.83, 1.39)	0.567	1.12 (0.75, 1.68)	0.564
Dire-Dawa	1.25 (0.97, 1.60)	0.088	1.22 (0.83, 1.79)	0.303
Survey Year (2000@)				
2005	0.40 (0.36, 0.45)	0.005**	0.42 (0.37, 0.47)	< 0.001**
2011	0.44 (0.40, 0.48)	0.004**	0.46 (0.42, 0.51)	< 0.001**
2016	0.30 (0.27, 0.33)	< 0.001***	0.38 (0.34, 0.44)	< 0.001***
Level	ICC	Std.err		(95% conf.Interval)
Zones	0.0435	0.009		(0.0283, 0.0660)

*p < 0.05, **p < 0.01, ***p < 0.001, COR: Crude Odds Ratio, AOR: Adjusted Odds Ratio, CI: Confidence Interval @ references

had no formal education (AOR: 0.64, 95% CI 0.50–0.81 and AOR: 0.21, 95% CI 0.11–0.38), women who had primary and secondary school education have at least 36% and 79% lower odds of ALRI indicating that the educational attainment of the mothers associated with the acute lower respiratory infection of their children. Compared with children from fathers with no formal educational background, children whose fathers completed higher and secondary education were less likely to develop ALRI (AOR: 0.37, 95% CI 0.24–0.57 and AOR: 0.31, 95% CI 0.16–0.59). Likewise, compared to children from poorer households, children from richer households had 80% (AOR: 0.20, 95% CI 0.15–0.27) lower odds of ALRI. Children whose mothers used unimproved water were 19% (AOR: 1.19, 95% CI 1.05–1.36) more likely to have acute lower respiratory infection symptoms compared to those whose mothers used improved water. Likewise, children whose mothers used unimproved toilet facilities were 2.59 (AOR: 2.59, 95% CI 2.08–3.22) times more likely to have the symptoms as compared to children whose mothers used the improved facilities. Moreover, mothers who didn't use clean fuel for cooking (AOR: 2.84, 95% CI 1.97–4.11) were more likely to have ALRI than their counterparts. The nutritional status of children is also associated with an acute lower respiratory infection. Compare to normal under-five children, underweight (AOR: 1.14, 95% CI 1.35–1.54), wasted (AOR: 1.51, 95% CI 1.24–1.84), and stunted (AOR: 1.17, 95% CI 1.01–1.37) under-five children were more likely to experience the symptoms of ALRI. Besides, compared to their counterparts, children having diarrhea for the last 2 weeks were 9.73 (AOR: 9.73, 95% CI 8.57–11.05) times more likely to be affected by ALRI. The odds of ALRI for all regions were higher than in Addis Ababa. Particularly, the odds of ALRI for those children living in Tigray, Amhara, and Oromia regions were 2.83, 2.35, and 2.85 higher than Addis Ababa respectively. The result also showed that compared to the survey in the year 2000, the temporal association, where children had 42%, 55%, and 66% reduced odds of acuter lower respiratory infection in 2005, 2011, and 2016 compared to 2000 survey year (see Table 2).

Model diagnostics

Various model diagnostics techniques were done for the final model. This study considered the potential interaction effects of several covariates on ALRI and there were no interaction effects. Variance inflation factor (VIF) is a tool used to measure how much the variance of an independent variable is influenced by its correlation with the other independent variables [68]. The VIF was used to assess multi-collinearity among independent covariates and no variables had VIF greater than 10 [68], revealing the absence of significant collinearity among covariates. A Receiver Operator Characteristic (ROC) curve is a graphical plot used to show the diagnostic ability of binary classifiers [69]. The predicting probability of the model (model accuracy) was evaluated using ROC (see Additional file 1: Fig. S1) and it was 73.02% indicating the model was good enough in differentiating a child having CIAF from not having it correctly [69].

Crude prevalence and BLUP of ALRI

The crude prevalence and the estimated BLUP of ALRI for under-five children have been pictorially presented in Fig. 3 across 72 Zones of the country. Figure 3 is the

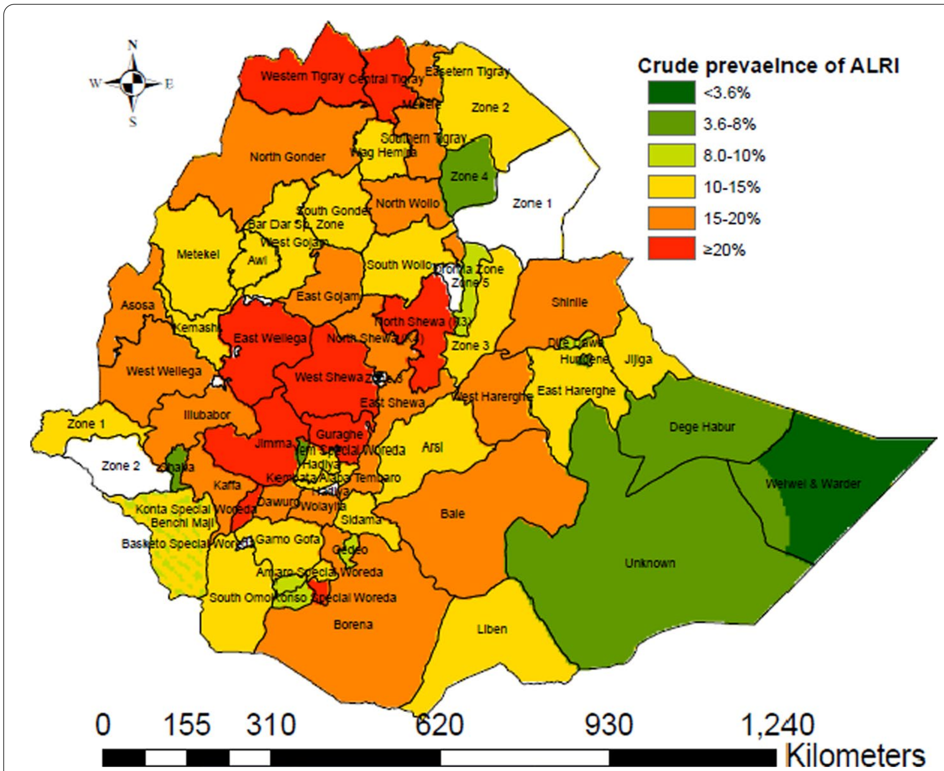

Fig. 3 The crude prevalence of ALRI among under-five children in the Ethiopian administrative zones

empirical kriging output mapped the crude prevalence of ALRI measures interpolating the available data to the areas where data were not taken. The red and blue colors indicated the areas with the highest and lowest crude prevalence of ALRI respectively.

One of the objectives of this study was to compare the performance of zones on the ALRI among U5C in Ethiopia using GLMM. Variance components were estimated by the restricted maximum likelihood (REML) and the ALRI was predicted by BLUP (see Fig. 4). The green color is the best performing Zones and the red is the worst performing Zones in terms of improving ALRI. The negative BLUP is associated with decreased odds of ALRI in the Zones, while a positive BLUP is associated with increased odds of ALRI in the Zones [55, 65, 70]. Based on the standardized BLUP estimates, the zones were ranked and the best five (lowest standardized BLUP values) and the worst five (highest standardized BLUP values) performing zones in terms of ALRI respectively were selected. Accordingly (East Haregie, Gedeo, Sidam, Awi, and Eastern Tigray) were the top "best" and (West Shewa, Guraghe, Jimma, Wolayita, and East Wellega) were the top "Worst" performing zones in terms of ALRI among under-five children respectively in Ethiopia. Both the crude prevalence and BLUP maps confirm a high degree of variation in ALRI at zonal levels in Ethiopia. This is maybe due to the urbanization and deforestation of the worst-performing zones and further studies should be done on the effects of climate and environmental covariates on ALRI among under-five children in Ethiopia.

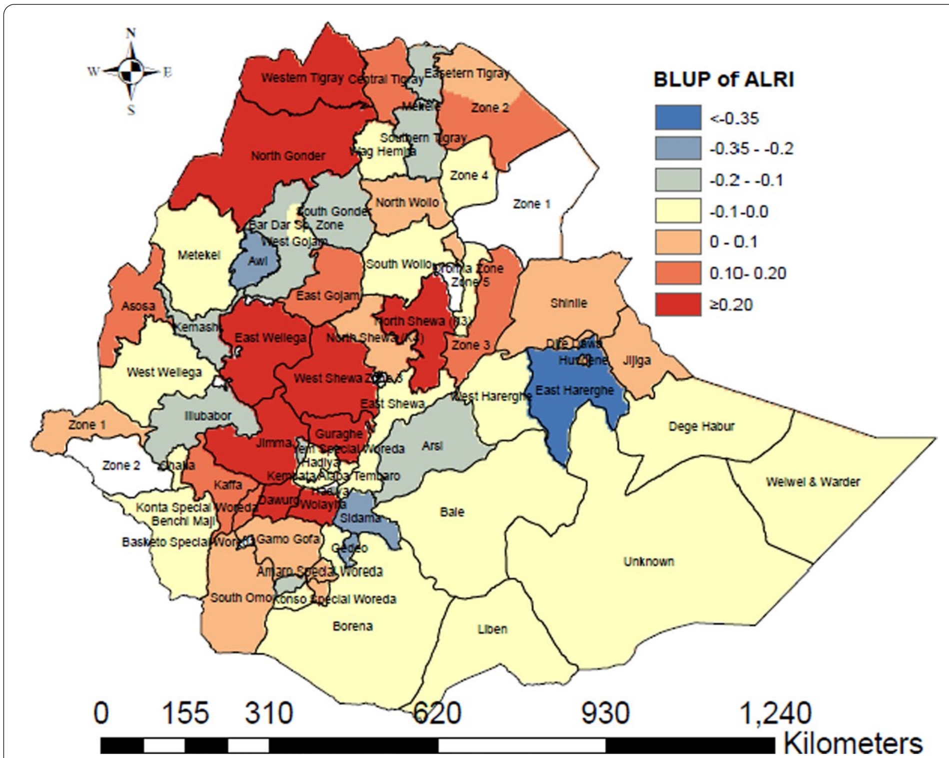

Fig. 4 The estimated BLUP of ALRI among under-five children among the Ethiopian administrative zones

Discussion

Acute lower respiratory infections are among the leading causes of morbidity and mortality in under-five children in low-income countries like Ethiopia. The study involved a total of 39,379 under-five children. This study examined the regional and temporal patterns in acute lower respiratory infection among children in Ethiopia from 2000 to 2016. The results showed considerable regional disparities in ALRI among the regions in the years 2000 to 2016. The findings also revealed trends of decreasing, increasing, and somehow stable ALRI across the regions of the country. Moreover, this study revealed that children from unemployed mothers have a substantially higher ALRI prevalence compared with children from employed mothers. This supports study findings where children from non-working mothers had a higher likelihood of having ALRI than children of employed women [10, 17, 21]. This could be because employed women afford to get the necessities to minimize the lower acute respiratory infection in children under five [21]. A prior study [1, 71] found that in children from households that use indoor biomass, a positive association is discovered between the methods of cooking of the households and risks of ARI symptoms, a result consistent with the findings of the present study.

This could be explained by the fact that mothers who are educated and employed had a better understanding of fuel use, improved toilet use, and family planning. Such mothers would also afford the necessities of food to practice nutrition that reduces the risk factors of ALRI [1, 17, 19, 21, 22]. This study also revealed that compared with those living in a better household, children living in poor economic conditions are more likely to suffer from ALRI. This is in line with finding from a prior study where, compared to children from poorer families, children from richer households had a lower record of ALRIs, indicating wealth index had a positive impact on ALRI [17–19, 23, 24]. Children from poorer households, their mothers do not afford healthcare necessities for themselves and their children. The Ethiopian government tried to overcome the economic healthcare barriers of the poor through low-cost insurance that covers healthcare both to the mother and the child [28].

The prevalence of ALRI was higher among the children living in the rural areas compared to the children living in the urban areas which are in line with a study finding in [8, 9]. As Ethiopia is the second populist country next to Nigeria in Africa the prevalence of deforestation in the rural part of the country is increased to fulfill the necessities such as cooking fuel, house, and farming. In addition, a study conducted in North Ethiopia [8] on repeated respiratory infection observation of under-five children reported that male children were more likely to develop ALRI as compared to female children. Moreover, this study found that children from educated parents had considerably lower ALRI than their counterparts. This finding is consistent with results from studies [19, 22]. This study revealed that malnourished children suffer greatly from ALRI, a finding consistent with the previous studies [4, 25, 26, 40]. Compared with urban children, rural children had four times higher risk of ALRI a finding consistent with results of similar studies in India [39], Bangladesh [41], and Nepal [40]. This might be because, in those countries, rural children have low socioeconomic status and poorer access to medical care, nutrition, improved water, and toilet facilities while those urban children have easier access to these services. However, this study contradicts the study conducted by Kossove who argued that rural women carry their children on their backs hence tend to report early to a health facility whenever they notice a sudden change in their breathing pattern. Further, studies in this area should be encouraged [39].

The variation of ALRI across administrative zones of Ethiopia was quite different and statistically significant. This is maybe due to the urbanization and deforestation of the worst-performing zones and further studies should be done on the effects of climate and environmental covariates on ALRI among under-five children in Ethiopia. The findings generated from this research would improve the awareness of people about ALRI health issues and will help policymakers implement appropriate policy measures. Apart from this, contribution, this study had several limitations. Since the symptoms of ALRI were reported by mothers not measured and hence subject to report bias.

Conclusions

The acute lower respiratory infection is considerably associated with some socioeconomic, demographic, biological and behavioral characteristics' of household, mothers and child. Children from mothers who use unclean cooking fuel and unimproved toilets from uneducated parents, poor households, and unemployed mothers face an increased risk of acute lower respiratory infection. Besides, wasted and underweighted children develop acute lower respiratory infections more than their normal counterparts. Besides regional disparities, the risks of acute lower respiratory infection bear zonal discrepancy. The risk of acute lower respiratory infection in Ethiopia from 2000 to 2016 was improved. The findings of this study provide information valuable to Ethiopian policymakers who plan interventions by keeping up positive determinants that enable to minimize children's risk of acute lower respiratory infections.

Abbreviations

ALRIs: Acute lower respiratory infections; CI: Confidence interval; EAs: Enumeration areas; EDHS: Ethiopian demographic and health surveys; OR: Odds ratio.

Supplementary Information

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Additional file 1: Figure S1. Areas under the receiver operating characteristic (AUC) curve for ALRI classification.

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Author contributions

MTF conceived the study, developed the research questions, designed the study, and wrote the introduction and discussion. HMF analyzed the data, wrote the methodology, and the result sections. LMT wrote and edit the manuscript. All authors read and approved the final manuscript.

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Availability of data

The dataset used for the current study is available at the DHS program repository and the shapefile of the map of Ethiopia was accessed as an open-source without restriction from open Africa 2016 https://dhsprogram.com/data/available-datasets.cfm.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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