BMJ Open is committed to open peer review. As part of this commitment we make the peer review history of every article we publish publicly available.

When an article is published we post the peer reviewers' comments and the authors' responses online. We also post the versions of the paper that were used during peer review. These are the versions that the peer review comments apply to.

The versions of the paper that follow are the versions that were submitted during the peer review process. They are not the versions of record or the final published versions. They should not be cited or distributed as the published version of this manuscript.

BMJ Open is an open access journal and the full, final, typeset and author-corrected version of record of the manuscript is available on our site with no access controls, subscription charges or pay-per-view fees (http://bmjopen.bmj.com).

If you have any questions on BMJ Open's open peer review process please email info.bmjopen@bmj.com

BMJ Open

Spatio-temporal distribution and associated factors of anemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-045544
Article Type:	Original research
Date Submitted by the Author:	04-Oct-2020
Complete List of Authors:	Hailgebreal, Samuel; Arba Minch University, Department of Health Informatics Nigatu, Araya Mekonnen, Zeleke; University of Gondar College of Medicine and Health Sciences, Public Health ; Endehabtu, Berhanu; Health Informatics
Keywords:	PUBLIC HEALTH, Anaemia < HAEMATOLOGY, PAEDIATRICS

SCHOLARONE™
Manuscripts

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Spatio-temporal distribution and associated factors of anemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Samuel Hailgebreal[1*], Araya Mesfin Nigatu[2], Zeleke Abebaw Mekonnen[2,3], Berhanu Fikadie Endehabtu[2]

Affiliation

[1]Department of Health Informatics, College of Health Science, Arbaminch University, Ethiopia

[2]Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia

[3]Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia

Corresponding author

Samuel Hailgebreal

Email: samuastd@gmail.com

Abstract

Objectives: Anemia is a global public health problem with major health and socio-economic consequences. Though childhood anemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anemia overtime. Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anemia using the Ethiopian Demographic and health survey (EDHS) data from 2005-2016.

Design: Survey-based cross-sectional study design was employed for the EDHS.

Setting: Data were collected in all nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.

Participants: The source population for this study was all 6–59 months of children in Ethiopia. A total weighted sample of 21,302 children aged 6-59 months were included in this study.

Outcome measure: The outcome variable was child anemia status.

Results: The prevalence of anemia has been declined from 53.9% in 2005 to 44.6% in 2011, but it showed increment 2016 to 57.6%. The Spatial analysis revealed that the spatial distribution of anemia varied across the country. In spatial scan statistics analysis, a total of 22 clusters (RR= 1.54, P-value < 0.001) in 2005, 180 clusters (RR = 1.14, P-value < 0.001) in 2011, and 219 clusters (RR = 1.44, P-value < 0. 0.001) in 2016 significant primary clusters were identified. Child age, women age, maternal anemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anemia.

Conclusions: In this study, childhood anemia remains a public health problem. The spatial distribution of childhood anemia was significantly varied across the country. Identifying the risk areas and determinants would help to design strategies in the area. Therefore, regions with a

high risk of childhood anemia, individual and community level factors should be intensified by allocating additional resources and providing appropriate and tailored strategies.

***Keywords**:* Anemia, children, EDHS, Spatial analysis, Ethiopia

Strengths and limitations of this study

- This study applied different methods of spatial pattern, trend and a multilevel regression models accounting the nested nature of EDHS data
- The study was based on three consecutive EDHS dataset's representing the whole country of Ethiopia
- The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables
- Respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the generalizability of the findings

Background

Anemia is a condition characterized by a low level of hemoglobin in the blood(1). Over 273 million under-five children suffer from anemia worldwide(2). Sub-Saharan Africa is one of the most affected regions which accounts for about 53.8%(2). World health organization had developed a classification system to facilitate international comparisons of anemia as public health crises. The problem was considered severe if anemia prevalence is ≥40%, moderate from 20% to 39.9%, and mild from 5% to 19.9%(3). The high prevalence of anemia and its consequences on children's health, especially on their growth and development, have made it an important public health problem and it also increases the risk of mortality and morbidity which come from other diseases(4,5).

Anemia is a public health problem that affects populations in both industrialized and non-industrialized countries. It affects all segments of the population. It is frequently observed among children and pregnant women who are the most vulnerable group because their requirements for iron are higher than any other group. Childhood anemia is mostly caused by dietary Iron deficiency. Foliate, vitamin B12 and vitamin A deficiencies, chronic inflammation, parasitic infections, and inherited disorders can also contribute to childhood anemia (6). For children, age 6-59month Anemia is defined as a hemoglobin level below 11.0 g/dl(6). Childhood anemia is mostly coexisting with malaria, parasitic infection, nutritional deficiencies, and hemoglobinopathies(7).

The prevalence of anemia in Africa, South East Asia, America, and European regions was,62.3%,53.8%,23.3%, and,22.9%, respectively(3). Pregnant women and children in low-income countries were at risk for anemia because they were believed to be those with the greatest problems with inadequate nutrition, high infectious disease burden, and poor access to routine health care(8). In sub-Saharan Africa, Anemia is a major public health problem associated with an increased risk of death and impaired cognitive development(9). In Ethiopia, the three crude summaries of the country reported between,2005 and 2016, indicated the prevalence of anemia among Ethiopian children declined from,54% to,44% from, 2005 to,2011 but increased to,57% in 2016(10–12).

Different studies across different countries showed that the prevalence of anemia among 6-59-month children is high and a severe public health problem. Evidence from different studies indicated that women age, residence, family income, maternal education(13), an introduction of complementary foods, poor breastfeeding practice, poor utilization of folic acid by mothers(14), maternal anemia(15), unemployment of the parent, malaria, and presence of sickle hemoglobin(13), household wealth index, sex of the child(16), and nutritional status were factors for childhood anemia. There are few studies done in Ethiopia on factors associated with anemia. But at the national level, there was no yet study done on the spatio-temporal patterns of childhood anemia and associated factors using multilevel analysis. Therefore, this study attempts to fill the gap by investigating the spatial distribution of anemia and its associated factors using multilevel model analysis in Ethiopia using the EDHS survey between 2005-20016 data.

Methods

Study design and setting

The survey-based cross-sectional study design was employed using the Ethiopian Demography and Health Surveys (EDHS) in 2005, 2011, and 2016. Data access, extraction, and analysis were conducted from January to June 2020. The study was conducted in Ethiopia located at the horn of Africa (3º-14ºN and 33º – 48ºE). Administratively, the country is divided into nine regional states and two city administrations. Each region is sub-divided into zones, districts, towns, and kebeles (the smallest administrative units).

Source and study population

The source population for this study was all 6–59 months of children in Ethiopia. The study population was all children aged from 6-59 months in the selected enumeration areas within five years before the survey.

Sampling size and sampling technique

A total of 21,302 children (3,868 children in 2005, 8,958 children in 2011, and 8476 Children in 2016) were included in this study. Weighted values were used to restore the representativeness of the sample data. Sample weights were calculated in each children's Record (KR) EDHS dataset. The survey covered all nine regions and the two city administrations of Ethiopia. Participants were selected based on a stratified two-stage cluster sampling technique in each survey year (2005, 2011, and 2016). After excluding clusters with zero coordinates and missing information, a total of 503 clusters in 2005, 569 clusters in 2011, and 615 clusters in 2016 were included. The detailed sampling procedure was available in each EDHS report(10–12)

Data collection tools and procedures

The three EDHS datasets were downloaded from the measure DHS program (Demographic and Health Survey) website (www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses. Data extraction was performed using STATA version 14.1 similarly, location data (latitude and longitudinal) were extracted from the downloaded excel file. Then after extraction, the missing values for the significant independent variables were excluded and the analysis was undertaken using a complete set of data.

Key variables and Measurements

Dependent variable: The study variables were grouped into dependent and independent variables. The dependent variable is child anemia status, categorized as "anemic/not-anemic" variable. Children whose hemoglobin level was less than 11Hb were taken as anemic and not anemic otherwise.

Independent variables:

From the EDHS dataset all sociodemographic variables, Maternal and Child-related factors (individual and community level) were taken as independent variables in the three-consecutive survey.

Data management and analysis

The data were cleaned using STATA 14.1 software and Microsoft excel. The data were weighted using sampling weight, primary sampling unit, and strata before any statistical analysis to restore the representativeness of the survey to take into account the sampling design when calculating standard errors to get reliable statistical estimates.

Spatial analysis

The weighted frequency of outcome variable with cluster number was cross-tabulated in STATA software and exported to excel to get the case to the total proportion. Geographic coordinate data were merged in STATA 14.1. Observations within clusters having longitude and latitude 0 were dropped from the spatial analysis section. Then CSV file imported to ArcGIS 10.7 for spatial analysis.

Spatial autocorrelation analysis

The spatial autocorrelation (Global Moran's I) statistic measures whether childhood anemia patterns were dispersed, clustered or randomly distributed in the study area. Moran's, I output value ranges from (-1 to +1). Values close to −1 indicate disease dispersed, whereas moran's I close to +1 indicate childhood anemia clustered and distributed randomly if I value is zero.

Anselin Local Moran's I was used to investigating the local level cluster locations of anemia in terms of positively correlated (high-high and low-low) clusters or negatively correlated (high-low and low-high).

Hot spot analysis (Getis-Ord Gi* statistic)

Getis-OrdGi* statistics were computed to measure how spatial autocorrelation varies over the study location by calculating GI* statistic for each area. Z-score is computed to determine the statistical significance of clustering, and the p-value computed for the significance. Statistical output with high GI* indicates "hotspot" whereas low GI* means a "cold spot". hot spot areas indicated that there was a high proportion of anemia and the cold spot indicated that there was a low proportion of anemia.

Spatial interpolation

Spatial interpolation technique is used to predict anemia in the un-sampled areas in the country based on sampled EAs. There are various deterministic and geostatistical interpolation methods. Ordinary Kriging spatial interpolation method was used for this study for predictions of childhood anemia in unobserved areas of Ethiopia since it had low mean square error and residual as compared to the other interpolation techniques.

Spatial scan statistical analysis

Spatial scan statistical analysis Bernoulli based model was employed to test for the presence of statistically significant spatial clusters of anemia using Kulldorff's Sat Scan version 9.6 software. The spatial scan statistic uses a circular scanning window that moves across the study area. Children with anemia were taken as cases and those who were not-anemic as controls to fit the Bernoulli model. The default maximum spatial cluster size of <50% of the population was used, as an upper limit, which allowed both small and large clusters to be detected and ignored clusters that contained more than the maximum limit. The scanning window with maximum likelihood was the most likely performing cluster, and the p-value was assigned to each cluster using Monte Carlo hypothesis testing by comparing the rank of the maximum likelihood from the real data with the maximum likelihood from the random datasets. The primary and secondary clusters were identified and assigned p-values and ranked based on their likelihood ratio test, based on 999 Monte Carlo replications(17).

Model building

Four models were fitted using **melogit**, a STATA command**,** the null model without predictors, the model I with only individual-level variables, model II with only community-level variables, and model III both individual-level and community-level variables. Model comparison was conducted by using deviance and likelihood ratio.

ICC (Intra-class correlation), MOR (median odds ratio), and PCV (proportional change in variance) were computed to measure the variation between clusters. The intra-class correlation coefficient (ICC) quantifies the degree of heterogeneity of childhood anemia between clusters (the proportion of the total observed individual variation in anemia that is attributable between cluster variations) calculated as ICC= $\sigma 2/ (\sigma 2+\pi 2/3)$(18) but MOR is quantifying the variation or heterogeneity in outcomes between clusters and is defined as the median value of the odds ratio between the cluster at high risk of anemia and cluster at lower risk when randomly picking out two clusters (EAs) MOR: exp(sqrt(2*Va)*0,6745) ~ MOR = exp (0.95* sqrt(Va)(19). PCV measures the total variation attributed by individual-level factors and community-level factors in the multilevel model as compared to the null model PCV. In the multivariable multilevel logistic regression analysis variables with a p-value of <0.05 were considered as statistically significant. Adjusted Odds Ratio (AOR) with their corresponding 95% confidence interval was determined to identify factors associated with anemia. After comparing all models, a model with low deviance was considered as a better model.

Multicollinearity was checked using the Variance Inflation Factor (VIF). VIF less than 10% was taken as no multicollinearity.

Ethics and confidentiality

Ethical clearance was obtained from the ethical review board of the University Of Gondar Institute Of Public Health, CMHS. Permission for data access was obtained from the measure demographic and health survey through an online request by a written letter of objective and significance of the study from http://www.dhsprogram.com

Patient and public involvement

This study did not involve patients and the public

Results

Descriptive characteristics of the study population

A total of 21,302 children with known hemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively. The majority of the participants were in the age group of 36-47 (23%), 36-47 (24%), and, 12-23 (22%) in EDHS 2005, 2011, and 2016 survey respectively. The mean age of children was 32.57 ±15.6-SD, 32.6±15.4-SD, and 31.7±15.6-SD in 2005, 2011, and 2016 respectively. Among the eligible children, male participants were high proportion in 2011 and 2016 EDHS as compared to 2005 survey periods. The majority of children were from rural residency in five years preceding the survey in three surveys. About 78.6%, 70%, and 67% of women were unable to read and write in 2005, 2011, and 2016 survey respectively. Children from poor and middle economic class families were more anemic than children from rich families across the three EDHS survey (Table 1). During the study period the trends in the prevalence of childhood anemia in Ethiopia, were ups and down across regions **(Fig.1)**.

Table 1: Descriptive characteristics of study participants included in the analysis for childhood anemia five years preceding the survey from EDHS 2005 - 2016 in Ethiopia

Characteristics	**2005 (N, 3868) Frequency (%)**	**2011(N, 8958) Frequency (%)**	**2016(N, 8476) Frequency (%)**
Sex of child			
Male	1,931(49.93)	4,500(51.35)	4,395(51.85)
Female	1,937(50.07)	4,358(48.65)	4,081(48.15)
Age of child			
6-11	418 (10.81)	1,029(11.48)	1,000(11.80)
12-23	842 (21.76)	1,804(20.14)	1,902(22.43)
24-35	825 (21.33)	1,895(21.16)	1,803(21.27)
36-47	919 (23.76)	2,184(24.37)	1,832(21.62)
48-59	864 (22.34)	2,047(22.85)	1,939(22.87)
Mean ± SD	**32.57 ±15.6**	**32.6±15.4**	**31.7±15.6**
Residence			
Urban	244 (6.31)	1,047(11.69)	857(10.12)
Rural	3,624 (93.69)	7,911(88.31)	7,619(89.88)
Religion			
Orthodox	1,624 (41.97)	3,416(38.13)	2,913(34.37)
Muslim	1,276 (32.99)	3,108(34.70)	3,432(40.48)
Protestant	836 (21.61)	2,151(24.01)	1,874(22.11)
Others	133 (3.43)	283(3.16)	258(3.05)
Women age			
15-29	1,930(49.90)	4,908(54.78)	4,356(51.40)
30-39	1,474(38.10)	3,223(35.98)	3,335(39.34)
40-49	464(12.00)	828(9.24)	785(9.26)
Women education			
No education	3,042 (78.63)	6,285(70.16)	5,685(67.07)
Primary	684 (17.68)	2,389(26.67)	2,275(26.84)
Secondary	136 (3.51)	168(1.88)	346(4.08)
Higher	7 (0.18)	117(1.30)	170(2.01)
Marital status			
Single	7(0.17)	50(0.56)	45(0.53)

Married	3,704(95.74)	8,425(94.04)	8,129(95.9)
Widowed	80(2.06)	178(1.99)	93(1.10)
Divorced	78(2.03)	306 (3.41)	210(2.48)
Husband education			
No-education	2,235 (58)	4,532(50.87)	4, 33(51.10)
Primary	1,233(32)	3,710(41.65)	3,273(38.62)
Secondary	362(9)	412(4.63)	572(6.75)
Higher education	31(0.81)	255 (2.86)	300(3.53)
Wealth index			
Poor	1,697(43.86)	4,048(45.19)	3,977(46.92)
Middle	854(22.07)	1,873(20.91)	1,821(21.48)
Rich	1,318(34.07)	3,038 (33.91)	2,678(31.60)
Women working status			
Not working	2,841(73.45)	5,793(64.67)	6,140(72.44)
Working	1,027(26.55)	3,165(35.33)	2,336(27.56)
Total	3,868(100)	8,958(100)	8,476(100)

Community-level characteristics of the study population

Findings from this study revealed that there is a regional variation of childhood anemia, with 83% in Somalia, 75%, in Afar, 72% in Dire Dawa, and 67% in Harari. However, Amhara, and Benishangul with 43% which was relatively low compared to other regions.

Childhood Anemia varies by urban-rural of residence. Children residing in communities with low poverty level had a lower percent of anemia (51.2%) as compared to with high community poverty level (62.5%%). Children from low community women education level (59.5%) were more anemic than children resided with high community women (53%) educational level (Table 2).

Table 2: Community Level Factors of under five children participated on EDHS (2016), Ethiopia. (N, 8476)

Background characteristics	Child anemia status		
Community level factors	**Not-anemic (%)**	**Anemic (%)**	**Total (%)**
Residence			
Urban	435(50.6)	424(49.4)	857(100)
Rural	3164(41.5)	4455(58.5)	7619(100)
Region			
Amhara	950(57.5)	703(42.5)	1653(100)
Oromia	1273(34.2)	2446(65.8)	3719(100)
SNNP	875(49.1)	906(50.9)	1781(100)
Somali	58(16.7)	290(83.3)	348(100)
Tigray	263(46)	309(54)	572(100)
Addis Ababa	82(50.9)	79(49.1)	161(100)
Afar	21(25.3)	62(74.7)	83(100)
Benishangul	51(56.6)	39(43.4)	90(100)
Gambelia	8(42.1)	11(57.9)	19(100)
Harari	5(31.2)	11(68.8)	16(100)
Dire Dawa	9(28.1)	23(71.9)	32(100)
Community women education			
Low	2281(40.5)	3358(59.5)	5639(100)
High	1315(46.4)	1520(53.6)	2837(100)
Community women poverty			
Low	1815(48.8)	1905(51.2)	3719(100)
High	1782(37.5)	2974(62.5)	4756(100)
Total			8476(100)

Spatio-temporal distribution of anemia among children age 6-59 months in Ethiopia

The spatial distribution of childhood anemia in Ethiopia was non-random in all three consecutive surveys. A global spatial autocorrelation statistic was estimated using Moran's *I* statistic. The global Moran's I test value was 0.176 (P-value <0.001) in 2005, 0.18 (P-value < 0.001) in 2011, and 0.09(P-value < 0.005) in 2016 Ethiopian Demographic and health surveys.

Hot spot analysis of the three surveys

The spatial distribution of childhood anemia in Ethiopia was different in the three survey periods. In EDHS 2005, a high proportion of childhood anemia was detected in Dire Dawa, Harari, Eastern Oromia, Benishangul in Metekel zone, Gambela, Southern and Eastern Tigray, and Somali region mainly Liben, Afdar, and Fafna zone which was hotspot area within 95% confidence level. On the counterpart, GamoGofa, Wolayita, Hadiya, Southern Omo, and Segen zone of SNNPR, Addis Ababa, central Oromia, Jima, North Shewa zone were cold spot area. In EDHS 2011, highly significant clustering of childhood anemia was detected in Somalia, Dire Dawa, Harari, Afar, Gambela, Benishangul, Eastern Oromia, Bale, and Arsi zone were the hotspot areas within 95% level of confidence. The low hotspot area of childhood anemia was detected in central Tigray, East and West Gojam, North Gondar, a central part of Oromia, Addis Ababa and SNNPR were areas identified as the low percentage of childhood anemia in the 2011 EDHS survey.

In EDHS-2016 sampled data, hot spot (high risk) regions for childhood anemia were observed in Somalia, Dire Dawa, Harari, Gambela, Eastern, and Southern part of Oromia. However, Amhara, Benishangul, and Southern Nations Nationalities and Peoples (SNNP) were identified as cold spot (low risk) regions for childhood anemia within a 95% confidence interval (**Fig.2**)

Spatial interpolation

Based on EDHS-2005 sampled data, the geostatistical analysis predicts that the highest prevalence of childhood anemia (65.75%-88.89%) was detected in East Oromia, Ilubabur, Arsi, some parts of Benishangul, Agnuak zone in Gambela, North Shewa Amhara region, South and central Tigray Afar in zone2, some parts of Dire Dawa city and Somalia. In EDHS-2011 Geostatistical analysis, a high percent of anemia was detected in Afar, most parts of Somalia, Oromia in East Harerge and Borena, some part of Dire Dawa, and the Meketel zone in Benishangul. In 2016 EDHS most of Somalia, some parts of Gambela, Guji and some parts of

Borena, East Shewa, East Harerge and Arsi in Oromia and part of Dire Dawa were highly prevalent areas in childhood anemia **(Fig.3)**

Spatial scan statistics

In 2005 EDHS most likely (primary clusters) and secondary clusters of anemia were identified. A total of 3 significant clusters were identified. One was most likely (primary) clusters and 2 were secondary clusters of spatial sat scan analysis. The primary cluster's spatial window was located in Somalia, which was centered at (9.018373 N, 43.110635 E) of geographic location with a 97.93 km radius, and Log-Likelihood ratio (LLR) of 20.03, at $p < 0.001$ which was detected as the most likely cluster with Maximum Likelihood. It showed that children within the spatial window had 1.54 times more likely a higher risk of anemia than the children outside areas of the spatial window. The secondary clusters scanning window was located in the southern part of Somali region. Which was centered at (3.998656 N, 41.240691 E) with a 92.08 km radius and LLR of 1.73 at p-value 0.0010. It showed that children within the spatial window had a 1.73 times higher risk of anemia than children outside the window.

In 2011 EDHS, a total of 10 clusters were identified and five of them were significant clusters with p-value <0.05. A total of 180 locations/spots with a total sampled population of 2478 were found as primary cluster areas were identified using sat scan analysis with a p-value < 0.001. The primary cluster spatial window was located mainly in Somali, Afar, Eastern Oromia, Dire Dawa, and Harari. The primary cluster spatial window was centered at (8.975207 N, 43.790264 E) / 540.29 km, with a relative risk (RR) of 1.43 and a log-likelihood ratio (LLR) of 127.79. It showed that children within the spatial window had 1.4 times more likely a higher risk of anemia than the children outside areas of the spatial window. The secondary cluster spatial window was located mainly in Afar regional state and 72 cases were found among the total population.

The secondary cluster spatial window was centered at (12.758587 N, 40.175990 E) / 39.58 km, with a relative risk (RR) of 1.68 and a log-likelihood ratio (LLR) of 21.5 P-value=0.001.

In 2016 EDHS, a total of 7 clusters (1 most likely cluster) which were located in Somalia, Afar, Eastern Oromia, Dire Dawa, and Harari. The cluster window was centered with a radius at (7.650693 N, 47.007920 E) / 912.19 km with a Relative Risk (RR) of 1.44. The Log-Likelihood Ratio (LLR) for the most likely cluster was 182.86, p <0.001. Secondary clusters were located in Gambela which was centered at (8.195862 N, 34.289837 E) with a radius of 29.01 km, and LLR of 18.8 at p-value 0.001. It showed that children within the spatial window had a 1.5 times higher risk of anemia than outside the window **(Fig.4)**.

Multilevel Analysis

The intra-cluster correlation coefficient (ICC) in the empty model indicated that 18.8% of the total variability for children anemia was due to differences between clusters and the remaining unexplained 81.2% attributable to individual differences. The median odds ratio for anemia was 2.3 in the null model which indicates that there was variation between clusters. If we randomly select children from two different clusters children at the cluster with a higher risk of anemia had 2.3 times higher odds of experiencing anemia as compared with children at cluster with a lower risk of anemia.

Bi-variable multilevel logistic regression analysis was done to identify variables for multivariable multilevel logistic analysis and Variable with a p-value less than 0.2 were considered for multivariable analysis.

Individual-level predictors for anemia

In multivariable multilevel mixed-effect logistic regression analysis individual-level factors such as the age of the child, wealth index, mother age, maternal anemic status, birth order, fever, stunting, and wasting status were a significant predictor of childhood anemia.

Children age between 12–23 months (AOR = 0.66, 95%CI = 0.53-0.81), between 24–35 months (AOR= 0.35, 95% CI = 0.28-0.43), between 36–47 months (AOR = 0.23-95%CI = 0.19-0.29), and between 48–59 months (AOR = 0.15, 95%CI = 0.12-0.19) were less likely to develop anemia when compared with children age between 6–11 months.

The likelihood of developing anemia for those children residing with the family wealth index of middle and rich was lower by 21% (AOR=0.79, 95%CI = 0.67-0.94), and 23% (AOR=0.77, 95%CI = 0.65-0.91), respectively as compared with children with poor wealth index. Children whose mother's age were between 40-49 had 25% decreased odds of developing childhood anemia as compared to age 15-29, (AOR=0.75, 95%CI = 0.59-0.95).

The odds of experiencing anemia for those birth orders 4-5, 6, and above six were 1.22 times (AOR=1.22, 95%CI = 1.01-1.47) and,1.35 times (AOR=1.35, 95%CI = 1.08-1.67) higher as compared with first-order respectively. The odds of developing anemia of children born from who had anemia history mother was 1.39 higher than that of children born from not anemic history before. Children who had fever were 39% (AOR =1.39, 95% CI: 1.24-1.58) more likely to develop anemia as compared with their counterparts. Children with moderate and severe stunting status were 35% (AOR=1.35, 95% CI: 1.17-1.54) and, 96% (AOR=1.95, 95% CI: 1.68-2.28), more likely to develop anemia respectively as compared to no stunting status. Similarly, children who had to sever wasting status were 51% more (AOR =1.51, 95% CI: 1.07-2.12) likely to develop anemia as compared with those children who had no wasting.

Community-level predictors for anemia

In the multivariable multilevel logistic regression model region of residence was significantly associated with community-level factors for childhood anemia.

Odds of children live in Somalia were 5.65 times (AOR=5.65, 95% CI: 3.92-8.16), Dire Dawa 3.45 times (AOR=3.45, 95% CI: 2.27-5.26), Afar 3.01 times (AOR=3.01, 95% CI: 2.09-4.34), and Oromia 2.34 times (AOR=2.34, 95% CI: 1.73-3.18) had more likely to develop childhood anemia as compared to Amhara regional state. Similarly, the odds of developing anemia in Addis Ababa was 2.10 times (AOR=2.10, 95% CI: 1.40-3.16), Gambella 1.94 times (AOR=1.94, 95% CI: 1.32-2.84), and Tigray 1.46 times (AOR=1.46, 95% CI: 1.08-1.98), more likely as compared to Amhara region. Benishangul and SNNPR had not significantly different in the prevalence of anemia as compared to the reference region Amhara (Table 3).

Table 3: Multilevel logistic regression analysis result of both individual and community level factors associated with anemia in Ethiopia, EDHS 2016

Individual Level	**Null Model**	**Model II AOR (95% CI)**	**Model III AOR (95% CI)**	**Model IV AOR (95% CI)**
Age in month				
6 – 11	--	1		1
12 – 23		0.66[0.54-0.82] **		0.66 [0.53-0.81] **
24 – 35		0.35[0.28-0.44] **		0.35 [0.28-0.43] **
36 – 47		0.23[0.18-0.28] **		0.23 [0.19-0.29] **
48 – 59	--	0. 15[0.12-0.19] **	---	0.15 [0.12-0.19] **
Religion				
Orthodox		1		1
Muslim		2.07[1.77-2.47] **		1.21 [0.97-1.46]
Protestant		1.20 [1.002-1.48] *		1.09[0.86-1.37]
Others	--	1.55[1.07-2.32] *	---	1.44[0.96-2.13]
Wealth index				
Poor		1		1
Middle		0.71[0.61-0.84] **		0.79 [0.67-0.94] *
Rich	--	0.72[0.63-0.85] **	---	0.77 [0.65-0.91] *
Child size at birth				
Small		1		1
Average		0.96[0.84-1.09]		0.93 [0.80-1.07]
Large	--	0.94[0.81-1.08]	---	0.96 [0.84-1.10]
Birth order				
1st		1		1
2-3		1.09[0.94-1.28]		1.13[0.97-1.32]
4-5		1.17[0.97-1.40]		1.22 [1.01-1.47] *

6 and above	--	1.30[1.05-1.62]	---	1.35 [1.08-1.67] **
No of children under 5				
1-2 children		1		1
≥ 3 children	--	1.22[1.1-1.4] *	---	1.09 [0.94-1.27]
Maternal anemia				
Not-anemic		1		1
Anemic	--	1.51[1.34, 1.72] **	---	1.39 [1.24-1.58] **
Maternal BMI				
≥18.5 kg/m2		1		1
<18.5 kg/m2	--	1.12[0.97-1.26]	---	1.05 [0.92-1.19]
Mather's working status				
Not-working		1		1
Working	--	0.88[0.77-0.99] *	---	0.92 [0.81-1.04]
Women age				
15-29		1		1
30-39		0.91[0.71-1.06]		0.90 [0.78-1.04]
40-49	--	0.75[0.59-1.12] *	---	0.75 [0.59-0.95] *
Breastfeeding				
No		1		1
Yes	--	0.92[0.81-1.04]	---	0.98 [0.87-1.12]
Vitamins in last 6 month				
No		1		1
Yes	---	0.90[0.81-1.09]	---	0.93 [0.84-1.05]
Diarrhea last 2 week				
No		1		1
Yes	---	0.88[0.73, 1.04]	---	0.90 [0.76-1.07]
Fever in last 2 weeks				
No		1		1
Yes	---	1.35[1.15-1.59] **	---	1.32 [1.13-1.56] *
Stunting status				
No-stunting		1		
Moderate stunting		1.27[1.10-1.46] **		1.35 [1.17-1.54] **
Severely stunting	---	1.81[1.55-2.11] **	---	1.96 [1.68-2.28] **
Wasting status				
No-wasting		1		
Moderate wasting		1.27[1.11-1.45]		0.98 [0.80-1.19]
Severe wasting	---	1.68[1.55-2.10] *	---	1.51 [1.07-2.12] *
Place of residence				
Urban			1	1
Rural	--	--	1.40[1.12-1.78]	1.28 [0.99-1.64]
Region				
Amhara		--	1	1
Tigray			1.46 [1.09-1.97] **	1.46 [1.08-1.98] **
Afar			3.90 [2.84-5.35] **	3.01 [2.09-4.34] **
Oromia			2.48 [1.89-3.25] **	2.34 [1.73-3.18] **
Somali			6.34[4.65-8.63]	5.65 [3.92-8.16] **

Benishangul			0.86 [0.62-1.17]	0.81 [0.58-1.15]
SNNPR			1.33 [1.00-1.76]	1.30 [0.94-1.80]
Gambela			1.93 [1.38-2.69] **	1.94 [1.32-2.84] **
Hareri			3.08 [2.15-4.43] **	2.98 [1.99-4.46] **
Addis Ababa			1.91[1.29-2.83] **	2.10 [1.40-3.16] **
Dire Dawa	--	--	3.92 [2.67-5.77] **	3.45 [2.27-5.26] **
Community education				
Low education			1	1
High education	--	--	1.07[0.90-1.26]	1.13[0.94-1.34]
Community poverty				
Low poverty			1	1
High poverty	--	--	1.41[1.17-1.68] *	1.15[0.94-1.40]
Model comparison and Random effect				
ICC	0.187	--	--	--
Log-likelihood	-4981.63	-4513.17	-4836.83	-4436.60
Deviance	9963.26	9026.34	9673.66	8873.2
PVC (%)	Ref	41.22	60.11	62.59
MOR	2.30	1.72	1.42	1.38

*Key: 1: reference group; p-value 0.05-0.01 *: p-value < 0.01 ***

Multicollinearity

Multicollinearity was checked for those variables included in the final model using VIF. Accordingly, the VIF for all predictor variables included in the final model was below 10 indicating the absence of multicollinearity among the predictor variables.

Comparison of models

Deviance was used to compare the models. The model with the lowest value of deviance was considered to be the better mode.

Discussion

This study tried to identify spatio-temporal distribution and predictors of childhood anemia across the regions in Ethiopia. 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used. In this study, the trend of anemia was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL:

0.56-0.59] of children were anemic in 2016 preceding the survey. This finding was in line with a study done in Gondar, Northwest Ethiopia 58.6%(20), whereas higher than the study done in cape Verde, west Africa 51.8%(21), and southern Ethiopia(22). Among children of 6–59 months, anemia is still considered to be a major public health problem in Ethiopia. Though the levels of anemia among children vary by background factors like region and lowest household wealth index and maternal related factors, more of the children in Ethiopia were suffering anemia.

The spatial pattern figures out that the geographical inequality of anemia by using sat scan and GIS spatial techniques like cluster mapping tools and interpolation techniques. The spatial analysis indicates that the distribution of childhood anemia was non- random across the country with global Moran's I index of 0.176 in 2005, 0.18 in 2011, and 0.09 in 2016 with significant p-value which indicates significant clustering areas. Findings from this study were in line with a study done in Nigeria, Malawi, Tanzania, and Uganda (23,24).

The spatial pattern of sat scan analysis showed that Eastern Somalia regions were primary (most likely) cluster and secondary cluster also located in the southern part of Somalia in 2005 sat scan analysis. In 2011 Somali, Afar, Eastern Oromia, Dire Dawa, and Harari were located in the primary window and centered at (8.975207 N, 43.790264 E/ 540.29 km with a significant p-value. Similarly, spatial sat scan analysis showed that Somalia, Afar, Eastern Oromia, Dire Dawa, Harari were hotspot areas in the 2016 EDHS spatial analysis.

This study indicated that children age 12-59 months were less affected by childhood anemia. This finding was consistent with studies conducted in Ethiopia and Togo (25–27). This could be explained by the fact that children who are getting older receive a diet that is richer and complete, with a sufficient intake of iron which could prevent the occurrence of iron deficiency anemia. The deficiency may result from inadequate dietary intake of iron, malabsorption of iron an increased iron demand during rapid growth might it be the possible reason (28).

The finding of this study indicated that children whose mother's age was between 40-49 were less anemic as compared to age 15-29. This finding is a study done in line with other studies conducted in sub-Saharan Africa and Ghana (15,29). This group consists of more at-risk population segments (Adolescent) for anemia. They are vulnerable to malnutrition because they are growing faster than at any time after their first year of life which contributes to the intergenerational cycle of malnutrition and he most common forms of malnutrition among Ethiopian adolescent girls is iron deficiency anaemia. Aside from, the bodies of the growing adolescent mother and her baby may compete for nutrients, raising the infant's risk of low birth weight, however, the lack of such nutrients might lead to anemia.

Children from households of middle and rich wealth indexes were less affected by childhood anemia as compared to children from a poor household. This finding has also been demonstrated in similar studies in Nigeria and northern Ethiopia (23,30). This is due to the reason that children from poor households are less likely to get iron-rich foods like animal foods and vitamin-rich foods especially vitamins A and C which are very important for iron absorption.

Maternal anemia was highly associated with the occurrence of childhood anemia. This finding was in line with a study done in South Africa, Haiti, and India(31–33). Reasons may be mothers and children share a common home environment, socioeconomic, and dietary conditions, and maternal and child anemia may reflect the common nutritional status of the household and poor maternal iron intake during pregnancy, reduce breast milk might be the possible reason.

EDHS data set indicated that the incidence of fever had an impact on childhood anemia. This is in line with studies done in Ghana and South Ethiopia Wolaita (22,34) Results showed that children who had a fever in the last two weeks before the survey had had a higher likelihood

578 of anemia than children who had not to fever. This could be attributed to the infectious cause of childhood fever mainly malaria, tuberculosis, and Leishmaniasis which cause anemia by destructing red blood cells or other related mechanisms.

581 The nutritional status of children had a significant association with childhood anemia. The stunting status of children was an independent predictor in the multilevel mixed effect model of this study. The result of this study indicated that it was in line with previous studies conducted in South Africa(33), Bangladesh(35,36), and Ethiopia(37,38). This study revealed that there was a greater prevalence of anemia among stunted children compared to non-stunted children. Children suffering from nutritional deficiency were more likely to have weak immune systems which makes them vulnerable to various illnesses and healthiness such as parasitic infections or chronic inflammation. Many of these conditions reduce the hemoglobin level in the blood leading to increased anemia prevalence. The statement is supported by the evidence given in other studies(39)that nutritional deficiency causes several health hazards.

591 Besides, severely wasting children were 1.51 times more likely to be anemic than their counterpart. Since stunting and wasting are long-term and short-term indicators of malnutrition, the results implied that under-nourished children experience a higher risk of developing anemia as compared to nourished children. Odds of experiencing anemia for those birth order four up to five and six and greater than six were higher than that of with first order. This finding was similar to a study done in Indian(15,40). This could be due to the distribution of scarce resources within the family and interrelated to maternal exhaustion of micronutrients feeding practice.

599 In a multivariable multilevel analysis, the odds of developing childhood anemia were higher among children who lived in Somalia, Dire Dawa, Afar, and Gambela as compared to the Amhara region. This might be due to the unavailability and inaccessibility of health facilities as

compared to the regions. Regional variation in the nutrient intake can cause significant health disparity, and this variability may be mediated by factors such as food availability, food customs, and culture.

This study was used different methods of spatial pattern, trend and a multilevel regression model used because of nested or cluster samples to show the effect of individual predictors and community-level variables on the dependent variable. The study was based on a large dataset representing the whole country of Ethiopia and which was weighted to make it nationally representative and adjusted for the design to get a reliable estimate. However, there were some limitations to this study. The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables. Also, respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the overall result and the generalizability of the findings.

Conclusion

Findings from this study indicated that the prevalence of childhood anemia decreased between the 2005-2011 survey while the prevalence increased from 2011-2016 EDHS. The spatial pattern of child anemia in Ethiopia was non-random among the three consecutive surveys with the global Moran's I value of 0.176, 0.18, and 0.09 in EDHS 2005, 2011, and 2016 respectively. In this study, Sat Scan analysis identified the primary and secondary clusters for the three survey periods. In 2005 EDHS the hotspot area was identified in eastern and southern parts of Somalia, in 2011 Somali, Afar, Eastern Oromia, Dire Dawa, and Harari were among the hotspot regions. Spatial sat scan analysis revealed that spatial clustering of childhood anemia was identified in Somalia, Afar, Eastern Oromia, Dire Dawa, Harari hotspot area in the 2016 EDHS period.

Child age, women age, wealth index, maternal anemia, had a fever, birth order, stunting, wasting and region were significant predictors among 6-59 months. Therefore, these results provide further insight into identifying the true picture of childhood anemia spatio-temporal clusters in the country and enable timely spatial targeting factors to alleviate home delivery. Therefore, policymakers and health planners should design effective intervention strategies for the identified hot spot areas and individual and community-level factors.

Abbreviations

AOR-Adjusted Odds Ratio, CSA-Central Statics Agency, CI-Confidence Interval, COR-Crude Odds Ratio, EDHS-Ethiopia Demographic and Health Survey, GPS-Global Positioning System, ICC-Intra Class Correlation Coefficient, LLR-Log-Likelihood Ratio, MOR-Median odds ratio, OR-Odds Ratio, RR-Relative Risk, PVC-Proportional Change in Variance, SNNPR-Southern Nations, Nationalities, and Peoples' Region.

Declarations

onsent to participate

The study was approved by the institutional ethical review committee board of the University of Gondar and ethical clearance was obtained from the board. Upon this clearance, the study was conducted. The congeniality of the data was maintained by using the extracted data only for the study purpose and keeping the data from a third party.

Consent for publication

Not-applicable

Data sharing statement

The data in which the authors used to produce this manuscript are available upon reasonable request

Competing interests

The authors declare that they have no competing interests.

Funding

No funding

Contributors

Proposal preparation, acquisition of data, analysis, and interpretation of data was done by SA. AM, ZM and BF guided the study design data collection and analysis. SA drafted the manuscript and all authors have a substantial contribution in revising and finalizing the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors gratefully acknowledge the support received from the University of Gondar. We also thank the Ethiopian Central Statistics Agency for providing us with the data and shape files for this study.

References

1. WHO. Nutritional Anaemias : Tools for Effective Prevention. World Health Organization. 2017. 1–83 p.
2. WHO. Global estimates of the prevalence of anaemia in infants and children aged 6 – 59 months , 2011 Global estimates of the prevalence of anaemia , all women of reproductive age , 15 – 49 years , 2011. Scaling Up Nutr [Internet]. 2015; Available from: http://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011_maps.pdf?ua
3. WHO. The global prevalence of anaemia in 2011. Who [Internet]. 2011;1–48. Available from: https://apps.who.int?iris/hendle/10665/177094
4. Pollitt E. Early iron deficiency anemia and later mental retardation. Oxford University Press; 1999.
5. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005. Public Health Nutr. 2009;12(4):444–54.
6. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993-2005. Public Health Nutr. 2009;12(4):444–54.
7. Leal LP, Batista Filho M, de Lira PIC, Figueiroa JN, Osório MM. Temporal trends and

anaemia-associated factors in 6- to 59-month-old children in Northeast Brazil. Public Health Nutr. 2012;15(9):1645–52.
8. Olivares M, Walter T, Hertrampf E, Pizarro F. Anaemia and iron deficiency disease in children. Br Med Bull [Internet]. 1999 Sep 1;55(3):534–43. Available from: https://doi.org/10.1258/0007142991902600
9. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: a cross-sectional study. BMJ Open [Internet]. 2018 May 1;8(5):e019654. Available from: http://bmjopen.bmj.com/content/8/5/e019654.abstract
10. Central Statistical Agency, ORC Macro. Ethiopia Demographic and Health Survey 2005. Heal San Fr [Internet]. 2006;(September):[446]. Available from: http://www.measuredhs.com/pubs/pdf/FR179/FR179[23June2011].pdf
11. Central Statistical Agency [Ethiopia], ICF International. Ethiopia Demographic and Health Survey 2011. 2012;1–452.
12. ECSA. Ethiopian Demographic Health Survey 2016. 2016. 161 p.
13. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health. 2019;19(1):1–9.
14. Malako BG, Teshome MS, Belachew T. Anemia and associated factors among children aged 6-23 months in Damot Sore District, Wolaita Zone, South Ethiopia. BMC Hematol. 2018;18(1):1–9.
15. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: A cross-sectional study. BMJ Open. 2018;8(5):1–14.
16. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in nigeria: A bayesian semi-parametric modelling. Int Health. 2014;6(1):35–45.
17. Kulldorff M. SatScan user guide 2006. 2018;
18. Bartko JJ. The Intraclass Correlation Coefficient as a Measure of Reliability. Psychol Rep. 1966 Aug;19(1):3–11.
19. Assessment IS. Understanding Variability in Multilevel Models Sophia Rabe-Hesketh Example : PISA (Programme for International Student Assessment) PISA : Distribution of SES.
20. Enawgaw B, Workineh Y, Tadesse S, Mekuria E, Addisu A, Genetu M. Prevalence of anemia and associated factors among hospitalized children attending the University of Gondar Hospital, Northwest Ethiopia. Electron J Int Fed Clin Chem Lab Med. 2019;30(1):35–47.
21. Semedo RML, Santos MMAS, Baião MR, Luiz RR, Da Veiga G V. Prevalence of Anaemia and Associated Factors among Children below Five Years of Age in Cape Verde, West Africa. J Heal Popul Nutr. 2014;32(4):646–57.
22. Tiku YS, Mekonnen TC, Workie SB, Amare E. Does Anaemia Have Major Public Health Importance in Children Aged 6–59 Months in the Duggina Fanigo District of Wolaita Zone, Southern Ethiopia? Ann Nutr Metab [Internet]. 2018;72(1):3–11. Available from: https://www.karger.com/DOI/10.1159/000484324
23. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in Nigeria: a Bayesian semi-parametric modelling. Int Health [Internet]. 2014 Jan 31;6(1):35–45. Available from: https://doi.org/10.1093/inthealth/iht034
24. Roberts DJ, Matthews G, Snow RW, Zewotir T, Sartorius B. Investigating the spatial

variation and risk factors of childhood anaemia in four sub-Saharan African countries. BMC Public Health. 2020;20(1):126.
25. Gebreweld A, Ali N, Ali R, Fisha T. Prevalence of anemia and its associated factors among children under five years of age attending at Guguftu health center, South Wollo, Northeast Ethiopia. PLoS One [Internet]. 2019 Jul 5;14(7):e0218961. Available from: https://doi.org/10.1371/journal.pone.0218961
26. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health [Internet]. 2019;19(1):215. Available from: https://doi.org/10.1186/s12889-019-6547-1
27. Mohammed SH, Habtewold TD, Esmaillzadeh A. Household, maternal, and child related determinants of hemoglobin levels of Ethiopian children: Hierarchical regression analysis. BMC Pediatr. 2019;19(1):1–10.
28. Keikhaei B, Zandian K, Ghasemi A, Tabibi R. Iron-Deficiency Anemia among Children in Southwest Iran. Food Nutr Bull. 2007 Dec;28(4):406–11.
29. Campbell JR, Holland J. Development research. Focaal. 2007;2005(45):3–17.
30. Gebreegziabiher G, Etana B, Niggusie D. Determinants of Anemia among Children Aged 6–59 Months Living in Kilte Awulaelo Woreda, Northern Ethiopia. Benz EJ, editor. Anemia [Internet]. 2014;2014:245870. Available from: https://doi.org/10.1155/2014/245870
31. Ayoya MA, Ngnie-Teta I, Séraphin MN, Mamadoultaibou A, Boldon E, Saint-Fleur JE, et al. Prevalence and risk factors of anemia among children 6-59 months old in Haiti. Anemia. 2013;2013:2–5.
32. Pasricha SR, Black J, Muthayya S, Shet A, Bhat V, Nagaraj S, et al. Determinants of anemia among young children in rural India. Pediatrics. 2010;126(1).
33. Ntenda PAM, Nkoka O, Bass P, Senghore T. Maternal anemia is a potential risk factor for anemia in children aged 6–59 months in Southern Africa: a multilevel analysis. BMC Public Health [Internet]. 2018;18(1):650. Available from: https://doi.org/10.1186/s12889-018-5568-5
34. Shenton LM, Jones AD, Wilson ML. Factors Associated with Anemia Status Among Children Aged 6–59 months in Ghana, 2003–2014. Matern Child Health J. 2020;24(4):483–502.
35. Khan JR, Awan N, Misu F. Determinants of anemia among 6–59 months aged children in Bangladesh: evidence from nationally representative data. BMC Pediatr [Internet]. 2016;16(1):3. Available from: https://doi.org/10.1186/s12887-015-0536-z
36. Rahman MS, Mushfiquee M, Masud MS, Howlader T. Association between malnutrition and anemia in under-five children and women of reproductive age: Evidence from Bangladesh Demographic and Health Survey 2011. PLoS One. 2019 Jul;14(7):e0219170–e0219170.
37. Belachew A, Tewabe T. Under-five anemia and its associated factors with dietary diversity, food security, stunted, and deworming in Ethiopia: systematic review and meta-analysis. Syst Rev. 2020 Feb;9(1):31.
38. Malako BG, Asamoah BO, Tadesse M, Hussen R, Gebre MT. Stunting and anemia among children 6–23 months old in Damot Sore district, Southern Ethiopia. BMC Nutr. 2019;5(1):1–11.
39. Pelletier DL, Frongillo Jr EA, Schroeder DG, Habicht JP. The effects of malnutrition on child mortality in developing countries. Bull World Health Organ. 1995;73(4):443–8.
40. Goswmai S, Das KK. Socio-economic and demographic determinants of childhood anemia. J Pediatr (Rio J). 2015;91(5):471–7.

Figure legend/caption

Figure 1: Trends in anemia overtime across the regions in Ethiopia, EDHS 2005 to 2016

Figure 2: Hot spot and cold spot analysis of anemia in Ethiopian, EDHS 2005 to 20016

Figure 3: Ordinary Kriging interpolation of anemia in Ethiopia, EDHS 2005 to 2016

Figure 4: SaTScan scan statistics analysis of anemia in Ethiopia, EDHS, 2005-2016

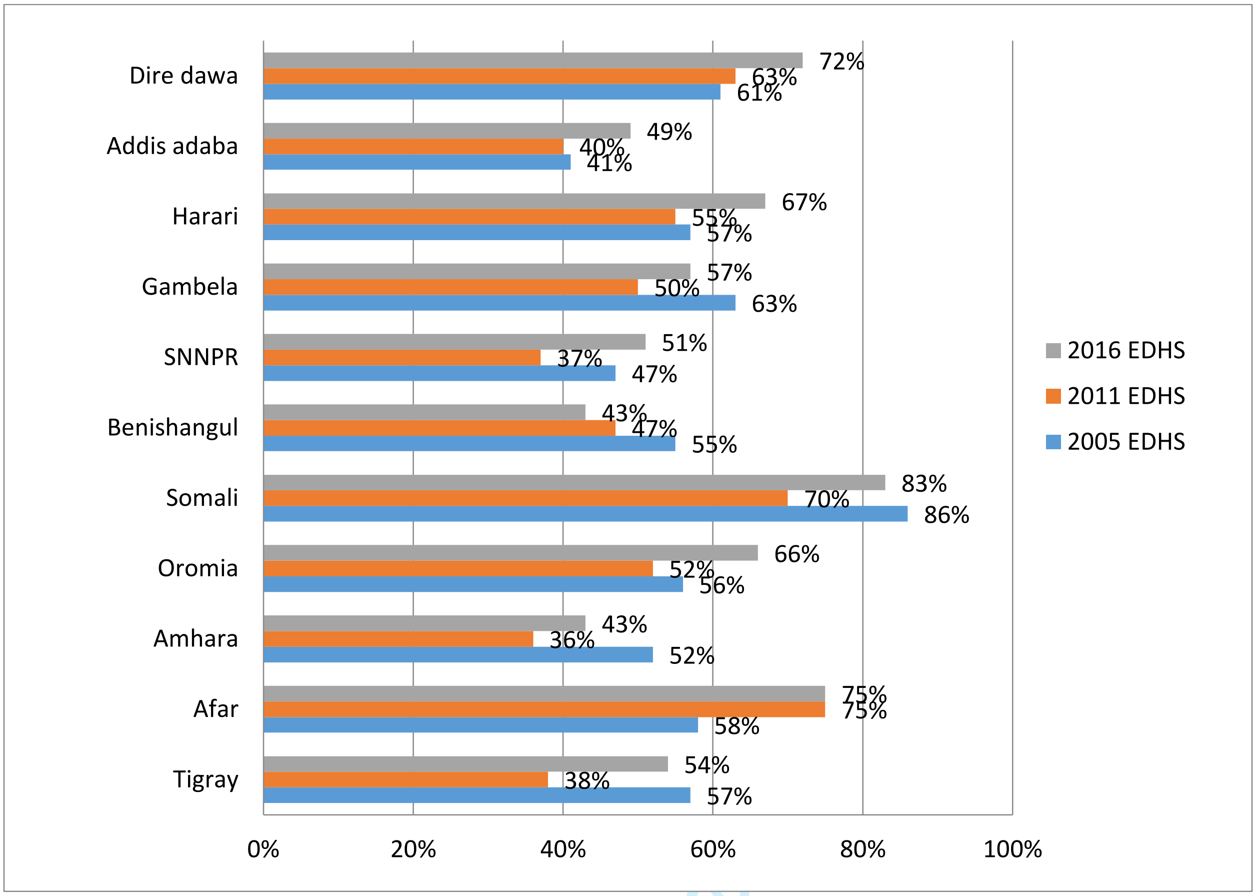
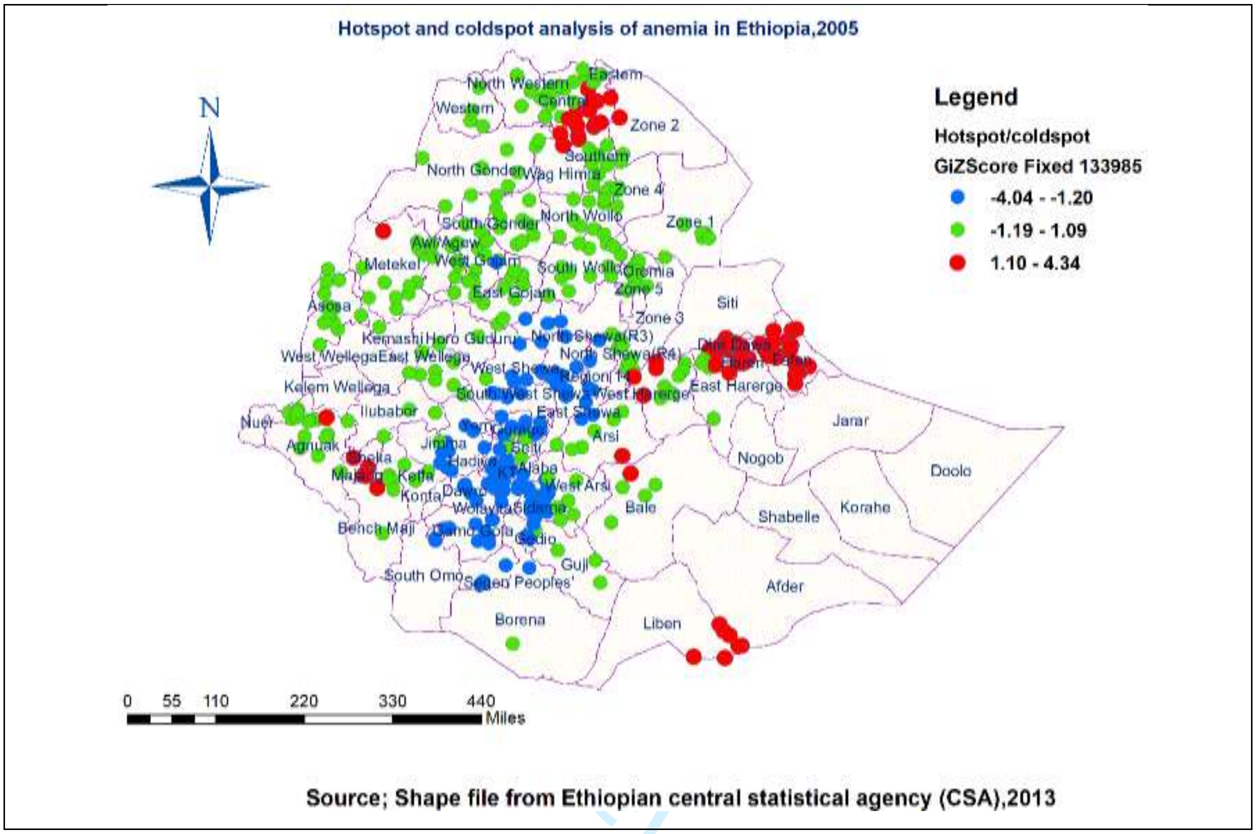
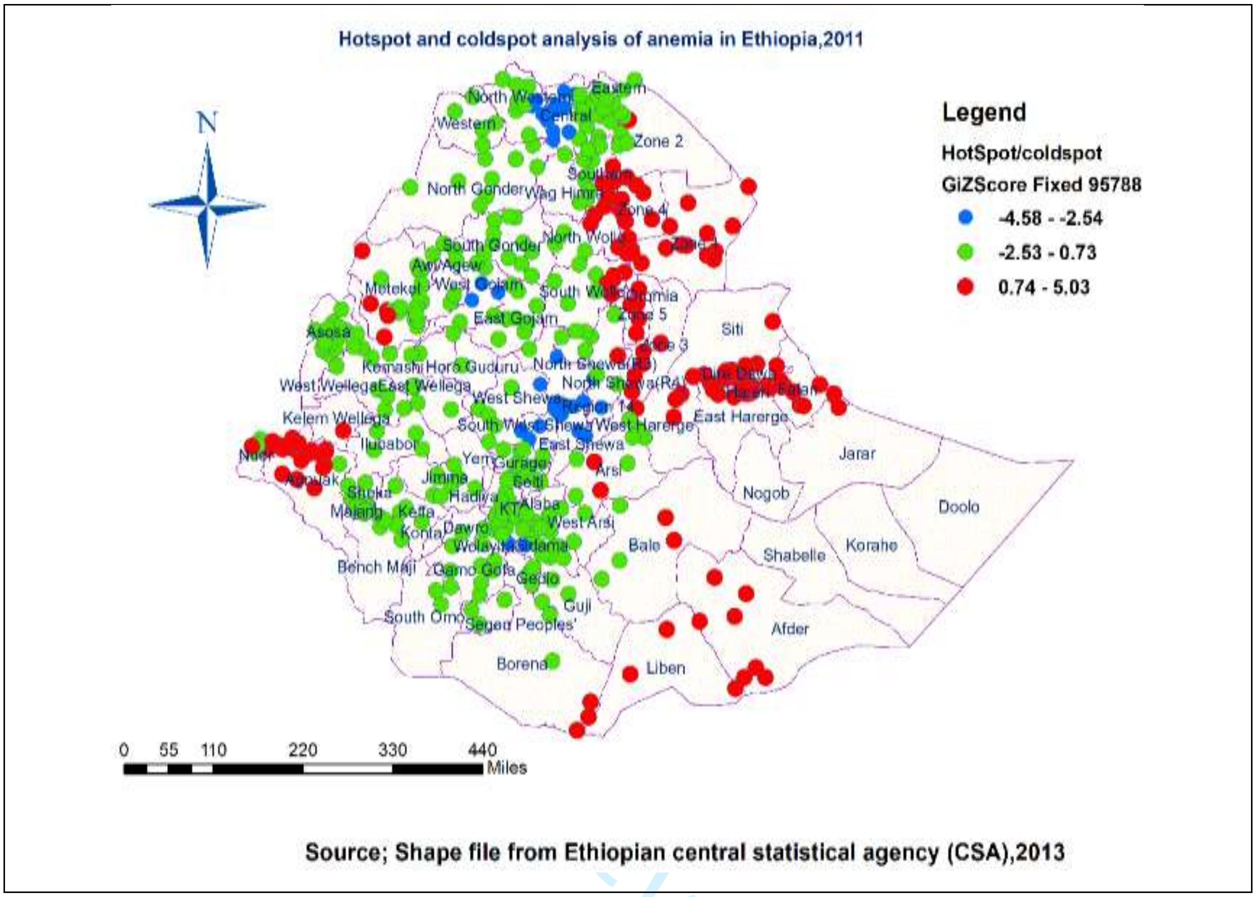


Figure 1: Trends in anemia overtime across the regions in Ethiopia, EDHS 2005 to 2016


Hotspot and coldspot analysis of anemia in Ethiopia,2005
Legend
Hotspot/coldspot
GiZScore Fixed 133985
-4.04 - -1.20
-1.19 - 1.09
1.10 - 4.34
N
0 55 110 220 330 440
Miles
Source; Shape file from Ethiopian central statistical agency (CSA),2013


Hotspot and coldspot analysis of anemia in Ethiopia,2011
N
Legend
HotSpot/coldspot
GiZScore Fixed 95788
-4.58 - -2.54
-2.53 - 0.73
0.74 - 5.03
0 55 110 220 330 440
Miles
Source; Shape file from Ethiopian central statistical agency (CSA),2013

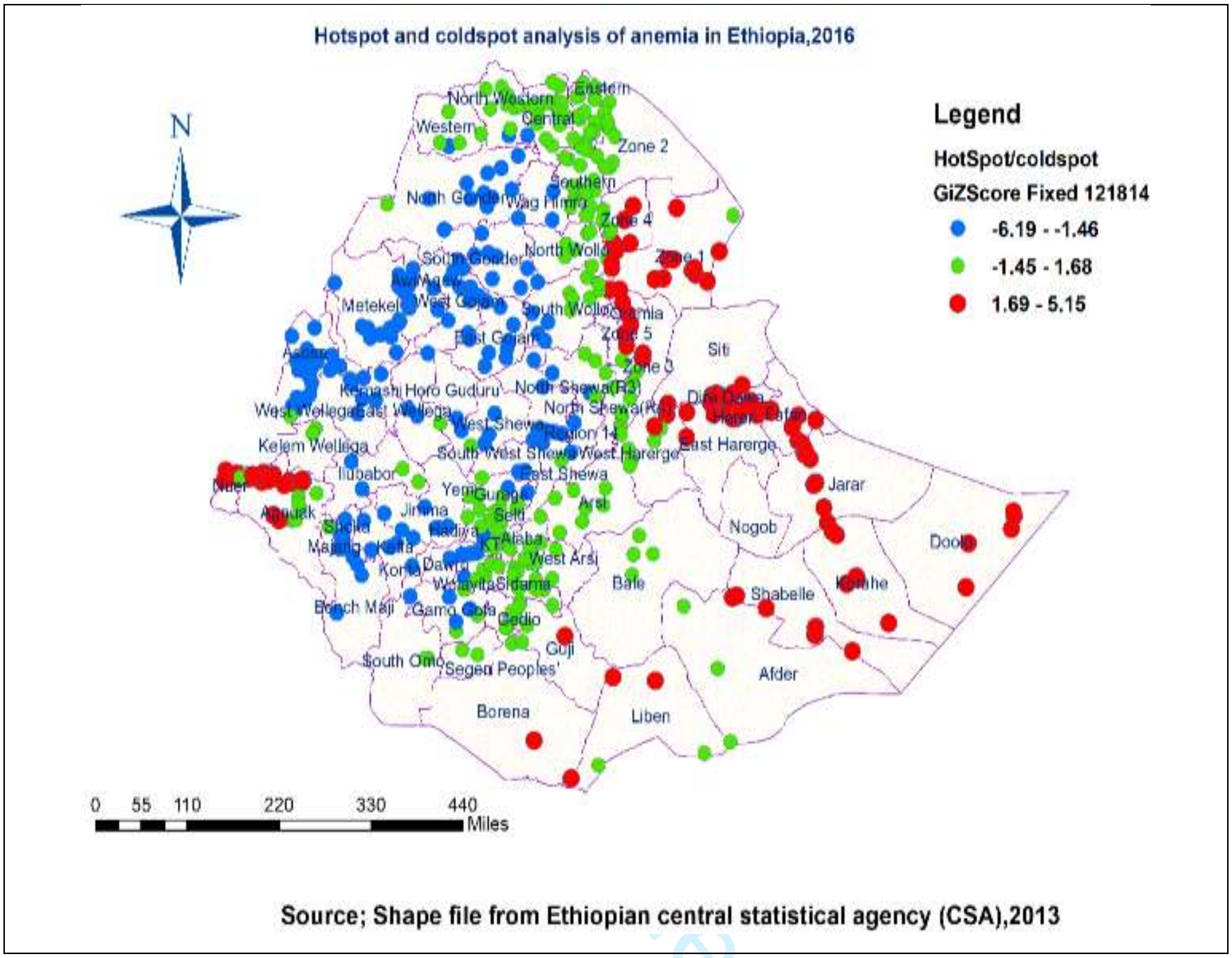
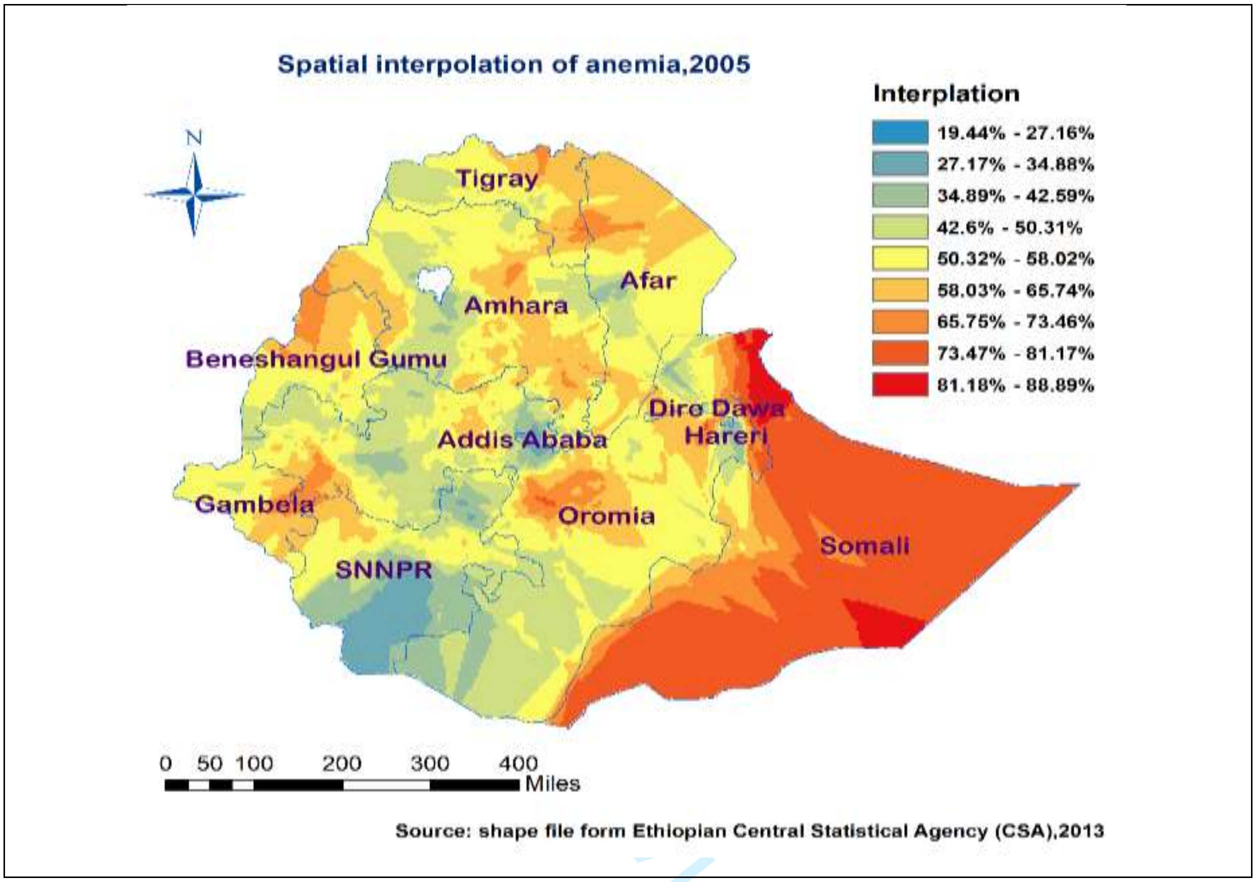
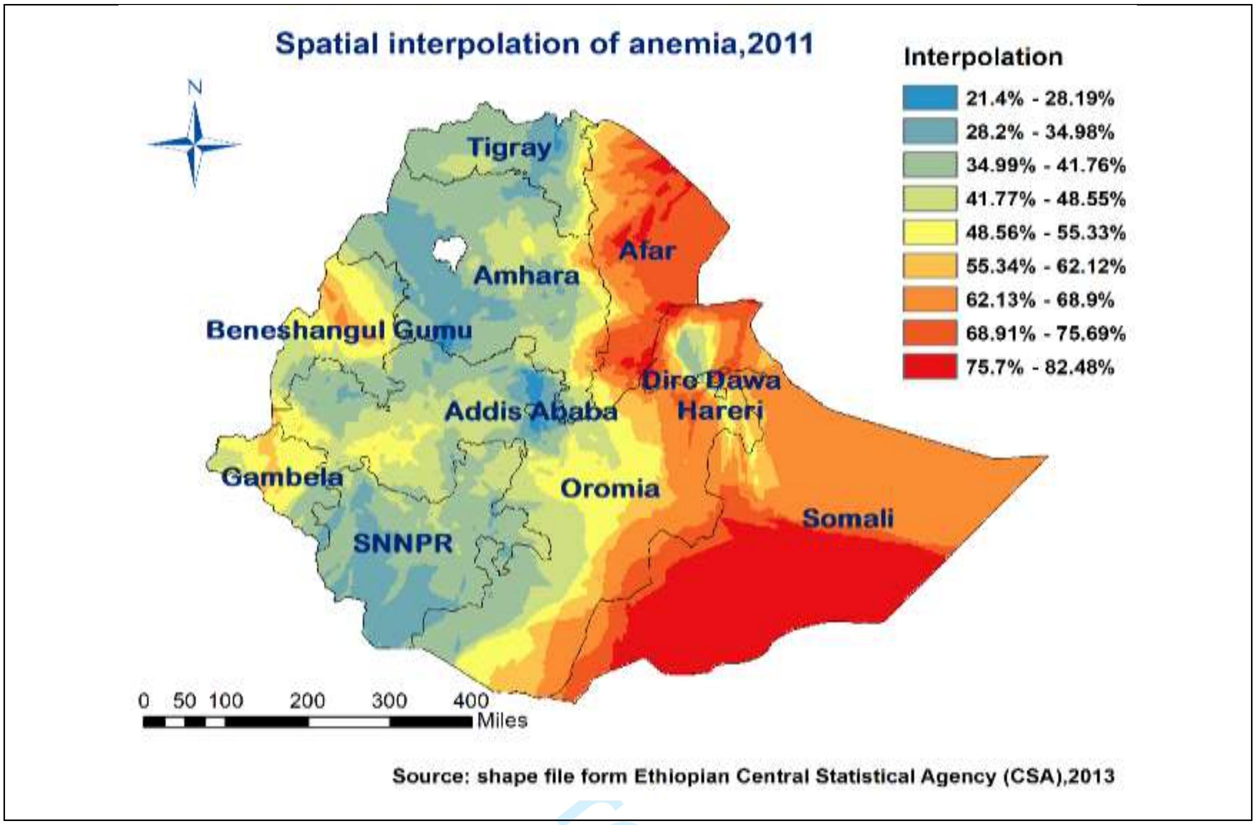


Figure 2: Hot spot and cold spot analysis of anemia in Ethiopian, EDHS 2005 to 20016


Spatial interpolation of anemia,2005
Interplation
19.44% - 27.16%
27.17% - 34.88%
34.89% - 42.59%
42.6% - 50.31%
50.32% - 58.02%
58.03% - 65.74%
65.75% - 73.46%
73.47% - 81.17%
81.18% - 88.89%
N
Tigray
Afar
Amhara
Beneshangul Gumu
Diro Dawa
Hareri
Addis Ababa
Gambela
Oromia
Somali
SNNPR
0 50 100 200 300 400
Miles
Source: shape file form Ethiopian Central Statistical Agency (CSA),2013


Spatial interpolation of anemia,2011
Interpolation
21.4% - 28.19%
28.2% - 34.98%
34.99% - 41.76%
41.77% - 48.55%
48.56% - 55.33%
55.34% - 62.12%
62.13% - 68.9%
68.91% - 75.69%
75.7% - 82.48%
N
Tigray
Afar
Amhara
Beneshangul Gumu
Dire Dawa
Hareri
Addis Ababa
Gambela
Oromia
Somali
SNNPR
0 50 100 200 300 400
Miles
Source: shape file form Ethiopian Central Statistical Agency (CSA),2013

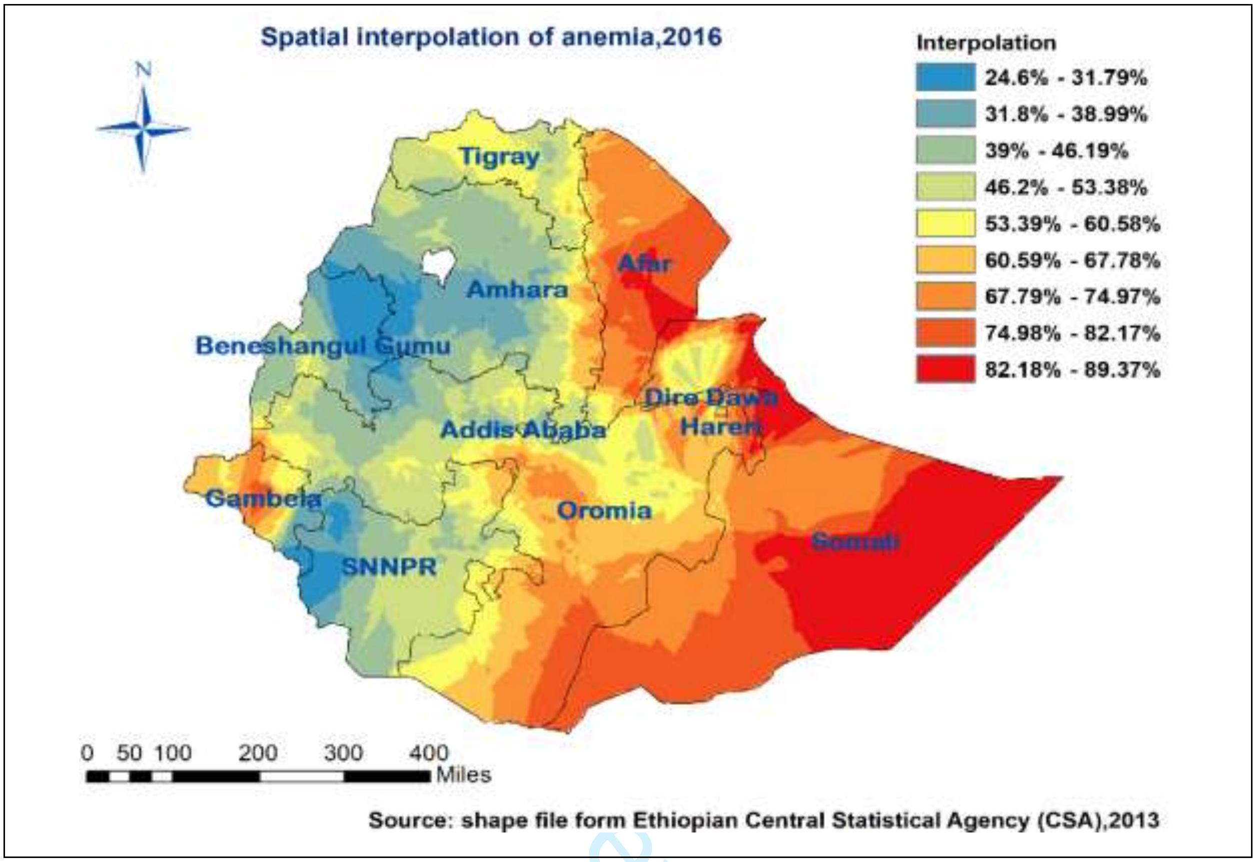
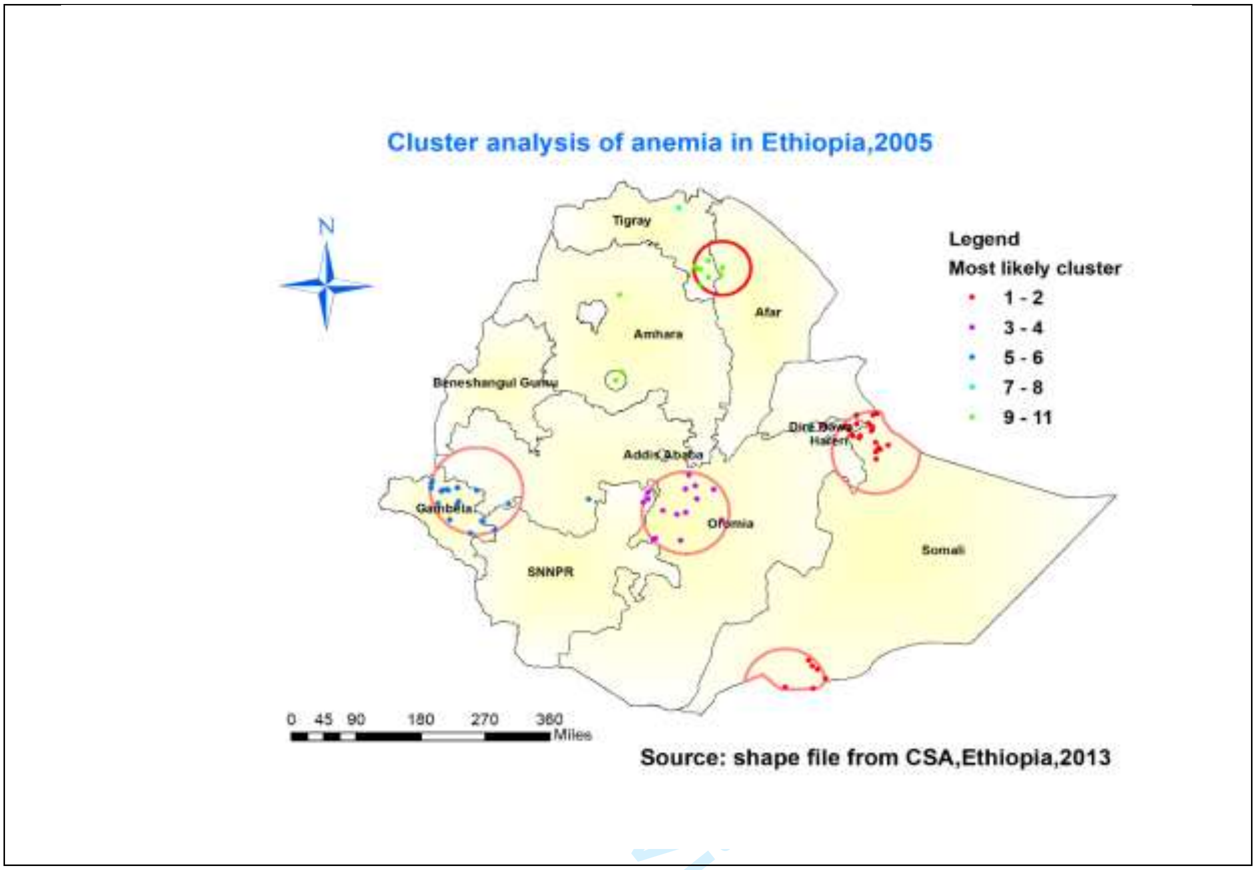
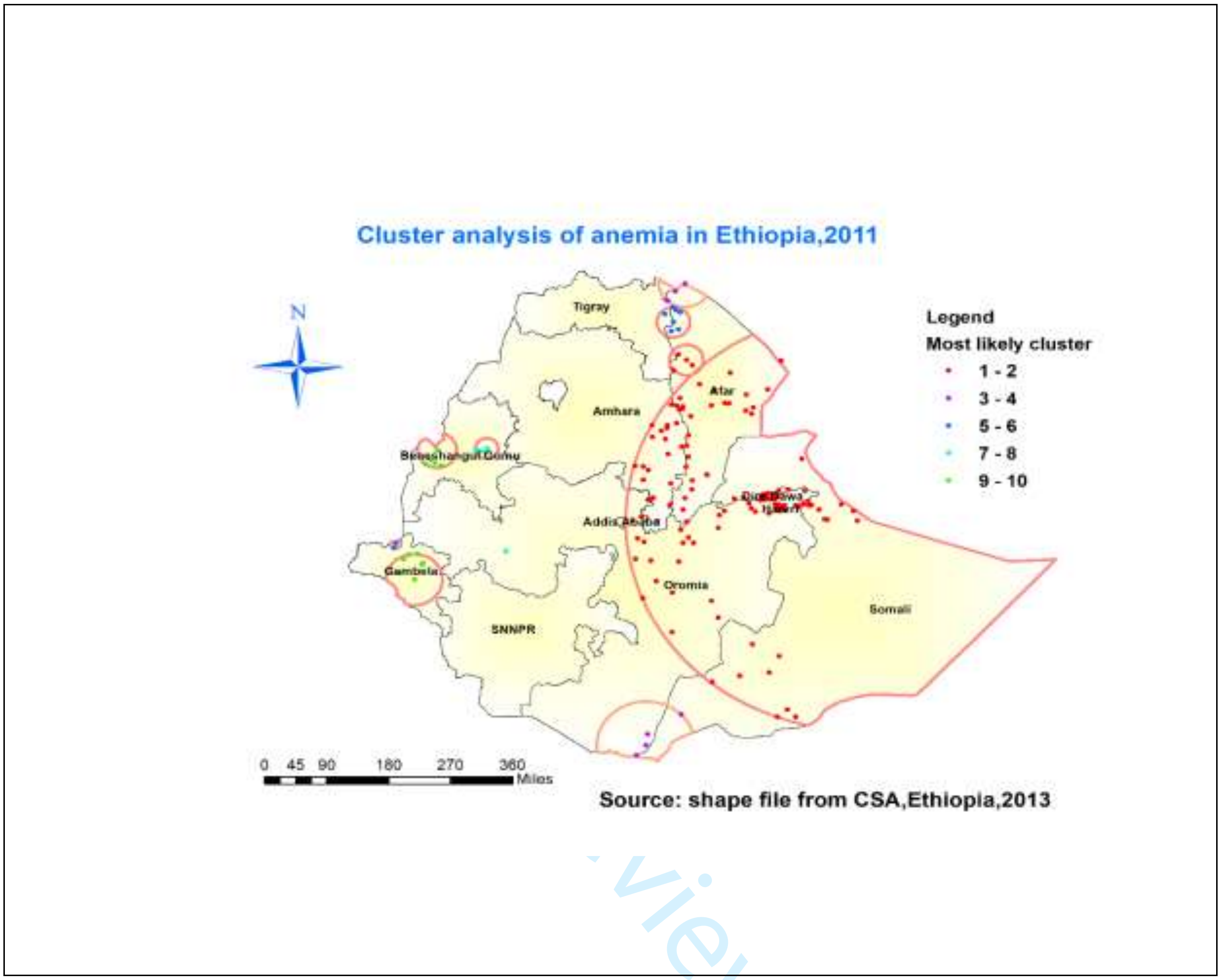


Figure 3: Ordinary Kriging interpolation of anemia in Ethiopia, EDHS 2005 to 2016


Cluster analysis of anemia in Ethiopia,2005
N
Tigray
Afar
Amhara
Beneshangul Gumu
Dire Dawa
Hareri
Addis Ababa
Gambela
Oromia
SNNPR
Somali
Legend
Most likely cluster
1 - 2
3 - 4
5 - 6
7 - 8
9 - 11
0 45 90 180 270 360
Miles
Source: shape file from CSA,Ethiopia,2013


Cluster analysis of anemia in Ethiopia,2011
N
Tigray
Afar
Amhara
Benishangul Gumu
Addis Ababa
Dire Dawa
Harari
Gambela
Oromia
Somali
SNNPR
Legend
Most likely cluster
1 - 2
3 - 4
5 - 6
7 - 8
9 - 10
0 45 90 180 270 360
Miles
Source: shape file from CSA,Ethiopia,2013

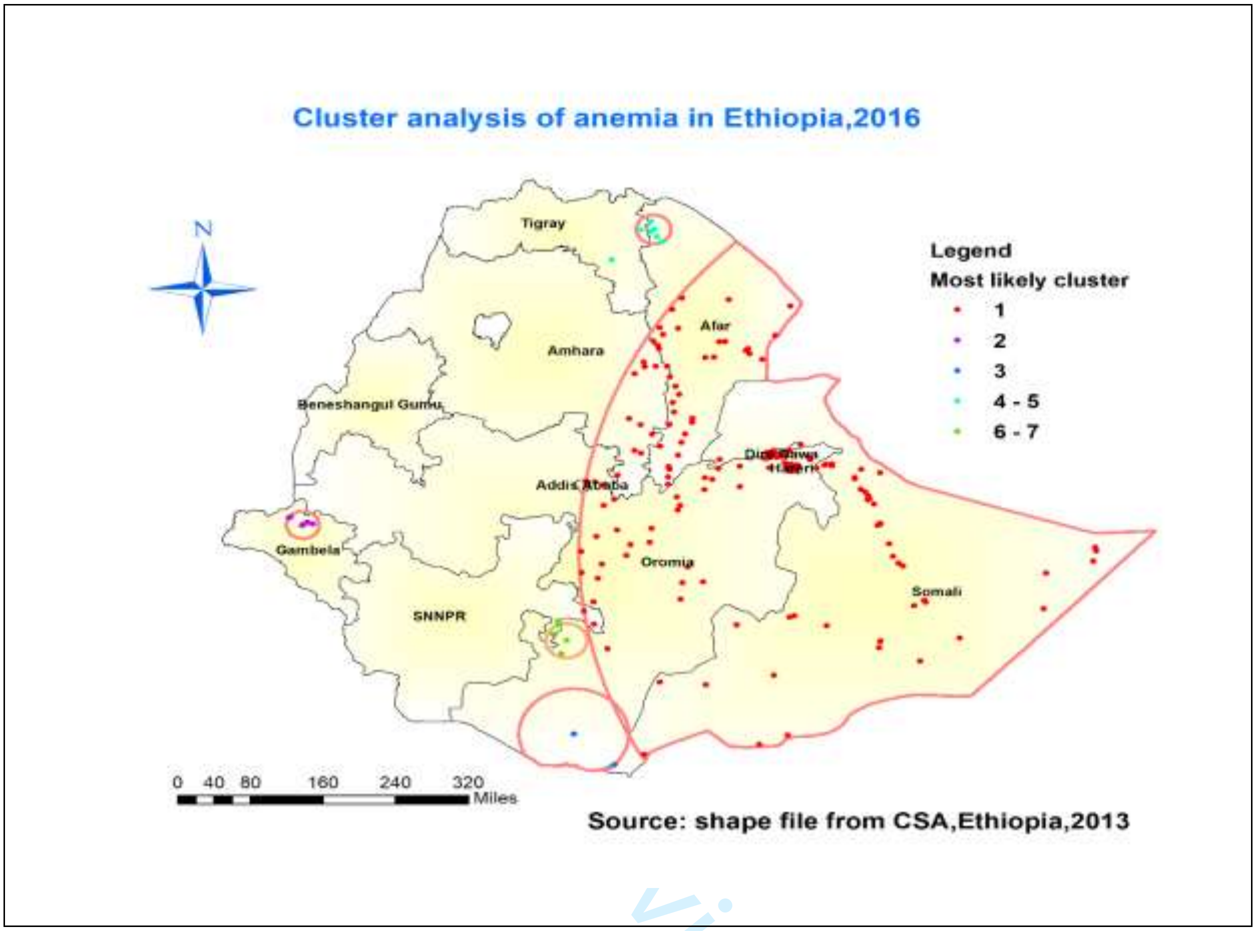


Figure 4: SaTScan scan statistics analysis of anemia in Ethiopia, EDHS, 2005-2016

BMJ Open

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-045544.R1
Article Type:	Original research
Date Submitted by the Author:	27-Feb-2021

Complete List of Authors:	Samuel, Hailegebreal; Arba Minch University, Department of Health Informatics Nigatu, Araya; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia Mekonnen, Zeleke; Ethiopia Ministry of Health, Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia; Endehabtu, Berhanu; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia

Primary Subject Heading:	Paediatrics
Secondary Subject Heading:	Public health
Keywords:	Anaemia < HAEMATOLOGY, PAEDIATRICS, Community child health < PAEDIATRICS

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Samuel Hailegebreal[1*], Araya Mesfin Nigatu[2], Zeleke Abebaw Mekonnen[2,3], Berhanu Fikadie Endehabtu[2]

Affiliation

[1]Department of Health Informatics, College of Health Science, Arbaminch University, Ethiopia

[2]Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia

[3]Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia

Corresponding author

Samuel Hailegebreal

Email: samuastd@gmail.com

Abstract

Objectives: Anaemia is a global public health problem with major health and socio-economic consequences. Though childhood anaemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anaemia overtime. Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and health survey (EDHS) data from 2005-2016.

Design: Survey-based cross-sectional study design was employed for the EDHS.

Setting: Data were collected in all nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.

Participants: The source population for this study was all 6–59 months of children in Ethiopia. A total of 21,302 children aged 6-59 months were included in this study.

Outcome measure: The outcome variable was child anaemia status.

Results: The prevalence of anaemia declined from 53.9% in 2005 to 44.6% in 2011, but it showed an increment in 2016 to 57.6%. The Spatial analysis revealed that the spatial distribution of anaemia varied across the country. In spatial scan statistics analysis, a total of 22 clusters (RR= 1.54, P-value < 0.001) in 2005, 180 clusters (RR = 1.14, P-value < 0.001) in 2011, and 219 clusters (RR = 1.44, P-value < 0. 0.001) in 2016 significant primary clusters were identified. Child age, women age, maternal anaemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anaemia.

Conclusions: In this study, childhood anaemia remains a public health problem. The spatial distribution of childhood anaemia was significantly varied across the country. Identifying the risk areas and determinants would help to design strategies in the area. Therefore, in regions

with a high risk of childhood anaemia, individual and community level factors should be intensified by allocating additional resources and providing appropriate and tailored strategies.

***Keywords**:* Anemia, children, EDHS, Spatial analysis, Ethiopia

Strengths and limitations of this study

- This study applied different methods of spatial pattern, trend and a multilevel regression models accounting for the nested nature of EDHS data
- The study was based on three consecutive EDHS dataset's representing the whole country of Ethiopia
- The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables
- Respondents' without coordinate (longitude and latitude) were excluded from the spatial analysis, which could affect the generalizability of the findings

Background

Anaemia is a condition characterized by a low level of haemoglobin in the blood(1). Over 273 million under-five children suffer from anaemia worldwide(2). Sub-Saharan Africa is one of the most affected regions, accounting for about 53.8%(2). World health organization had developed a classification system to facilitate international comparisons of anaemia as public health crises. The problem was considered severe if anaemia prevalence is ≥40%, moderate from 20% to 39.9%, and mild from 5% to 19.9%(3). The high prevalence of anaemia and its consequences on children's health, especially on their growth and development, have made it important public health problem, It also increases the risk of mortality and morbidity that come from other diseases(4,5).

Anaemia is a public health problem that affects populations in both industrialized and non-industrialized countries. It affects all segments of the population. It is frequently observed among children and pregnant women who are the most vulnerable group because their iron requirements are higher than any other group. Childhood anaemia is mainly caused by dietary Iron deficiency. Foliate, vitamin B12 and vitamin A deficiencies, chronic inflammation, parasitic infections, and inherited disorders can also contribute to childhood anaemia (6). For children age 6-59month Anaemia is defined as a haemoglobin level below 11.0 g/dl(6). Childhood anaemia is mostly coexisting with malaria, parasitic infection, nutritional deficiencies, and hemoglobinopathies(7).

The 2015 WHO report, from the global anaemia prevalence in 2011 showed that Africa, South East Asia, America, and European regions was,62.3%,53.8%,23.3%, and,22.9%, respectively(3). Pregnant women and children in low-income countries were at risk for anaemia because they were believed to be those with the most significant problems with inadequate nutrition, high infectious disease burden, and poor access to routine health care(8). In sub-Saharan Africa, anaemia is a significant public health problem associated with an increased risk of death and impaired cognitive development(9). In Ethiopia, the three crude summaries of the country reported between 2005 and 2016 indicated the prevalence of anaemia among Ethiopian children declined from 54% to 44% from 2005 to 2011 but increased to 57% in 2016(10–12).

Various-studies showed that the prevalence of anaemia among 6-59-month children is high and a severe public health problem. Evidence from various studies indicated that women age, residence, family income, maternal education(13), an introduction of complementary foods, poor breastfeeding practice, poor utilization of folic acid by mothers(14), maternal anaemia(15), unemployment of the parent, malaria, and presence of sickle haemoglobin(13), household wealth index, sex of the child(16), and nutritional status were factors for childhood anaemia. Few studies have been done on factors associated with anemia in Ethiopia, to date; the risk areas (hot spot) of anaemia among children are not identified. Thus, this study aimed to explore the spatiotemporal patterns of anaemia among children in Ethiopia over the last one and half-decades to point out whether there was either the shift or improvement in anaemia risk areas following intervention programs in between the survey periods in Ethiopia. Geographical differences in the causes of anemia can be partially explained by large-scale variability in environmental drivers, particularly nutritional and infectious causes(17). The risk of malaria is known to be associated with elevation and land surface temperature(18). Environmental drivers of anemia tend to show a high degree of spatial dependence. Therefore, detecting the geographic variation of anemia during childhood is important to prioritize and design targeted intervention programs to reduce anemia especially in those areas with a consistently higher risk of anemia over time. Therefore, this study attempts to fill the gap by investigating the spatio-temporal distribution of anaemia and its associated factors using multilevel model analysis in Ethiopia using the EDHS survey between 2005-2016 data.

Methods and materials

Study design, setting and period

The survey-based cross-sectional study design was employed using the Ethiopian Demography and Health Surveys (EDHS) in 2005, 2011, and 2016. Data access, extraction, and analysis were conducted from January to June 2020. The study was conducted in Ethiopia located at the horn of Africa (3º-14ºN and 33º – 48ºE). Administratively, the country is divided into nine regional states and two city administrations. Each region is sub-divided into zones, districts, towns, and kebeles (the smallest administrative units).

Source and study population

All 6–59 months children in Ethiopia were the source population for this study whereas all children aged from 6-59 months in the selected enumeration areas within five years before the survey were the study population.

Sample size and sampling technique

A total of 21,302 children (3,868 in 2005, 8,958 - in 2011, and 8476 in 2016) were included in this study. children's Record (KR) EDHS dataset was used for analysis. The survey covered all nine regions and the two city administrations of Ethiopia. Participants were selected based on a stratified two-stage cluster sampling technique in each survey year. After excluding clusters with zero coordinates and missing information, a total of 503 clusters in 2005, 569 clusters in 2011, and 615 clusters in 2016 were used for analysis. The detailed sampling procedure was available in each EDHS report(10–12)

Data collection tools and procedures

The three EDHS datasets were downloaded from the measure DHS program (Demographic and Health Survey) website (www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses. Similarly, location data (latitude and longitudinal) were extracted from the downloaded excel file. After extraction, the missing values for the significant independent variables were excluded and the analysis was undertaken using a complete set of data. In all survey years for all children age 6-59 month from whom consent was obtained from their parents. Blood samples were drawn from the drop of blood taken from a finger prick or a heel prick in the case of 6-11 month, and collected in a microcuvette. Haemoglobin analysis was carried out on-site using a battery-operated portable HemoCue analyzer.

Key variables and Measurements

Dependent variable: The study variables were grouped into dependent and independent variables. The dependent variable is child anaemia status, categorized as "anaemic/not-anaemic" variable. Children whose haemoglobin level was less than 11g/dl were considered anaemic and not anaemic otherwise.

Independent variables:

sociodemographic (religion, mother age, marital status, educational status, husband education, wealth index, mothers working status, numbers of under five children) Maternal and Child- related (child sex, age, birth size, birth order, maternal BMI, maternal anaemia, breastfeeding, fever, diarrhoea, vitamin supplement, stunting and wasting). Community-level (residence, region, community women education and community women poverty).

We created community education and community poverty variables by aggregating the individual characteristics within their clusters. The aggregates were computed using the median values of the proportions of women in each category of a given variable. We categorized the aggregate values of a cluster into groups based on national median values, since all aggregates were not normally distributed.

Community women's education: was defined as the proportion of women who attended primary, secondary and higher education within the cluster. The aggregate of individual primary, secondary and higher educational attainment can show the overall educational and academic status of women within the cluster. They were categorized into two categories a higher proportion of women's education within the cluster and a lower proportion of women education based on the national median value.

Community poverty status: defined as the proportion of poor and poorest mothers within the cluster. For each cluster, the proportion of poor and poorest as-was aggregated and show overall poverty status within the cluster. It was categorized into two categories based on national median value as higher proportion of poor/poorest mother's and lower proportion of mothers within a cluster.

Data management and analysis

The data were cleaned using STATA 14.1 software and Microsoft excel. The data were weighted using sampling weight, primary sampling unit, and strata before any statistical analysis to restore the representativeness of the survey to take into account the sampling design when calculating standard errors to get reliable statistical estimates.

Spatial analysis

For the spatial analysis, ArcGIS V.10.7 software was used to evaluate whether the pattern was clustered, dispersed or random across the study area, and SaTScan V.9.6 software was used for the local cluster detection analysis. It uses a circular window that moves systematically throughout the study area to identify a significant SaTScan clustering of childhood anaemia.

Spatial autocorrelation analysis

The spatial autocorrelation (Global Moran's I) statistic measures whether childhood anaemia patterns were dispersed, clustered or randomly distributed in the study area. Moran's I output value ranges from (-1 to +1). Values close to −1 indicate disease dispersed, whereas Moran's I close to +1 indicate childhood anaemia clustered and distributed randomly if I value zero. Anselin Local Moran's I was used to indicate the local level cluster locations of anaemia positively correlated (high-high and low-low) clusters or negatively correlated (high-low and low-high).

Hot spot analysis (Getis-Ord Gi* statistic)

Local Moran's I, Gettis-OrdGi* statistics was computed to measure how spatial autocorrelation of anemia among under-five children varies across different locations in Ethiopia. Hotspot analysis computes Z-score and p-value to determine the statistical significance of the clustering of anaemia over the study area at different significance levels simultaneously. Statistical output with high GI* indicates "hotspot" whereas low GI* means a "cold spot". hot spot areas showed that there was a high proportion of anaemia and the cold spot indicated a low proportion of anaemia.

Spatial interpolation

There are various deterministic and geostatistical interpolation methods. Among all of the methods, ordinary Kriging and empirical Bayesian Kriging are considered the best methods since they incorporate spatial autocorrelation and statistically optimize the weight. Ordinary Kriging spatial interpolation method was used for this study for predictions of childhood anaemia in unobserved areas of Ethiopia since it had low mean square error and residual as compared to the other interpolation techniques.

Spatial scan statistical analysis

Spatial scan statistical analysis used to Identifying most likely clusters was done using the spatial Scan statistical method. This method is widely recommended as it is very important in detecting local clusters and has higher power than other available spatial statistical methods. Bernoulli based model was employed to test for statistically significant spatial clusters of anaemia using Kulldorff's Sat Scan version 9.6 software. Children with anaemia were taken as cases, and were not-anaemic as controls to fit the Bernoulli model. The default maximum spatial cluster size of <50% of the population was used. The scanning window with maximum likelihood was the most likely cluster, and the p-value was assigned to each cluster using Monte Carlo hypothesis testing. The primary and secondary clusters were identified and assigned p-values and ranked based on their likelihood ratio test, based on 999 Monte Carlo replications(19).

Associated factors of anaemia

Four models were fitted using **melogit**, a STATA command, the null model without predictors, model I with only individual-level variables, model II with only community-level variables, and Model III both individual-level and community-level variables. Model comparison was conducted by using deviance and likelihood ratio.

Intra-class correlation (ICC), median odds ratio (MOR), and proportional change in variance (PCV) were computed to measure the variation between clusters. The intra-class correlation coefficient (ICC) quantifies the degree of heterogeneity of childhood anaemia between clusters (the proportion of the total observed individual variation in anaemia that is attributable between cluster variations) calculated as

$$ICC = \frac{\sigma 2}{(\sigma 2 + \pi 2/3)}$$ (20)

but MOR is quantifies the variation or heterogeneity in outcomes between clusters and is defined as the median value of the odds ratio between the cluster at high risk of anaemia and cluster at lower risk when randomly picking out two clusters (EAs).

$MOR = e^{(0.95 * \text{sqrt}(\text{Va})}$(21).

PCV measures the total variation attributed by individual-level factors and community-level factors in the multilevel model compared to the null model PCV. In the multivariable multilevel logistic regression analysis variables with a p-value of <0.05 were considered as statistically significant. Adjusted Odds Ratio (AOR) with their corresponding 95% confidence interval was determined to identify factors associated with anaemia. After comparing all models, a model with low deviance was considered a better model. Multicollinearity was checked using the Variance Inflation Factor (VIF). VIF less than 10% was taken as no multicollinearity.

Ethics and confidentiality

Ethical clearance was obtained from the ethical review board of the University of Gondar Institute of Public Health, CMHS. Permission for data access was obtained from the measure demographic and health survey through an online request by a written letter of objective and significance of the study from http://www.dhsprogram.com

Patient and public involvement

This study did not involve patients and the public

Results

Descriptive characteristics of the study population

A total of 21,302 children with known haemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anaemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively. The majority of the participants were in the age group of 36-47 (23%), 36-47 (24%), and, 12-23 (22%) in EDHS 2005, 2011, and 2016 survey respectively. The mean age of children was 32.57 ±15.6-SD, 32.6±15.4-SD, and 31.7±15.6-SD in 2005, 2011, and 2016 respectively. Among children involved in the analysis, male participants were high proportion in 2011 and 2016 EDHS compared to 2005 survey periods. The majority of children were from rural residency in five years preceding the survey in three surveys. About 78.6%, 70%, and 67% of women were unable to read and write in 2005, 2011, and 2016 survey respectively. Children from poor and middle-class families were more anaemic than children from rich families across the three EDHS survey (Table 1). During the study period, the trends in the prevalence of childhood anaemia in Ethiopia, were fluctuates across regions **(Fig.1)**.

Table 1: Descriptive characteristics of study participants included in the analysis for childhood anaemia in EDHS 2005,2011, and2016 in Ethiopia

Characteristics	2005 (N, 3868) Frequency (%)	2011(N, 8958) Frequency (%)	2016(N, 8476) Frequency (%)
Sex of child			
Male	1,931(49.93)	4,500(51.35)	4,395(51.85)
Female	1,937(50.07)	4,358(48.65)	4,081(48.15)
Children age (6-59) month			
6-11	418 (10.81)	1,029(11.48)	1,000(11.80)
12-23	842 (21.76)	1,804(20.14)	1,902(22.43)
24-35	825 (21.33)	1,895(21.16)	1,803(21.27)
36-47	919 (23.76)	2,184(24.37)	1,832(21.62)
48-59	864 (22.34)	2,047(22.85)	1,939(22.87)
Mean ± SD	**32.57 ±15.6**	**32.6±15.4**	**31.7±15.6**
Residence			
Urban	244 (6.31)	1,047(11.69)	857(10.12)
Rural	3,624 (93.69)	7,911(88.31)	7,619(89.88)
Religion			
Orthodox	1,624 (41.97)	3,416(38.13)	2,913(34.37)
Muslim	1,276 (32.99)	3,108(34.70)	3,432(40.48)
Protestant	836 (21.61)	2,151(24.01)	1,874(22.11)
Others	133 (3.43)	283(3.16)	258(3.05)

Women age			
15-29	1,930(49.90)	4,908(54.78)	4,356(51.40)
30-39	1,474(38.10)	3,223(35.98)	3,335(39.34)
40-49	464(12.00)	828(9.24)	785(9.26)
Women education			
No education	3,042 (78.63)	6,285(70.16)	5,685(67.07)
Primary	684 (17.68)	2,389(26.67)	2,275(26.84)
Secondary	136 (3.51)	168(1.88)	346(4.08)
Higher	7 (0.18)	117(1.30)	170(2.01)
Marital status			
Single	7(0.17)	50(0.56)	45(0.53)
Married	3,704(95.74)	8,425(94.04)	8,129(95.9)
Widowed	80(2.06)	178(1.99)	93(1.10)
Divorced	78(2.03)	306 (3.41)	210(2.48)
Husband education			
No-education	2,235 (58)	4,532(50.87)	4, 33(51.10)
Primary	1,233(32)	3,710(41.65)	3,273(38.62)
Secondary	362(9)	412(4.63)	572(6.75)
Higher education	31(0.81)	255 (2.86)	300(3.53)
Wealth index			
Poor	1,697(43.86)	4,048(45.19)	3,977(46.92)
Middle	854(22.07)	1,873(20.91)	1,821(21.48)
Rich	1,318(34.07)	3,038 (33.91)	2,678(31.60)
Women working status			
Not working	2,841(73.45)	5,793(64.67)	6,140(72.44)
Working	1,027(26.55)	3,165(35.33)	2,336(27.56)
Total	3,868(100)	8,958(100)	8,476(100)

Community-level characteristics of the study population

Findings from this study revealed a regional variation of childhood anaemia, with 83% in Somali, 75%, in Afar, 72% in Dire Dawa, and 67% in Harari. However, Amhara, and Benishangul with 43%, which was relatively low compared to other regions.

Childhood anaemia varies by urban-rural of residence. Children residing in communities with low poverty level had a lower percent of anaemia (51.2%) than high community poverty level (62.5%%). Children from low community women education level (59.5%) were more anaemic than children resided with high community women (53%) educational level (Table 2).

Table 2: Community Level Factors of under five children participated on EDHS (2016), Ethiopia. (N, 8476)

Background characteristics	Child anaemia status		
Community level factors	**Not-anaemic (%)**	**Anaemic (%)**	**Total (%)**
Residence			
Urban	435(50.6)	424(49.4)	857(100)
Rural	3164(41.5)	4455(58.5)	7619(100)
Region			
Amhara	950(57.5)	703(42.5)	1653(100)
Oromia	1273(34.2)	2446(65.8)	3719(100)
SNNP	875(49.1)	906(50.9)	1781(100)
Somali	58(16.7)	290(83.3)	348(100)
Tigray	263(46)	309(54)	572(100)
Addis Ababa	82(50.9)	79(49.1)	161(100)
Afar	21(25.3)	62(74.7)	83(100)
Benishangul	51(56.6)	39(43.4)	90(100)
Gambelia	8(42.1)	11(57.9)	19(100)
Harari	5(31.2)	11(68.8)	16(100)
Dire Dawa	9(28.1)	23(71.9)	32(100)
Community women education			
Low	2281(40.5)	3358(59.5)	5639(100)
High	1315(46.4)	1520(53.6)	2837(100)
Community women poverty			
Low	1815(48.8)	1905(51.2)	3719(100)
High	1782(37.5)	2974(62.5)	4756(100)

Total	8476(100)

Spatio-temporal distribution of anaemia among children age 6-59 months in Ethiopia

The spatial distribution of childhood anaemia in Ethiopia was non-random in all three consecutive surveys. . The global Moran's I test value was 0.176 (P-value <0.001) in 2005, 0.18 (P-value < 0.001) in 2011, and 0.09(P-value < 0.005) in 2016 Ethiopian Demographic and health surveys.

Hot spot analysis of the three surveys

The spatial distribution of childhood anaemia in Ethiopia was different in the three survey periods. In EDHS 2005, a high proportion of childhood anaemia was detected in Dire Dawa, Harari, Eastern Oromia, Benishangul in Metekel zone, Gambela, Southern and Eastern Tigray, and Somali region mainly Liben, Afdar, and Fafna zone which was hotspot area within 95% confidence level. On the counterpart, GamoGofa, Wolayita, Hadiya, Southern Omo, and Segen zone of SNNPR, Addis Ababa, central Oromia, Jima, North Shewa zone were cold spot area. In EDHS 2011, a highly significant clustering of childhood anaemia was detected in Somalia, Dire Dawa, Harari, Afar, Gambela, Benishangul, Eastern Oromia, Bale, Arsi zone were the hotspot areas within 95% level of confidence. The low hotspot area of childhood anaemia was detected in central Tigray, East and West Gojam, North Gondar, a central part of Oromia, Addis Ababa and SNNPR were areas identified as the low percentage of childhood anaemia in the 2011 EDHS survey.

In EDHS-2016 sampled data, hot spot (high risk) regions for childhood anaemia were observed in Somali, Dire Dawa, Harari, Gambela, Eastern, and Southern part of Oromia. However, Amhara, Benishangul, and Southern Nations Nationalities and Peoples (SNNP) were identified as cold spot (low risk) regions for childhood anaemia within a 95% confidence interval (**Fig.2**)

Spatial interpolation

Based on EDHS-2005 sampled data, the geostatistical analysis predicts that the highest prevalence of childhood anaemia (65.75%-88.89%) was detected in East Oromia, Ilubabur, Arsi, some parts of Benishangul, Agnuak zone in Gambela, North Shewa Amhara region, South and central Tigray Afar in zone2, some parts of Dire Dawa city and Somali. In EDHS-2011 Geostatistical analysis, a high percentage of anaemia was detected in Afar, most parts of Somalia, Oromia in East Harerge and Borena, some part of Dire Dawa, and the Meketel zone in Benishangul. In 2016 EDHS most of Somali, some parts of Gambela, Guji and some parts of Borena, East Shewa, East Harerge and Arsi in Oromia and part of Dire Dawa were highly prevalent areas in childhood anaemia **(Fig.3)**

Spatial scan statistics

In 2005 EDHS, a total of 3 significant clusters were identified, one most likely (primary) cluster and 2 were secondary clusters of spatial sat scan analysis. The primary cluster's spatial window was located in Somali, which was centered at (9.018373 N, 43.110635 E) of geographic location with a 97.93 km radius, and Log-Likelihood ratio (LLR) of 20.03, at $p < 0.001$ which was detected as the most likely cluster with Maximum Likelihood. It showed that children within the spatial window had 1.54 times more likely a higher risk of anaemia than the children outside the spatial window areas. The secondary clusters scanning window was located in the southern part of Somali region, which was centered at (3.998656 N, 41.240691 E) with a 92.08 km radius and LLR of 1.73 at p-value 0.0010. It showed that children within the spatial window had a 1.73 times higher risk of anaemia than children outside the window.

In 2011 EDHS, 10 clusters were identified and five of them were significant clusters with a p-value <0.05. A total of 180 locations/spots with a total sampled population of 2478 were found as primary cluster areas were identified using sat scan analysis with a p-value < 0.001. The primary cluster spatial window was located mainly in Somali, Afar, Eastern Oromia, Dire Dawa, and Harari. The primary cluster spatial window was centered at (8.975207 N, 43.790264 E) / 540.29 km, with a relative risk (RR) of 1.43 and a log-likelihood ratio (LLR) of 127.79. It showed that children within the spatial window had 1.4 times more likely a higher risk of anaemia than the children outside the spatial window areas. The secondary cluster spatial window was located mainly in Afar regional state. The secondary cluster spatial window was centered at (12.758587 N, 40.175990 E) / 39.58 km, with a relative risk (RR) of 1.68 and a log-likelihood ratio (LLR) of 21.5 P-value=0.001.

In 2016 EDHS, 7 clusters (1 most likely cluster) were located in Somali, Afar, Eastern Oromia, Dire Dawa, and Harari. The cluster window was centered with a radius at (7.650693 N, 47.007920 E) / 912.19 km with a Relative Risk (RR) of 1.44. The Log-Likelihood Ratio (LLR) for the most likely cluster was 182.86, p <0.001. Secondary clusters were located in Gambela which was centered at (8.195862 N, 34.289837 E) with a radius of 29.01 km, and LLR of 18.8 at p-value 0.001. It showed that children within the spatial window had a 1.5 times higher risk of anaemia than outside the window **(Fig.4)**.

Multilevel Analysis

The intra-cluster correlation coefficient (ICC) in the empty model indicated that 18.8% of the total variability for children anaemia was due to differences between clusters. The remaining unexplained 81.2% were attributable to individual differences. The median odds ratio for anaemia was 2.3 in the null model, indicating variation between clusters. If we randomly select children from two different clusters children at the cluster with a higher risk of anaemia had 2.3 times higher odds of experiencing anaemia than children at the cluster with a lower risk of anaemia.

Bi-variable multilevel logistic regression analysis was done to identify variables for multivariable multilevel logistic analysis, and variable with a p-value less than 0.2 were considered for multivariable analysis.

Individual-level predictors for anaemia

In multivariable multilevel mixed-effect logistic regression analysis, individual-level factors such as the age of the child, wealth index, mother age, maternal anaemic status, birth order, fever, stunting, and wasting status were significant predictor of childhood anaemia.

Children age between 12–23 months (AOR = 0.66, 95%CI = 0.53-0.81), between 24–35 months (AOR= 0.35, 95% CI = 0.28-0.43), between 36–47 months (AOR = 0.23-95%CI = 0.19-0.29), and between 48–59 months (AOR = 0.15, 95%CI = 0.12-0.19) were less likely to develop anaemia when compared with children age between 6–11 months.

The likelihood of developing anaemia for those children residing with the family wealth index of middle and rich was lower by 21% (AOR=0.79, 95%CI = 0.67-0.94), and 23% (AOR=0.77, 95%CI = 0.65-0.91), respectively as compared with children with low wealth index. Children whose mother's age were between 40-49 had 25% decreased odds of developing childhood anaemia compared to age 15-29, (AOR=0.75, 95%CI = 0.59-0.95).

The odds of experiencing anaemia for those birth orders 4-5, 6, and above six were 1.22 times (AOR=1.22, 95%CI = 1.01-1.47) and, 1.35 times (AOR=1.35, 95%CI = 1.08-1.67) higher as compared with first-order respectively. The odds of developing anaemia of children born from anaemia history mother were 1.39 higher more elevated than those born from not anaemic history before. Children who had fever were 39% (AOR =1.39, 95% CI: 1.24-1.58) more likely to develop anaemia than their counterparts. Children with moderate and severe stunting status were 35% (AOR=1.35, 95% CI: 1.17-1.54) and, 96% (AOR=1.95, 95% CI: 1.68-2.28), more likely to develop anaemia respectively as compared to no stunting status. Similarly, children who had to sever wasting status were 51% more (AOR =1.51, 95% CI: 1.07-2.12) likely to develop anaemia compared with those children who had no wasting.

Community-level predictors for anaemia

The multivariable multilevel logistic regression analysis region was significantly associated with community-level factors for childhood anaemia.

Odds of children live in Somali were 5.65 times (AOR=5.65, 95% CI: 3.92-8.16), Dire Dawa 3.45 times (AOR=3.45, 95% CI: 2.27-5.26), Afar 3.01 times (AOR=3.01, 95% CI: 2.09-4.34), and Oromia 2.34 times (AOR=2.34, 95% CI: 1.73-3.18) had more likely to develop childhood anaemia as compared to Amhara regional state. Similarly, the odds of developing anaemia in Addis Ababa were 2.10 times (AOR=2.10, 95% CI: 1.40-3.16), Gambella 1.94 times (AOR=1.94, 95% CI: 1.32-2.84), and Tigray 1.46 times (AOR=1.46, 95% CI: 1.08-1.98), more likely as compared to Amhara region. Benishangul and SNNPR had not significantly different in the prevalence of anaemia than the reference region Amhara (Table 3).

Table 3: Multilevel logistic regression analysis result of both individual and community level factors associated with anaemia in Ethiopia, EDHS 2016

Individual Level	Null Model	Model I AOR (95% CI)	Model II AOR (95% CI)	Model III AOR (95% CI)
Children age (6-59) month				
6 – 11	--	1		1
12 – 23		0.66[0.54-0.82] **		0.66 [0.53-0.81] **
24 – 35		0.35[0.28-0.44] **		0.35 [0.28-0.43] **
36 – 47		0.23[0.18-0.28] **		0.23 [0.19-0.29] **
48 – 59	--	0. 15[0.12-0.19] **	---	0.15 [0.12-0.19] **
Religion				
Orthodox		1		1
Muslim		2.07[1.77-2.47] **		1.21 [0.97-1.46]
Protestant		1.20 [1.002-1.48] *		1.09[0.86-1.37]

Others	--	1.55[1.07-2.32] *	---	1.44[0.96-2.13]
Wealth index				
Poor		1		1
Middle		0.71[0.61-0.84] **		0.79 [0.67-0.94] *
Rich	--	0.72[0.63-0.85] **	---	0.77 [0.65-0.91] *
Child size at birth				
Small		1		1
Average		0.96[0.84-1.09]		0.93 [0.80-1.07]
Large	--	0.94[0.81-1.08]	---	0.96 [0.84-1.10]
Birth order				
1st		1		1
2-3		1.09[0.94-1.28]		1.13[0.97-1.32]
4-5		1.17[0.97-1.40]		1.22 [1.01-1.47] *
6 and above	--	1.30[1.05-1.62]	---	1.35 [1.08-1.67] **
No of children under 5				
1-2 children		1		1
≥ 3 children	--	1.22[1.1-1.4] *	---	1.09 [0.94-1.27]
Maternal anemia				
Not-anemic		1		1
Anemic	--	1.51[1.34, 1.72] **	---	1.39 [1.24-1.58] **
Maternal BMI				
≥18.5 kg/m2		1		1
<18.5 kg/m2	--	1.12[0.97-1.26]	---	1.05 [0.92-1.19]
Mother's working status				
Not-working		1		1
Working	--	0.88[0.77-0.99] *	---	0.92 [0.81-1.04]
Women age				
15-29		1		1
30-39		0.91[0.71-1.06]		0.90 [0.78-1.04]
40-49	--	0.75[0.59-1.12] *	---	0.75 [0.59-0.95] *
Breastfeeding				
No		1		1
Yes	--	0.92[0.81-1.04]	---	0.98 [0.87-1.12]
Vitamins in last 6 month				
No		1		1
Yes	---	0.90[0.81-1.09]	---	0.93 [0.84-1.05]
Diarrhea last 2 week				
No		1		1
Yes	---	0.88[0.73, 1.04]	---	0.90 [0.76-1.07]
Fever in last 2 weeks				
No		1		1
Yes	---	1.35[1.15-1.59] **	---	1.32 [1.13-1.56] *
Stunting status				
No-stunting		1		
Moderate stunting		1.27[1.10-1.46] **		1.35 [1.17-1.54] **
Severely stunting	---	1.81[1.55-2.11] **	---	1.96 [1.68-2.28] **
Wasting status				

No-wasting		1		
Moderate wasting		1.27[1.11-1.45]		0.98 [0.80-1.19]
Severe wasting	---	1.68[1.55-2.10] *	---	1.51 [1.07-2.12] *
Place of residence				
Urban			1	1
Rural	--	--	1.40[1.12-1.78]	1.28 [0.99-1.64]
Region				
Amhara		--	1	1
Tigray			1.46 [1.09-1.97] **	1.46 [1.08-1.98] **
Afar			3.90 [2.84-5.35] **	3.01 [2.09-4.34] **
Oromia			2.48 [1.89-3.25] **	2.34 [1.73-3.18] **
Somali			6.34[4.65-8.63]	5.65 [3.92-8.16] **
Benishangul			0.86 [0.62-1.17]	0.81 [0.58-1.15]
SNNPR			1.33 [1.00-1.76]	1.30 [0.94-1.80]
Gambela			1.93 [1.38-2.69] **	1.94 [1.32-2.84] **
Hareri			3.08 [2.15-4.43] **	2.98 [1.99-4.46] **
Addis Ababa			1.91[1.29-2.83] **	2.10 [1.40-3.16] **
Dire Dawa	--	--	3.92 [2.67-5.77] **	3.45 [2.27-5.26] **
Community education				
Low education			1	1
High education	--	--	1.07[0.90-1.26]	1.13[0.94-1.34]
Community poverty				
Low poverty			1	1
High poverty	--	--	1.41[1.17-1.68] *	1.15[0.94-1.40]
Model comparison and Random effect				
ICC	0.187	--	--	--
Log-likelihood	-4981.63	-4513.17	-4836.83	-4436.60
Deviance	9963.26	9026.34	9673.66	8873.2
PVC (%)	Ref	41.22	60.11	62.59
MOR	2.30	1.72	1.42	1.38

*__Key: 1: reference group; p-value 0.05-0.01 *: p-value < 0.01 **__

Multicollinearity

Multicollinearity was checked for those variables included in the final model using VIF. Accordingly, the VIF for all predictor variables included in the final model was below 10 indicating the absence of multicollinearity among the predictor variables.

Comparison of models

560 Deviance was used to compare the models, and the lowest value of deviance (Model III) was considered the better mode.

562 ## Discussion

563 This study tried to identify spatio-temporal distribution and predictors of childhood anaemia across the regions in Ethiopia. 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used. In this study, anaemia's trend was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL: 0.56-0.59] of children were anaemic in 2016, preceding the survey. This finding was in line with a study done in Gondar, Northwest Ethiopia 58.6%(22), whereas higher than the study done in cape Verde, west Africa 51.8%(23), and southern Ethiopia(24). Among children of 6–59 months, anaemia is still considered a significant public health problem in Ethiopia. Though the levels of anaemia among children vary by background factors like region and lowest household wealth index and maternal related factors, more of the children in Ethiopia were suffering anaemia.

574 The spatial pattern shows the geographical inequality of anaemia by using sat scan and GIS spatial techniques like cluster mapping tools and interpolation techniques. The spatial analysis indicates that the distribution of childhood anaemia was non-random across the country with a global Moran's I index of 0.176 in 2005, 0.18 in 2011, and 0.09 in 2016 with a significant p-value, which indicates substantial-considerable clustering areas. This study's findings were in line with a study done in Nigeria, Malawi, Tanzania, and Uganda (25,26).

580 The spatial pattern of sat scan analysis showed that Eastern Somali regions were primary (most likely) cluster and secondary cluster also located in the southern part of Somali in 2005 sat scan analysis. In 2011 Somali, Afar, Eastern Oromia, Dire Dawa, and Harari were located in the primary window and centered at (8.975207 N, 43.790264 E/ 540.29 km with a

significant p-value. Similarly, spatial sat scan analysis showed that Somali, Afar, Eastern Oromia, Dire Dawa, Harari were hotspot areas in the 2016 EDHS spatial analysis. In addition, this study revealed that eastern parts of the country had similar spatiotemporal trend over the study periods. It might be, which are less developed compared with other Ethiopian states in terms of economy, gender, healthcare facility and food availability(27).

This study indicated that children age 12-59 months were less affected by childhood anaemia. This finding was consistent with studies conducted in Ethiopia and Togo (28–30). This could be explained by the fact that children who are getting older receive a richer and complete diet, with a sufficient intake of iron which could prevent the occurrence of iron deficiency anaemia. The deficiency may result from inadequate dietary intake of iron, malabsorption of iron an increased iron demand during rapid growth might it be the possible reason (31).

The finding of this study indicated that children whose mother's age was between 40-49 were less anaemic as compared to age 15-29. This finding is a study done in line with other studies conducted in sub-Saharan Africa and Ghana (15,32). This group consists of more at-risk population segments (Adolescent) for anaemia. They are vulnerable to malnutrition because they are growing faster than at any time after their first year of life which contributes to the intergenerational cycle of malnutrition and he most common forms of malnutrition among Ethiopian adolescent girls is iron deficiency anaemia. Aside from, growing adolescent mother and her baby's bodies may compete for nutrients, raising the infant's risk of low birth weight; however, the lack of such nutrients might lead to anaemia.

Children from households of middle and rich wealth indexes were less affected by childhood anaemia as compared to children from a poor household. This finding has also been demonstrated in similar studies in Nigeria and northern Ethiopia (25,33). This is due to the reason that children from poor households are less likely to get iron-rich foods like animal foods and vitamin-rich foods especially vitamins A and C which are very important for iron absorption.

Maternal anaemia was highly associated with the occurrence of childhood anaemia. This finding was in line with a study done in South Africa, Haiti, and India(34–36). Reasons may be mothers and children share a common home environment, socioeconomic, and dietary conditions, and maternal and child anaemia may reflect the household's common nutritional status, and poor maternal iron intake during pregnancy, reduce breast milk might be the possible reason.

EDHS data set indicated that the incidence of fever had an impact on childhood anaemia. This is in line with studies done in Ghana and South Ethiopia Wolaita (24,37) Results showed that children who had a fever in the last two weeks before the survey had had a higher likelihood of anaemia than children who had not to fever. This could be attributed to the infectious cause of childhood fever mainly malaria, tuberculosis, and Leishmaniasis which cause anaemia by destructing red blood cells or other related mechanisms.

The nutritional status of children had a significant association with childhood anaemia. The stunting status of children was an independent predictor in the multilevel mixed effect model of this study. The result of this study indicated that it was in line with previous studies conducted in South Africa(36), Bangladesh(38,39), and Ethiopia(40,41). This study revealed that there was a greater prevalence of anaemia among stunted children compared to non-stunted children. Children suffering from nutritional deficiency were more likely to have weak immune systems, making them vulnerable to various illnesses and healthiness such as parasitic infections or chronic inflammation. Many of these conditions reduce the haemoglobin level in the blood leading to increased anaemia prevalence. The statement is supported by the evidence given in other studies(42)that nutritional deficiency causes several health hazards.

Besides, severely wasting children were more likely to be anaemic than their counterpart. Since stunting and wasting are long-term and short-term indicators of malnutrition, the results implied that under-nourished children experience a higher risk of developing anaemia than nourished children. Odds of experiencing anaemia for those birth order four up to five and six and greater than six were higher than those of the first order. This finding was similar to a study done in Indian(15,43). This could be due to the distribution of scarce resources within the family and related to the maternal exhaustion of micronutrient feeding practices.

In a multivariable multilevel analysis, the odds of developing childhood anaemia were higher among children who lived in Somali, Dire Dawa, Afar, and Gambela compared to the Amhara region. This might be due to the unavailability and inaccessibility of health facilities as compared to the regions. Regional variation in the nutrient intake can cause significant health disparity, and this variability may be mediated by factors such as food availability, food customs, and culture.

This study, used different spatial pattern, trends, and a multilevel regression model because of nested or cluster samples to show the effect of individual predictors and community-level variables on the dependent variable. The study was based on a large dataset representing the whole country of Ethiopia and which was weighted to make it nationally representative and adjusted for the design to get a reliable estimate. However, there were some limitations to this study. The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables. Also, respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the overall result and the generalizability of the findings.

Conclusion

This study indicated that the prevalence of childhood anaemia decreased between the 2005-2011 survey while the prevalence increased from 2011-2016 EDHS. The spatial pattern of child anaemia in Ethiopia was non-random among the three consecutive surveys with the global Moran's I value of 0.176, 0.18, and 0.09 in EDHS 2005, 2011, and 2016. In this study, Sat Scan analysis identified the primary and secondary clusters for the three survey periods. In 2005 EDHS, the hotspot area was identified in eastern and southern parts of Somalia, in 2011, Somali, Afar, Eastern Oromia, Dire Dawa, and Harari were among the hotspot regions. Spatial sat scan analysis revealed that spatial clustering of childhood anaemia was identified in Somali, Afar, Eastern Oromia, Dire Dawa, Harari hotspot area in the 2016 EDHS period.

Child age, women age, wealth index, maternal anaemia, fever, birth order, stunting, wasting and region were significant predictors among 6-59 months. Therefore, these results provide further insight into identifying the true picture of childhood anaemia spatio-temporal clusters and enable timely spatial targeting factors to alleviate childhood anaemia. Therefore, policymakers and health planners should design effective intervention strategies for the identified hot spot areas and individual and community-level factors.

Abbreviations

AOR-Adjusted Odds Ratio, CSA-Central Statics Agency, CI-Confidence Interval, COR-Crude Odds Ratio, EDHS-Ethiopia Demographic and Health Survey, GPS-Global Positioning System, ICC-Intra Class Correlation Coefficient, LLR-Log-Likelihood Ratio, MOR-Median odds ratio, OR-Odds Ratio, RR-Relative Risk, PVC-Proportional Change in Variance, SNNPR- Southern Nations, Nationalities, and Peoples' Region.

Declarations

Onset to participate

The institutional ethical review committee board approved the study. Ethical clearance was obtained from ethical review board of the University of Gondar. Upon this clearance, the study was conducted. The congeniality of the data was maintained by using the extracted data only for the study purpose and keeping the data from a third party.

Consent for publication

Not-applicable

Data sharing statement

The data in which the authors used to produce this manuscript are available upon reasonable request

Competing interests

The authors declare that they have no competing interests.

Funding

No funding

Contributors

Proposal preparation, acquisition of data, analysis, and interpretation of data was done by SH, AM, ZM and BF guided the study design data collection and analysis. SH drafted the manuscript and all authors have a substantial contribution in revising and finalizing the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors gratefully acknowledge the support received from the University of Gondar. We also thank the Ethiopian Central Statistics Agency for providing us with the data and shape files for this study.

References

1. WHO. Nutritional Anaemias : Tools for Effective Prevention. World Health Organization. 2017. 1–83 p.
2. WHO. Global estimates of the prevalence of anaemia in infants and children aged 6 – 59 months , 2011 Global estimates of the prevalence of anaemia , all women of reproductive age , 15 – 49 years , 2011. Scaling Up Nutr [Internet]. 2015; Available from: http://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011_maps.pdf?ua=1
3. WHO. The global prevalence of anaemia in 2011. Who [Internet]. 2011;1–48. Available from: https://apps.who.int?iris/hendle/10665/177094
4. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005. Public Health Nutr. 2009;12(4):444–54.
5. Malkanthi RLDK, Silva KDRR, Jayasinghe-Mudalige UK. Risk Factors Associated with High Prevalence of Anemia among Children under 5 Years of Age in Paddy-Farming Households in Sri Lanka. Food Nutr Bull. 2010;31(4):475–82.
6. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993-2005. Public Health Nutr. 2009;12(4):444–54.
7. Leal LP, Batista Filho M, de Lira PIC, Figueiroa JN, Osório MM. Temporal trends and anaemia-associated factors in 6- to 59-month-old children in Northeast Brazil. Public Health Nutr. 2012;15(9):1645–52.
8. Olivares M, Walter T, Hertrampf E, Pizarro F. Anaemia and iron deficiency disease in children. Br Med Bull [Internet]. 1999 Sep 1;55(3):534–43. Available from: https://doi.org/10.1258/0007142991902600
9. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: a cross-sectional study. BMJ Open [Internet]. 2018 May 1;8(5):e019654. Available from: http://bmjopen.bmj.com/content/8/5/e019654.abstract
10. Central Statistical Agency, ORC Macro. Ethiopia Demographic and Health Survey 2005. Heal San Fr [Internet]. 2006;(September):[446]. Available from: http://www.measuredhs.com/pubs/pdf/FR179/FR179[23June2011].pdf
11. Central Statistical Agency [Ethiopia], ICF International. Ethiopia Demographic and Health Survey 2011. 2012;1–452.
12. ECSA. Ethiopian Demographic Health Survey 2016. 2016. 161 p.
13. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health. 2019;19(1):1–9.
14. Malako BG, Teshome MS, Belachew T. Anemia and associated factors among children aged 6-23 months in Damot Sore District, Wolaita Zone, South Ethiopia. BMC Hematol. 2018;18(1):1–9.
15. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: A cross-sectional study. BMJ Open. 2018;8(5):1–14.
16. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in nigeria: A bayesian semi-parametric modelling. Int Health. 2014;6(1):35–45.
17. Desalegn A, Mossie A, Gedefaw L. Nutritional Iron Deficiency Anemia: Magnitude and

Its Predictors among School Age Children, Southwest Ethiopia: A Community Based Cross-Sectional Study. PLoS One [Internet]. 2014 Dec 1;9(12):e114059. Available from: https://doi.org/10.1371/journal.pone.0114059

18. Guerra CA, Snow RW, Hay SI. Defining the global spatial limits of malaria transmission in 2005. Adv Parasitol. 2006;62:157–79.
19. Kulldorff M. SatScan user guide 2006. 2018;
20. Bartko JJ. The Intraclass Correlation Coefficient as a Measure of Reliability. Psychol Rep. 1966 Aug;19(1):3–11.
21. Assessment IS. Understanding Variability in Multilevel Models Sophia Rabe-Hesketh Example : PISA (Programme for International Student Assessment) PISA : Distribution of SES.
22. Enawgaw B, Workineh Y, Tadesse S, Mekuria E, Addisu A, Genetu M. Prevalence of anemia and associated factors among hospitalized children attending the University of Gondar Hospital, Northwest Ethiopia. Electron J Int Fed Clin Chem Lab Med. 2019;30(1):35–47.
23. Semedo RML, Santos MMAS, Baião MR, Luiz RR, Da Veiga G V. Prevalence of Anaemia and Associated Factors among Children below Five Years of Age in Cape Verde, West Africa. J Heal Popul Nutr. 2014;32(4):646–57.
24. Tiku YS, Mekonnen TC, Workie SB, Amare E. Does Anaemia Have Major Public Health Importance in Children Aged 6–59 Months in the Duggina Fanigo District of Wolaita Zone, Southern Ethiopia? Ann Nutr Metab [Internet]. 2018;72(1):3–11. Available from: https://www.karger.com/DOI/10.1159/000484324
25. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in Nigeria: a Bayesian semi-parametric modelling. Int Health [Internet]. 2014 Jan 31;6(1):35–45. Available from: https://doi.org/10.1093/inthealth/iht034
26. Roberts DJ, Matthews G, Snow RW, Zewotir T, Sartorius B. Investigating the spatial variation and risk factors of childhood anaemia in four sub-Saharan African countries. BMC Public Health. 2020;20(1):126.
27. Diao X, Taffesse AS, Thurlow J, Pratt AN, Yu B, Orkin K, et al. NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Highlights of Presentations Summer – Fall 2010 : h NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Capacity Building Initiatives 2010 : 2010;(December).
28. Gebreweld A, Ali N, Ali R, Fisha T. Prevalence of anemia and its associated factors among children under five years of age attending at Guguftu health center, South Wollo, Northeast Ethiopia. PLoS One [Internet]. 2019 Jul 5;14(7):e0218961. Available from: https://doi.org/10.1371/journal.pone.0218961
29. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health [Internet]. 2019;19(1):215. Available from: https://doi.org/10.1186/s12889-019-6547-1
30. Mohammed SH, Habtewold TD, Esmaillzadeh A. Household, maternal, and child related determinants of hemoglobin levels of Ethiopian children: Hierarchical regression analysis. BMC Pediatr. 2019;19(1):1–10.
31. Keikhaei B, Zandian K, Ghasemi A, Tabibi R. Iron-Deficiency Anemia among Children in Southwest Iran. Food Nutr Bull. 2007 Dec;28(4):406–11.
32. Campbell JR, Holland J. Development research. Focaal. 2007;2005(45):3–17.
33. Gebreegziabiher G, Etana B, Niggusie D. Determinants of Anemia among Children Aged 6–59 Months Living in Kilte Awulaelo Woreda, Northern Ethiopia. Benz EJ,

editor. Anemia [Internet]. 2014;2014:245870. Available from: https://doi.org/10.1155/2014/245870
34. Ayoya MA, Ngnie-Teta I, Séraphin MN, Mamadoultaibou A, Boldon E, Saint-Fleur JE, et al. Prevalence and risk factors of anemia among children 6-59 months old in Haiti. Anemia. 2013;2013:2–5.
35. Pasricha SR, Black J, Muthayya S, Shet A, Bhat V, Nagaraj S, et al. Determinants of anemia among young children in rural India. Pediatrics. 2010;126(1).
36. Ntenda PAM, Nkoka O, Bass P, Senghore T. Maternal anemia is a potential risk factor for anemia in children aged 6–59 months in Southern Africa: a multilevel analysis. BMC Public Health [Internet]. 2018;18(1):650. Available from: https://doi.org/10.1186/s12889-018-5568-5
37. Shenton LM, Jones AD, Wilson ML. Factors Associated with Anemia Status Among Children Aged 6–59 months in Ghana, 2003–2014. Matern Child Health J. 2020;24(4):483–502.
38. Khan JR, Awan N, Misu F. Determinants of anemia among 6–59 months aged children in Bangladesh: evidence from nationally representative data. BMC Pediatr [Internet]. 2016;16(1):3. Available from: https://doi.org/10.1186/s12887-015-0536-z
39. Rahman MS, Mushfiquee M, Masud MS, Howlader T. Association between malnutrition and anemia in under-five children and women of reproductive age: Evidence from Bangladesh Demographic and Health Survey 2011. PLoS One. 2019 Jul;14(7):e0219170–e0219170.
40. Belachew A, Tewabe T. Under-five anemia and its associated factors with dietary diversity, food security, stunted, and deworming in Ethiopia: systematic review and meta-analysis. Syst Rev. 2020 Feb;9(1):31.
41. Malako BG, Asamoah BO, Tadesse M, Hussen R, Gebre MT. Stunting and anemia among children 6–23 months old in Damot Sore district, Southern Ethiopia. BMC Nutr. 2019;5(1):1–11.
42. Pelletier DL, Frongillo Jr EA, Schroeder DG, Habicht JP. The effects of malnutrition on child mortality in developing countries. Bull World Health Organ. 1995;73(4):443–8.
43. Goswmai S, Das KK. Socio-economic and demographic determinants of childhood anemia. J Pediatr (Rio J). 2015;91(5):471–7.

Figure legend/caption

Figure 1: Trends in anemia overtime across the regions in Ethiopia, EDHS 2005 to 2016

Figure 2: Hot spot and cold spot analysis of anemia in Ethiopian, EDHS 2005 to 20016

Figure 3: Ordinary Kriging interpolation of anemia in Ethiopia, EDHS 2005 to 2016

Figure 4: SaTScan scan statistics analysis of anemia in Ethiopia, EDHS, 2005-2016

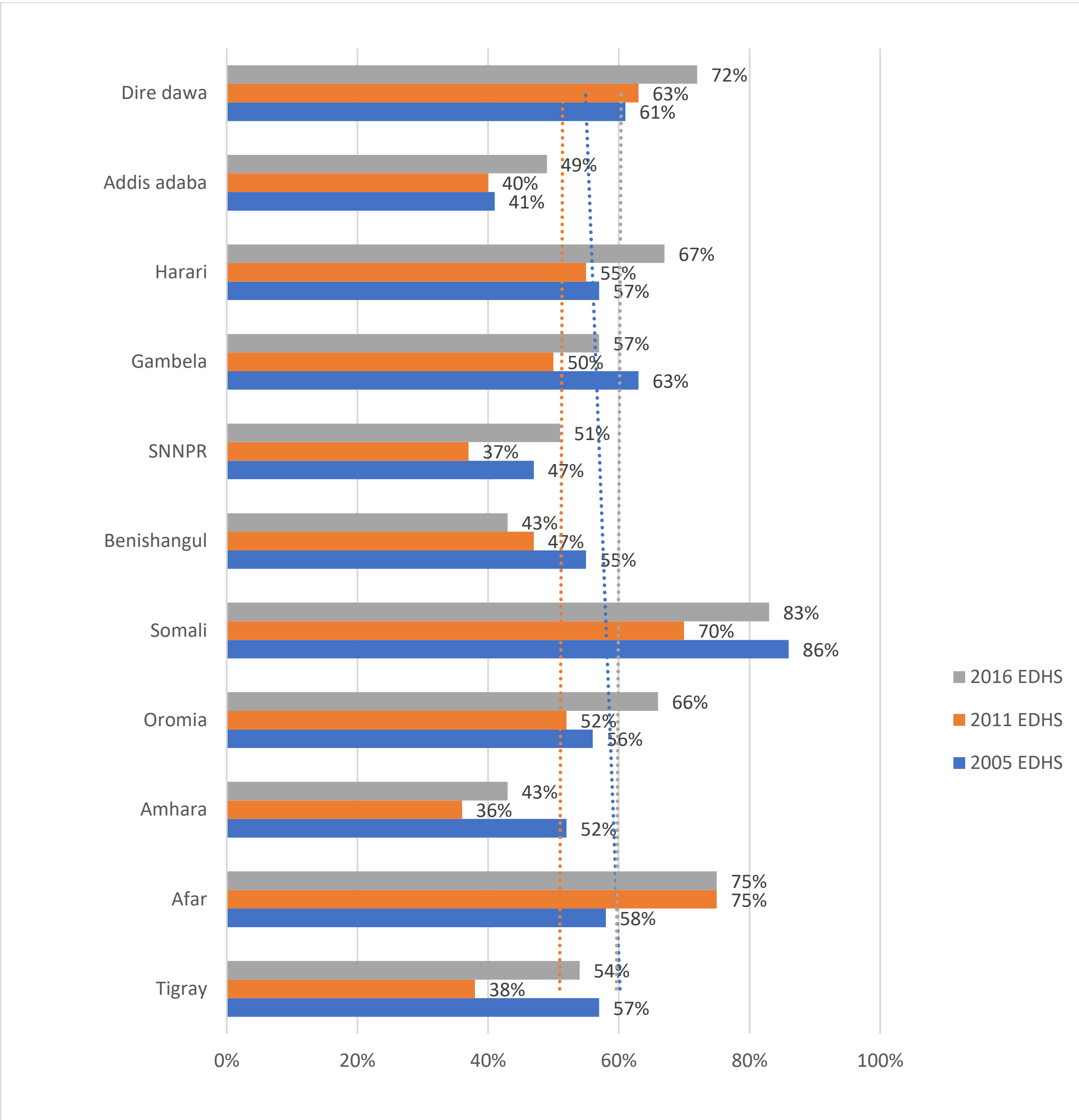
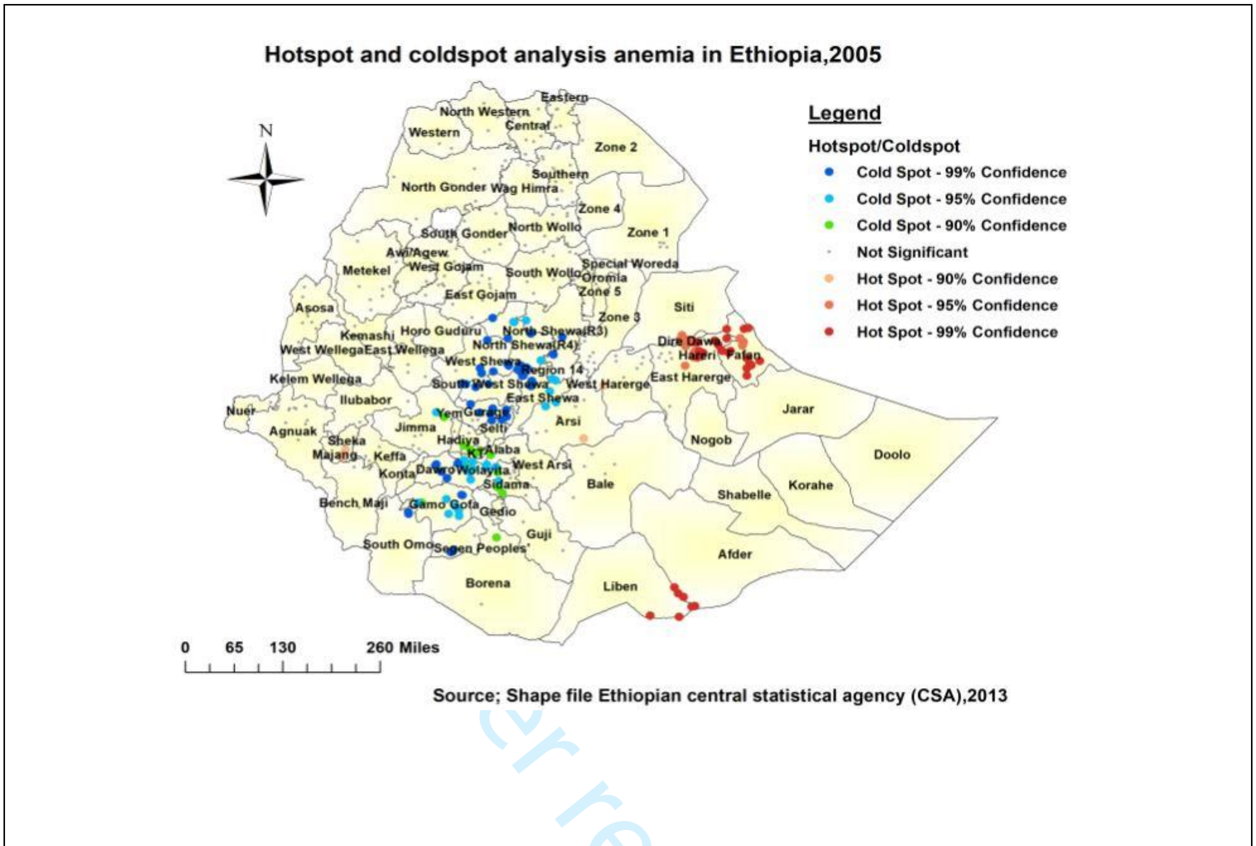
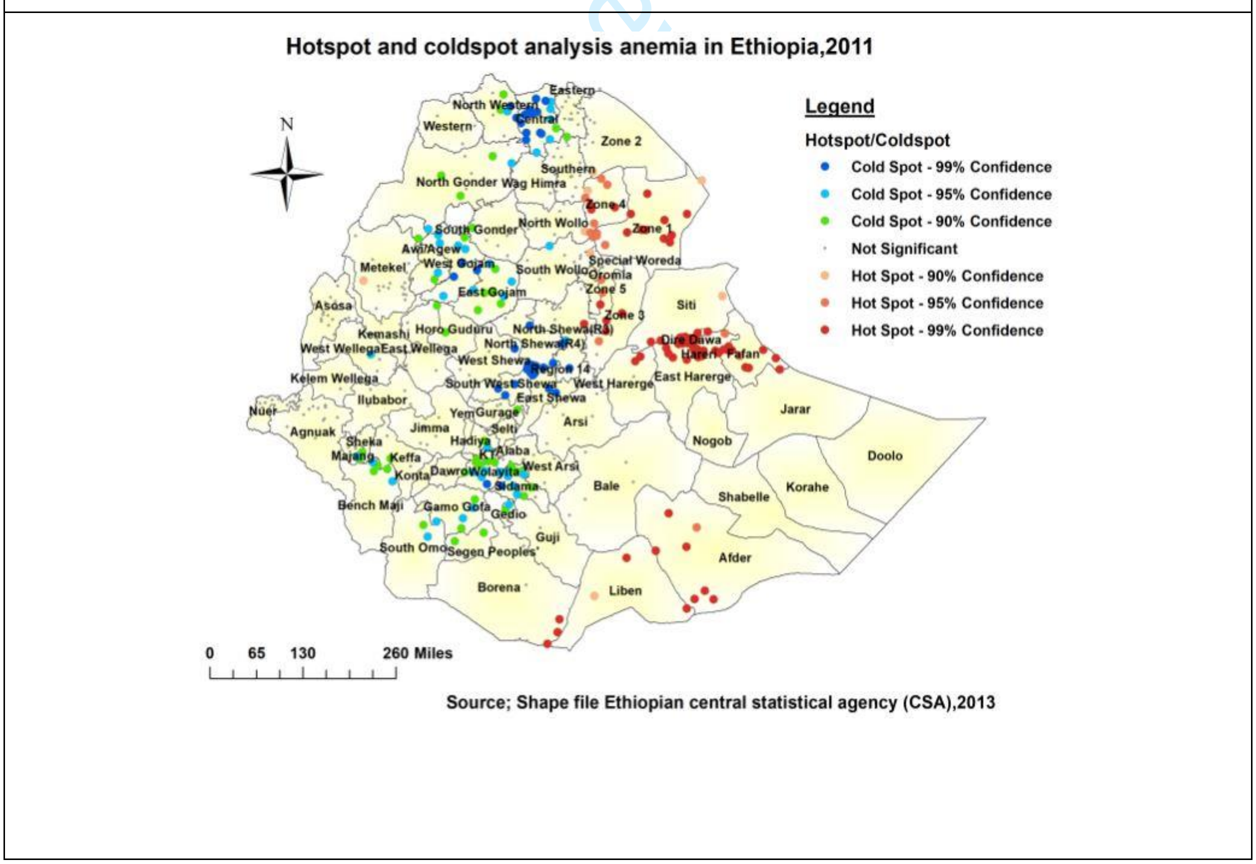


Figure 1: Trends in anemia overtime across the regions in Ethiopia, EDHS 2005 to 2016


Hotspot and coldspot analysis anemia in Ethiopia,2005
N
Legend
Hotspot/Coldspot
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
0 65 130 260 Miles
Source; Shape file Ethiopian central statistical agency (CSA),2013


Hotspot and coldspot analysis anemia in Ethiopia,2011
N
Legend
Hotspot/Coldspot
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
0 65 130 260 Miles
Source; Shape file Ethiopian central statistical agency (CSA),2013

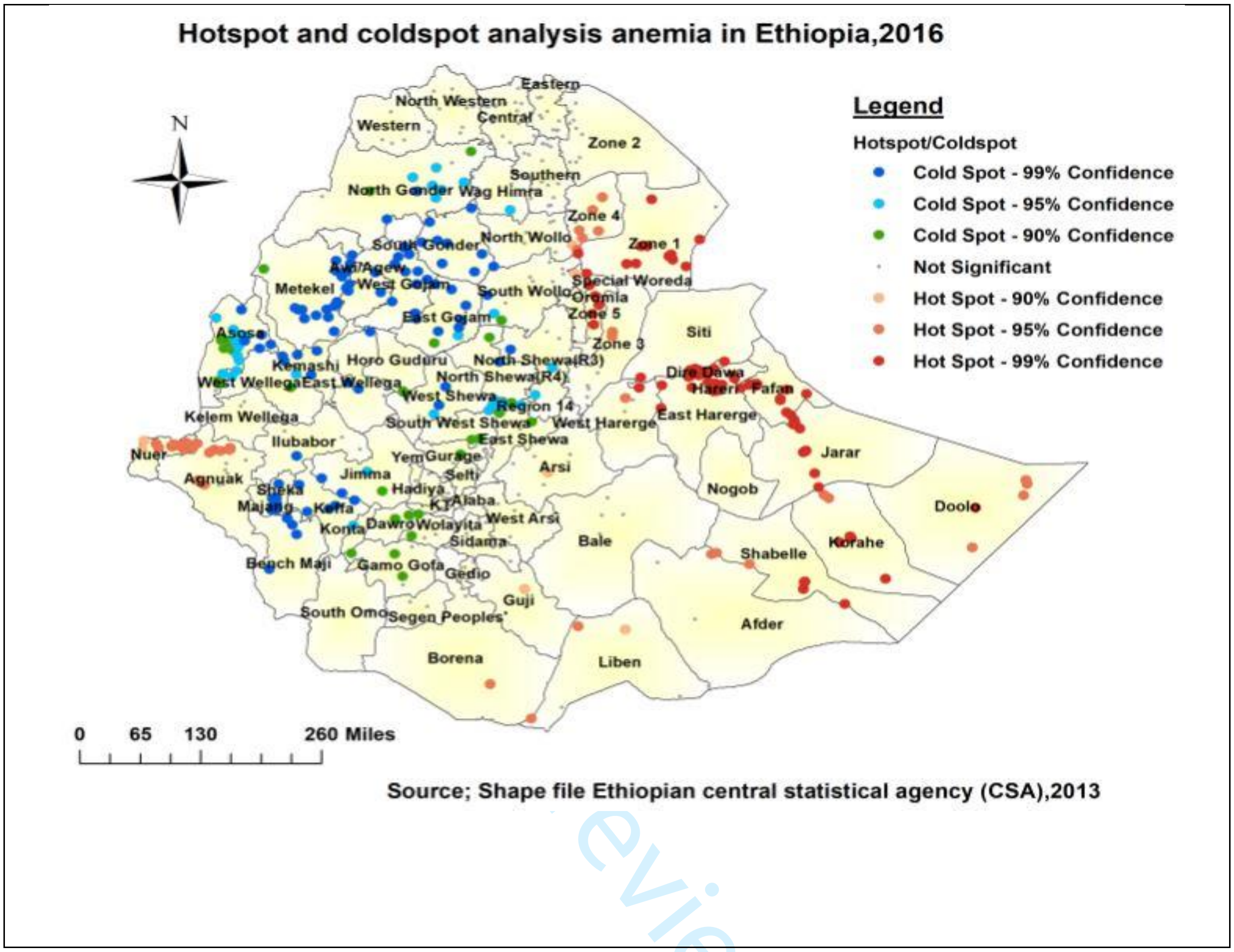
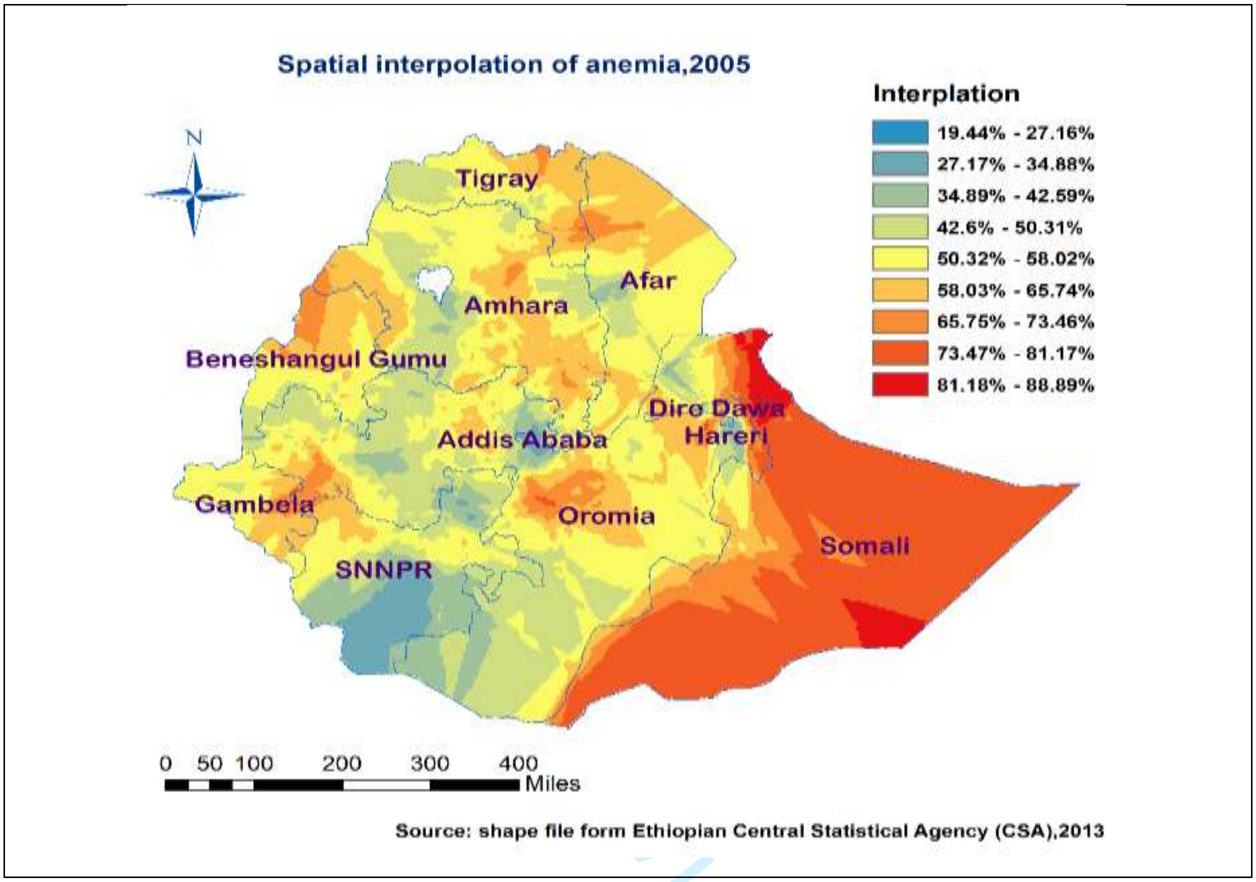
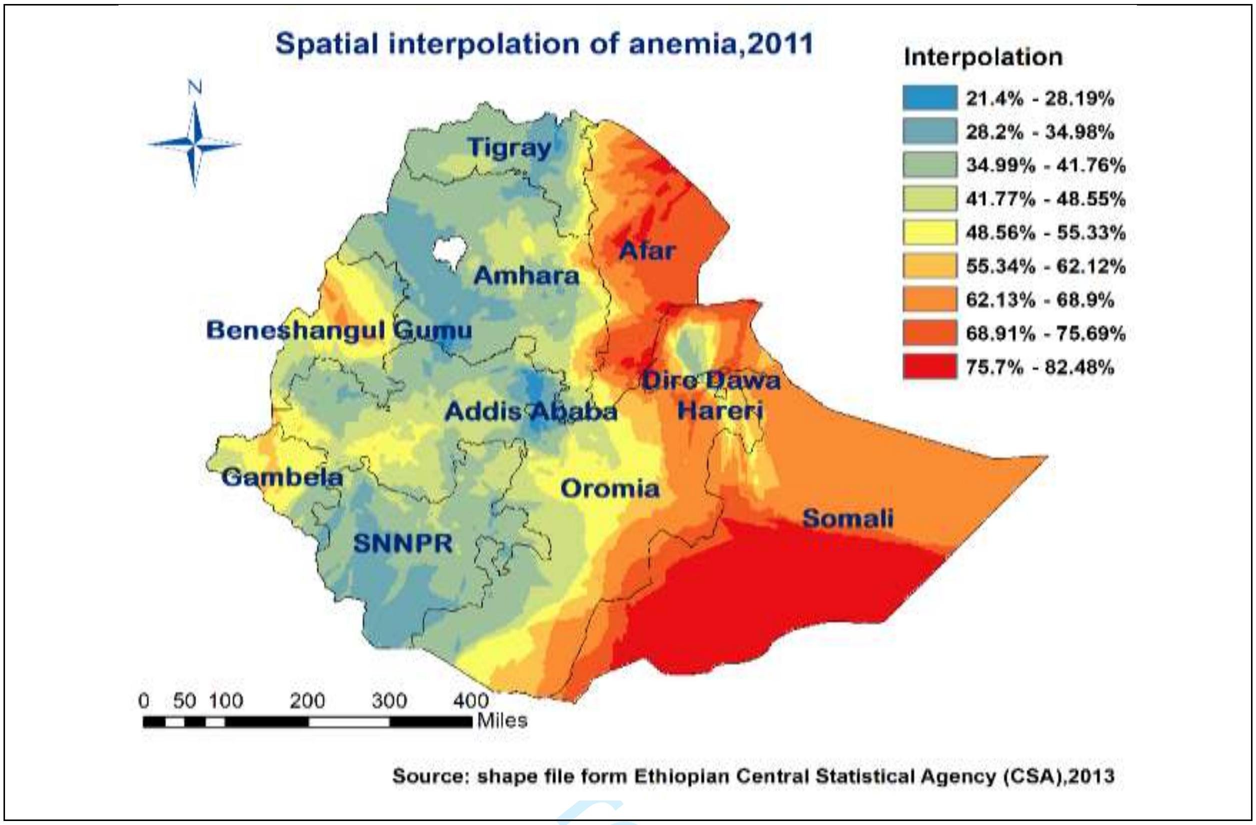


Figure 2: Hot spot and cold spot analysis of anemia in Ethiopian, EDHS 2005 to 20016


Spatial interpolation of anemia,2005
Interplation
19.44% - 27.16%
27.17% - 34.88%
34.89% - 42.59%
42.6% - 50.31%
50.32% - 58.02%
58.03% - 65.74%
65.75% - 73.46%
73.47% - 81.17%
81.18% - 88.89%
N
Tigray
Afar
Amhara
Beneshangul Gumu
Diro Dawa
Hareri
Addis Ababa
Gambela
Oromia
Somali
SNNPR
0 50 100 200 300 400
Miles
Source: shape file form Ethiopian Central Statistical Agency (CSA),2013


Spatial interpolation of anemia,2011
Interpolation
21.4% - 28.19%
28.2% - 34.98%
34.99% - 41.76%
41.77% - 48.55%
48.56% - 55.33%
55.34% - 62.12%
62.13% - 68.9%
68.91% - 75.69%
75.7% - 82.48%
N
Tigray
Afar
Amhara
Beneshangul Gumu
Dire Dawa
Hareri
Addis Ababa
Gambela
Oromia
Somali
SNNPR
0 50 100 200 300 400
Miles
Source: shape file form Ethiopian Central Statistical Agency (CSA),2013

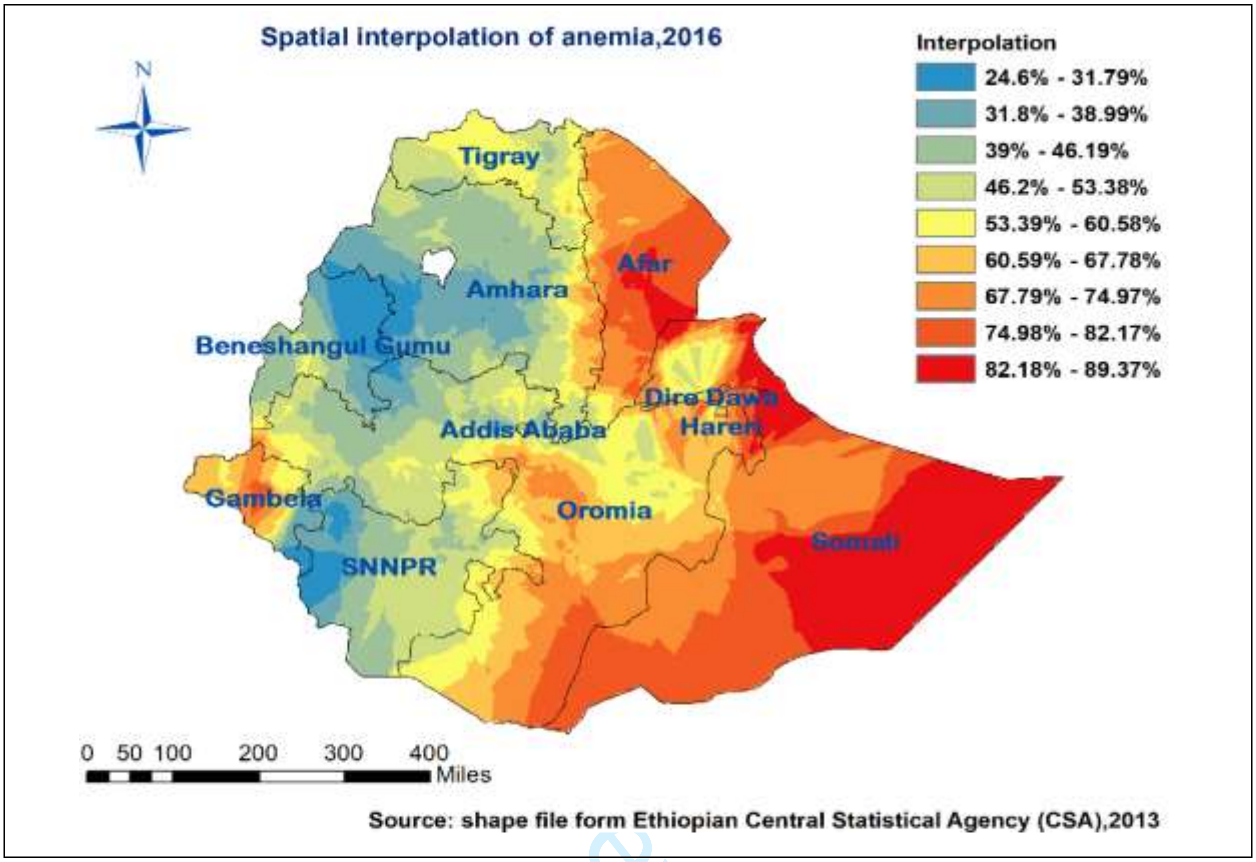
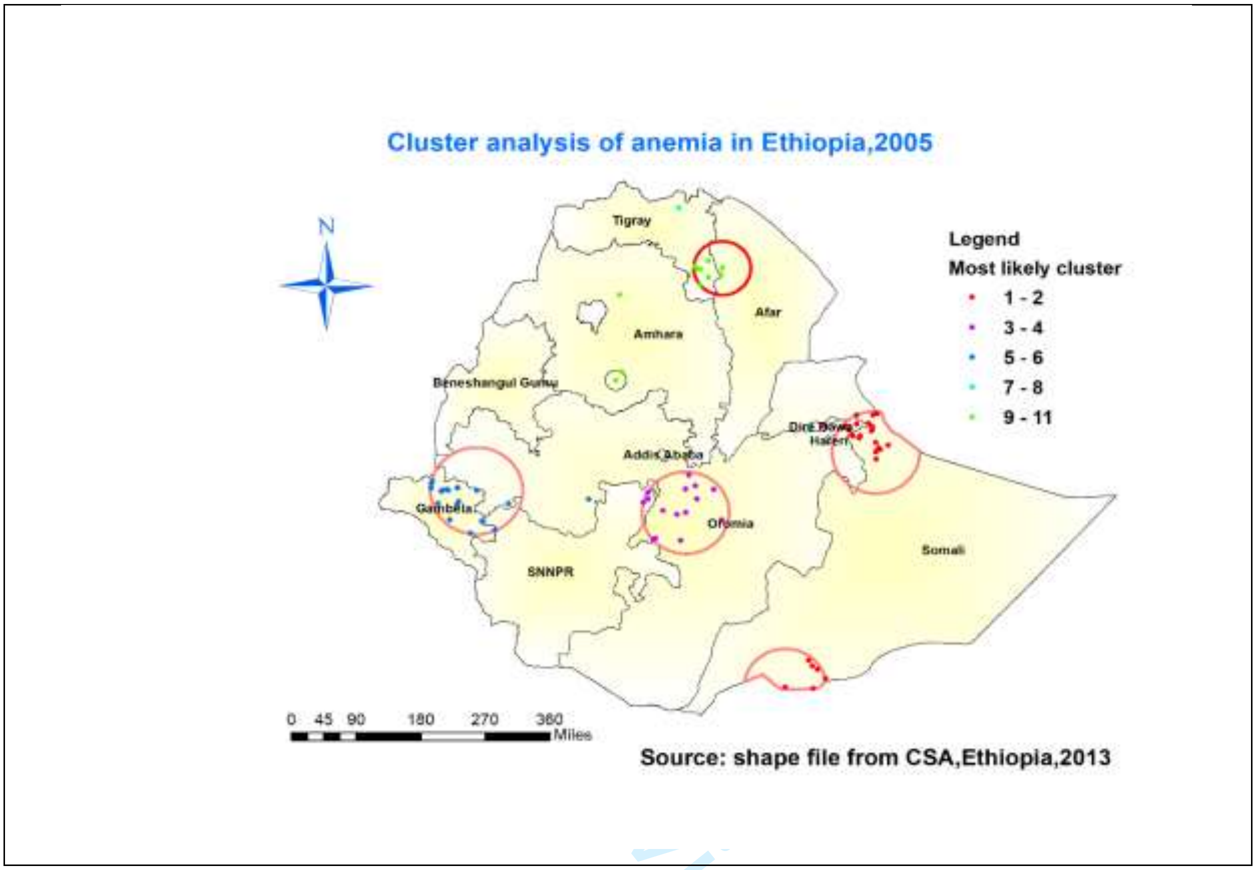
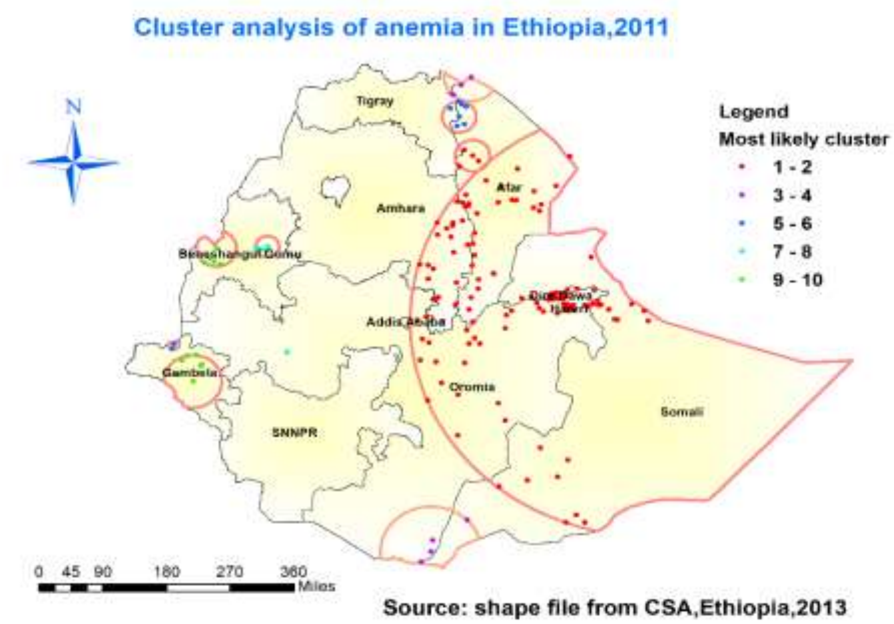


Figure 3: Ordinary Kriging interpolation of anemia in Ethiopia, EDHS 2005 to 2016


Cluster analysis of anemia in Ethiopia,2005
N
Tigray
Afar
Amhara
Beneshangul Gumu
Addis Ababa
Dire Dawa
Hareri
Gambela
Oromia
SNNPR
Somali
Legend
Most likely cluster
1 - 2
3 - 4
5 - 6
7 - 8
9 - 11
0 45 90 180 270 360
Miles
Source: shape file from CSA,Ethiopia,2013


Cluster analysis of anemia in Ethiopia,2011
N
Tigray
Afar
Amhara
Benishangul Gumu
Addis Ababa
Dire Dawa
Harari
Gambela
Oromia
Somali
SNNPR
Legend
Most likely cluster
1 - 2
3 - 4
5 - 6
7 - 8
9 - 10
0 45 90 180 270 360
Miles
Source: shape file from CSA,Ethiopia,2013

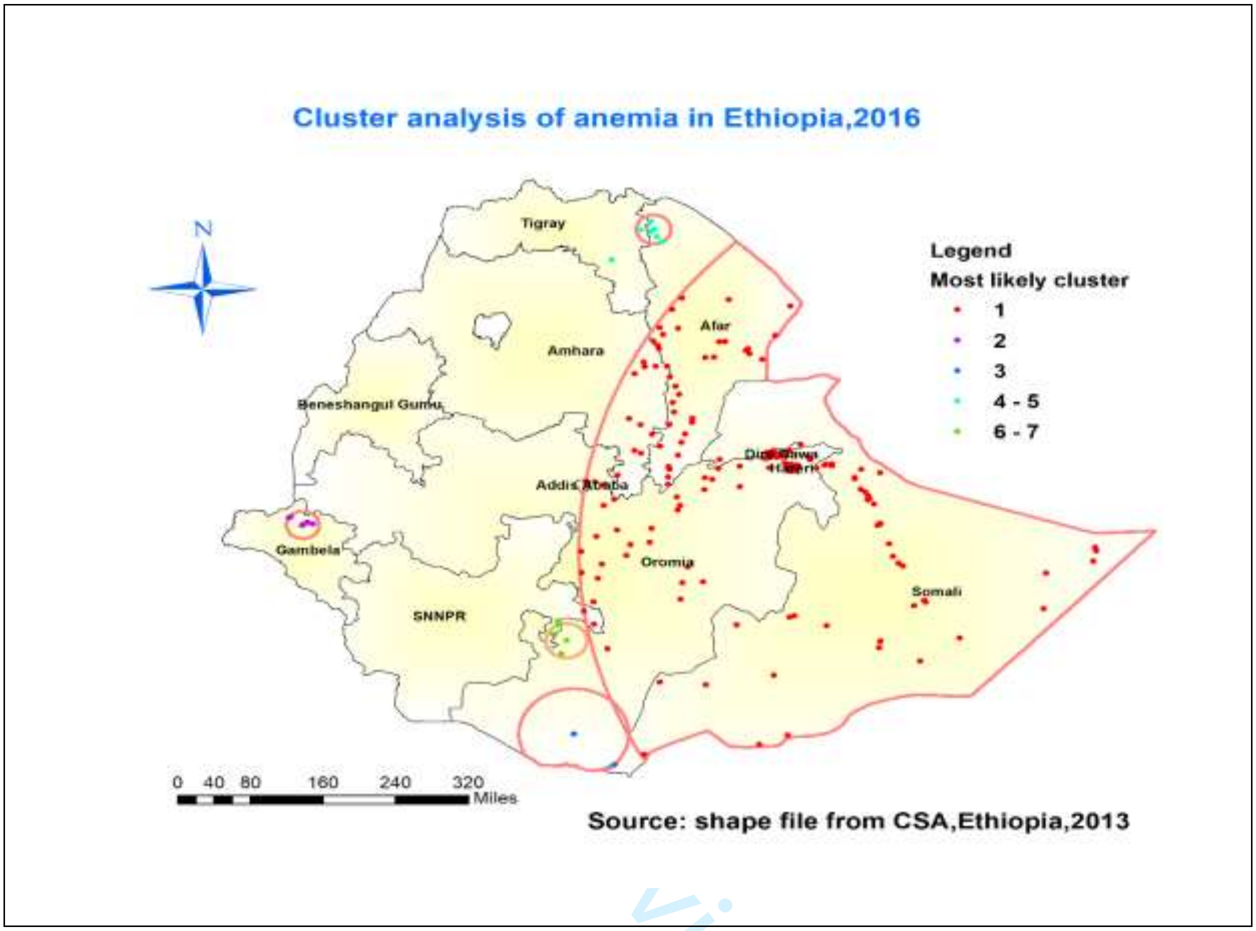


Figure 4: SaTScan scan statistics analysis of anemia in Ethiopia, EDHS, 2005-2016

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	Cross-sectional study design
		Aimed Spatiotemporal distribution and factors associated to childhood anaemia Spatial analysis revealed that the spatial distribution of anaemia varied across the country In mixed effect model Child age, women age, maternal anaemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anaemia.
Introduction		
Background/rationale	2	Though childhood anaemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anaemia overtime. study attempts to fill the gap by investigating the spatio-temporal distribution of anaemia and its associated factors using multilevel model, since its hierarchical nature.
Objectives	3	Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and health survey (EDHS) data from 2005-2016
Methods		
Study design	4	Survey-based cross-sectional study design was employed for the EDHS
Setting	5	All nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.
Participants	6	The source population for this study was all 6–59 months of children in Ethiopia. A total of 21,302 children aged 6-59 months were included in this study**.**
Variables	7	**Outcome measure:** The outcome variable was child anaemia status **Independent:** sociodemographic (religion, mother age, marital status, educational status, husband education, wealth index, mothers working status, numbers of under five children) Maternal and Child- related (child sex, age, birth size, birth order, maternal BMI, maternal anaemia, breastfeeding, fever, diarrhoea, vitamin supplement, stunting and wasting). Community-level (residence, region, community women education and community women poverty).
Data sources/ measurement	8*	DHS program (Demographic and Health Survey) website(www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses.
Bias	9	Cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables
Study size	10	A total of 21,302 children (3,868 in 2005, 8,958 - in 2011, and 8476 in 2016) were included in this study
Quantitative variables	11	Quantitative variables were handled in three level Level-0 intercept model Level-1 cluster with individual variables Level -2 community- level with cluster Level -3 mixed level individuals with community
Statistical methods	12	Multilevel model for associated factors, we use mixed effect to control confounding than traditional regression model.

		Spatial analysis was performed
		For associated factor predictors with missing dropped and for spatial analysis without spatial information was dropped
		Secondary data analysis and participants were selected based on a stratified two-stage cluster sampling technique
		Spatiotemporal pattern analysis was done for three-year data
Results		
Participants	13*	A total of 21,302 children
		Secondary data analysis
		Simply we take from EDHS
Descriptive data	14*	A total of 21,302 children with known haemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anaemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively The majority of children were from rural residency in five years preceding the survey in three surveys. About 78.6%, 70%, and 67% of women were unable to read and write in 2005, 2011, and 2016 survey respectively. Children from poor and middle-class families were more anaemic than children from rich families across the three EDHS survey
		Husband educational level was missing data
Outcome data	15*	The dependent variable was child anaemia status, categorized as "anaemic/not-anaemic" for this study.
Main results	16	The spatial distribution of childhood anaemia in Ethiopia was non-random in all three consecutive surveys. The global Moran's I test value was 0.176 (P-value <0.001) in 2005, 0.18 (P-value < 0.001) in 2011, and 0.09(P-value < 0.005) in 2016 Ethiopian Demographic and health surveys. In multivariable multilevel mixed-effect logistic regression analysis, individual-level factors such as the age of the child, wealth index, mother age, maternal anaemic status, birth order, fever, stunting, and wasting status were significant predictor of childhood anaemia.
		Not-applicable
		Not-applicable
Other analyses	17	Different spatial technique spatial autocreation, hotspot/cold spot analysis, interpolation, and sat scan analysis
Discussion		
Key results	18	This study tried to identify spatio-temporal distribution and predictors of childhood anaemia across the regions in Ethiopia. 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used. In this study, anaemia's trend was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL: 0.56-0.59] of children were anaemic in 2016, preceding the survey. This finding was in line with a study done in Gondar, Northwest Ethiopia 58.6%

		The spatial pattern shows the geographical inequality of anaemia by using sat scan and GIS spatial techniques like cluster mapping tools and interpolation techniques. The spatial analysis indicates that the distribution of childhood anaemia was non-random across the country with a global Moran's I index of 0.176 in 2005, 0.18 in 2011, and 0.09 in 2016 with a significant p-value, which indicates substantial-considerable clustering areas. This study's findings were in line with a study done in Nigeria, Malawi, Tanzania, and Uganda
Limitations	19	The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables Respondents' without coordinate (longitude and latitude) were excluded from the spatial analysis, which could affect the generalizability of the findings
Interpretation	20	Prevalence of childhood anaemia decreased between the 2005-2011 survey while the prevalence increased from 2011-2016 EDHS. The spatial pattern of child anaemia in Ethiopia was non-random among the three consecutive surveys with the global Moran's I value of 0.176, 0.18, and 0.09 in EDHS 2005, 2011, and 2016. In line study done Cape Verde, west Africa, Nigeria, Malawi, Tanzania, and Uganda
Generalisability	21	Policymakers and health planners should design effective intervention strategies for the identified hot spot areas and individual and community-level factors to anaemia. For health care community, and researcher to alleviate the problem.
Other information		
Funding	22	No funding

*Give information separately for exposed and unexposed groups.

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

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-045544.R2
Article Type:	Original research
Date Submitted by the Author:	29-Jun-2021
Complete List of Authors:	Samuel, Hailegebreal; Arba Minch University, Department of Health Informatics Nigatu, Araya; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia Mekonnen, Zeleke; Ethiopia Ministry of Health, Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia; Endehabtu, Berhanu; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia
Primary Subject Heading:	Paediatrics
Secondary Subject Heading:	Public health
Keywords:	Anaemia < HAEMATOLOGY, PAEDIATRICS, Community child health < PAEDIATRICS

SCHOLARONE™ Manuscripts

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: Based on the EDHS 2005- 2016: A spatial and multilevel analysis

Samuel Hailegebreal[1*], Araya Mesfin Nigatu[2], Zeleke Abebaw Mekonnen[2,3], Berhanu Fikadie Endehabtu[2]

Affiliation

[1]Arba Minch University, College of Medicine and Health Sciences, School of Public Health Department of Health Informatics, Ethiopia

[2]Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia

[3]Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia

Corresponding author

Samuel Hailegebreal

Email: samuastd@gmail.com

Abstract

Objectives: Anaemia is a global public health problem with major health and socio-economic consequences. Though childhood anaemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anaemia overtime in the country. Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and Health Survey (EDHS) data from 2005-2016.

Design: Survey-based cross-sectional study design was employed for the EDHS.

Setting: Data were collected in all nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.

Participants: The source population for this study was all 6–59 months of children in Ethiopia. A total of 21,302 children aged 6-59 months were included in this study.

Outcome measure: The outcome variable was child anaemia status.

Results: The prevalence of anaemia declined from 53.9% in 2005 to 44.6% in 2011, but it showed an increment in 2016 to 57.6%. The spatial analysis revealed that the spatial distribution of anaemia varied across the regions. The spatial scan statistics analysis indicated, a total of 22 clusters (RR= 1.5, P-value < 0.01) in 2005, 180 clusters (RR = 1.4, P-value < 0.01) in 2011, and 219 clusters (RR = 1.4, P-value < 0. 0.01) in 2016 significant primary clusters were identified. Child age, women age, maternal anaemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anaemia.

Conclusions: In this study, childhood anaemia remains a public health problem. The spatial distribution of childhood anaemia was significantly varied across the country. Individual-level and community-level factors were associated with childhood anaemia. Therefore, in regions

with a high risk of childhood anaemia, individual and community level factors should be intensified by allocating additional resources and providing appropriate and tailored strategies.

Keywords*:* Anaemia, Childhood, EDHS, Spatial, Multilevel, Ethiopia

Strengths and limitations of this study

- This study applied different methods of spatial pattern, trend and a multilevel logistic regression models accounting for the nested nature of EDHS data
- The study was based on three consecutive EDHS dataset's representing the whole country of Ethiopia
- The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables
- Respondents without coordinate (longitude and latitude) were excluded from the spatial analysis, which could affect the generalizability of the findings

Background

Anaemia is a condition characterized by a low level of haemoglobin in the blood(1). Over 273 million under-five children suffer from anaemia worldwide(2). Sub-Saharan Africa is one of the most affected regions, accounting for about 53.8%(2). World Health Organization (WHO) had developed a classification system to facilitate international comparisons of anaemia as public health crises. The problem was considered severe if anaemia prevalence is ≥40%, moderate from 20% to 39.9%, and mild from 5% to 19.9%(3). The high prevalence of anaemia and its consequences on children's health, especially on their growth and development, have made it important public health problem, It also increases the risk of mortality and morbidity that come from other diseases(4,5).

Anaemia is a public health problem that affects populations in both industrialized and non-industrialized countries which touches all segments of the population. It is frequently observed among children and pregnant women who are the most vulnerable group because their iron requirements are higher than any other group(6). Anaemia is defined as a haemoglobin level below 11.0 g/dl for children age 6-59 month. Childhood anaemia is mainly caused by dietary iron deficiency, foliate, vitamin B12, vitamin A deficiencies, chronic inflammation, parasitic infections, nutritional deficiencies, hemoglobinopathies and inherited disorders were contribute to childhood anaemia (7,8).

The 2015 WHO report, from the global anaemia prevalence in 2011 showed that Africa, south east Asia, America, and European regions were,62.3%,53.8%,23.3%, and 22.9%, respectively(3). In Sub-Saharan Africa, anaemia is a significant public health problem associated with an increased risk of death and impaired cognitive development(9).

Various-studies showed that the prevalence of anaemia among 6-59-month children is high and a severe public health problem. Evidence from various studies indicated that women age, residence, maternal education status(10), an introduction of complementary foods, poor breastfeeding practice, poor utilization of folic acid by mothers(11), maternal anaemia(12), unemployment of the parent, and presence of sickle haemoglobin, household wealth index, and sex of the child were associated with childhood anaemia(13) . Few studies have been done on factors associated with anaemia in Ethiopia, to date; the risk areas (hot spot) of anaemia among children are not identified. Thus, this study aimed to assess the spatiotemporal patterns of anaemia among under five children in Ethiopia over the last one and half-decades to point out whether there was either the shift or improvement in anaemia risk areas following intervention programs in between the survey periods in Ethiopia. Geographical differences in the causes of anaemia can be partially explained by large-scale variability in environmental drivers, particularly nutritional and infectious causes(14). The risk of malaria is known to be associated with elevation and land surface temperature(15). Environmental drivers of anaemia tend to show a high degree of spatial dependency. Therefore, detecting the geographic variation of anaemia during childhood is important to prioritize and design targeted intervention programs to reduce anaemia especially in those areas with a consistently higher risk of anaemia over time. Therefore, this study attempts to fill the gap by investigating the spatio-temporal distribution of anaemia and its associated factors using multilevel model analysis in Ethiopia using the EDHS survey between 2005-2016 data.

Methods and materials

Study design, setting and period

The survey-based cross-sectional study design was employed using the 2005, 2011, and 2016 EDHS. Data access, extraction, and analysis were conducted from January to June 2020. The study was conducted in Ethiopia located at the horn of Africa (3°-14°N and 33° – 48°E). Administratively, the country is divided into nine regions and two city administrations. Each region is sub-divided into zones, districts, towns, and kebeles (the smallest administrative units).

Source and study population

All 6–59 months children in Ethiopia were the source population for this study whereas all children aged from 6-59 months in the selected enumeration areas within five years before the survey were the study population.

Sample size and sampling technique

A total of 21,302 children (3,868 in 2005, 8,958 in 2011, and 8476 in 2016) were included in this study. Children's record (KR) dataset was used for analysis. The survey covered all nine regions and the two city administrations of Ethiopia. Participants were selected based on a stratified two-stage cluster sampling technique in each survey year. After excluding clusters with zero coordinates and missing information, a total of 503 clusters in 2005, 569 clusters in 2011, and 615 clusters in 2016 were used for analysis. The detailed sampling procedure was available in each survey years report(16–18)

Data collection tools and procedures

The data for this analysis were extracted from Demographic and Health Survey (DHS) program website (www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses. Similarly, spatial location data (latitude and longitudinal) were extracted from the downloaded excel file. After extraction, the missing values for the significant independent variables were excluded and the analysis was undertaken using a complete data set. In all survey years for all children age 6-59 month from whom consent was obtained from their parents. Blood samples were drawn from the drop of blood taken from a finger prick or a heel prick in the case of 6-11 month, and collected in a microcuvette. Haemoglobin analysis was carried out on-site using a battery-operated portable HemoCue analyzer.

Key variables and measurements

Dependent variable: The study variables were grouped into dependent and independent variables. The dependent variable is childhood anaemia status, categorized as "anaemic or not-anaemic". Children whose haemoglobin level was less than 11g/dl were considered anaemic and not anaemic otherwise.

Independent variables:

sociodemographic (religion, women age, marital status, educational status, husband education, wealth index, women working status, numbers of under five children) Maternal and Child- related (child sex, age, birth size, birth order, maternal BMI, maternal anaemia, breastfeeding, fever, diarrhoea, vitamin supplement, stunting and wasting). Community-level variables (residence, region, community women education and community women poverty).

We created community women education and community women poverty variables by aggregating the individual characteristics within their clusters. The aggregates were computed using the median values of the proportions of women in each category of a given variable. We categorized the aggregate values of a cluster into groups based on national median values, since all aggregates were not normally distributed.

Community women's education: was defined as the proportion of women who attended primary, secondary and higher education within the cluster. The aggregate of individual primary, secondary and higher educational attainment can show the overall educational and academic status of women within the cluster. They were categorized into two categories a higher proportion of women's education within the cluster and a lower proportion of women education based on the national median value.

Community women's poverty status: defined as the proportion of poor and poorest mothers within the cluster. For each cluster, the proportion of poor and poorest as-was aggregated and show overall poverty status within the cluster. It was categorized into two categories based on national median value as higher proportion of poor/poorest mother's and lower proportion of mothers within a cluster.

Data management and analysis

The data were cleaned using STATA 14.1 software and Microsoft excel. The data were weighted using sampling weight, primary sampling unit, and strata before any statistical analysis to restore the representativeness of the survey to take into account the sampling design when calculating standard errors to get reliable statistical estimates.

Spatial analysis

For the spatial analysis, ArcGIS V.10.7 software was used to evaluate whether the pattern was clustered, dispersed or random across the study area, and SaTScan™ software, version 9.6.1, was used for the local cluster detection analysis. It uses a circular window that moves systematically throughout the study area to identify a significant spatial clustering of childhood anaemia.

Spatial autocorrelation analysis

The spatial autocorrelation (Global Moran's I) statistic measures whether childhood anaemia patterns were dispersed, clustered or randomly distributed in the study area. Moran's I output value ranges from (-1 to +1). Values close to −1 indicate anaemia dispersed, whereas Moran's I close to +1 indicate childhood anaemia clustered and distributed randomly if I value zero. Anselin Local Moran's I was used to indicate the local level cluster locations of anaemia positively correlated (high-high and low-low) clusters or negatively correlated (high-low and low-high).

Hot spot analysis (Getis-Ord Gi* statistic)

Local Moran's I, Gettis-OrdGi* statistics was computed to measure how spatial autocorrelation of anaemia among under-five children varies across different locations in Ethiopia. Hotspot analysis computes Z-score and p-value to determine the statistical significance of the clustering of anaemia over the study area at different significance levels simultaneously. Statistical output with high GI* indicates "hotspot" whereas low GI* means a "cold spot". hot spot areas showed that there was a high proportion of anaemia and the cold spot indicated a low proportion of anaemia.

Spatial interpolation

There are various deterministic and geostatistical interpolation methods. Among all of the methods, ordinary Kriging and empirical Bayesian Kriging are considered the best methods since they incorporate spatial autocorrelation and statistically optimize the weight. Ordinary Kriging spatial interpolation method was used for this study for predictions of childhood anaemia in unobserved areas of Ethiopia since it had low mean square error and residual as compared to the other interpolation techniques.

Spatial scan statistical analysis

Spatial scan statistical analysis used to Identifying most likely(primary) and secondary spatial clusters. This method is widely recommended as it is very important in detecting local clusters and has higher power than other available spatial statistical methods. Bernoulli based model was employed to test for statistically significant spatial clusters of anaemia using Kulldorff's SaTScan™ version 9.6.1, software. Children with anaemia were taken as cases, and were not-anaemic as controls to fit the Bernoulli model. The default maximum spatial cluster size of <50% of the population was used. The scanning window with maximum likelihood was the most likely cluster, and the p-value was assigned to each cluster using Monte Carlo hypothesis testing. The primary and secondary clusters were identified and assigned p-values and ranked based on their likelihood ratio test, based on 999 Monte Carlo replications(19).

Associated factors of anaemia

Four models were fitted using **melogit**, a STATA command, the null model without predictors, model I with only individual-level variables, model II with only community-level variables, and Model III both individual-level and community-level variables. Model comparison was conducted by using deviance and likelihood ratio.

Intra-class correlation (ICC), median odds ratio (MOR), and proportional change in variance (PCV) were computed to measure the variation between clusters. The intra-class correlation coefficient (ICC) quantifies the degree of heterogeneity of childhood anaemia between clusters (the proportion of the total observed individual variation in anaemia that is attributable between cluster variations) calculated as

$ICC = \frac{\sigma^2}{(\sigma^2 + \sigma^2{}_b)}$ (20) , where, σ^2 is the community level variance and $\sigma^2{}_b$ indicates individual level variance. The individual variance ($\sigma^2{}_b$) equal to $\pi^2/3$.

but MOR is quantifying the variation or heterogeneity in outcomes between clusters and is defined as the median value of the odds ratio between the cluster at high risk of anaemia and cluster at lower risk when randomly picking out two clusters (EAs).

$MOR = e^{(0.95 * \text{ sqrt}(\sigma^2)}$(21) where, σ^2 indicates that cluster level variance.

PCV measures the total variation attributed by individual-level factors and community-level factors in the multilevel model compared to the null model PCV. In the multivariable multilevel logistic regression analysis variables with a p-value of <0.05 were considered as statistically significant. Adjusted Odds Ratio (AOR) with their corresponding 95% confidence interval was determined to identify factors associated with anaemia. After comparing all models, a model with low deviance was considered a better fitted model. Multicollinearity was checked using the Variance Inflation Factor (VIF). VIF less than 10% was taken as no multicollinearity.

Ethics and confidentiality

Ethical clearance was obtained from the ethical review board of the University of Gondar Institute of Public Health, CMHS. Permission for data access was obtained from the measure demographic and health survey through an online request by a written letter of objective and significance of the study from (http://www.dhsprogram.com)

Patient and public involvement

This study did not involve patients and the public

Results

Descriptive characteristics of the study population

A total of 21,302 children with known haemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anaemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively. The majority of the participants were in the age group of 36-47 (23.7%), 36-47 (24.4%), and, 48-59 (22.9%) in EDHS 2005, 2011, and 2016 survey respectively. The mean age of children was 32.6 ±15.6-SD, 32.6±15.4-SD, and 31.7±15.6-SD in 2005, 2011, and 2016 respectively. Among children involved in the analysis, male participants were higher in 2011 and 2016 EDHS compared to 2005 survey periods. The majority of children were from rural resident in three surveys. About 78.6%, 70.1%, and 67.1% of women were unable to read and write in 2005, 2011, and 2016 survey respectively. Children from poor and middle-class wealth index families were more anaemic than children from rich families across the three EDHS survey (Table 1).

During the study period, the trends in the prevalence of childhood anaemia in Ethiopia, were fluctuates across regions **(Fig.1)**.

Table 1: Descriptive characteristics of study participants included in the analysis for childhood anaemia five years preceding the survey from EDHS 2005-2016 in Ethiopia

Variables	2005 (N, 3868)	2011 (N, 8958)	2016 (N, 8476)
	Frequency (%)	Frequency (%)	Frequency (%)
Sex of child			
Male	1,931(49.9)	4,500(51.4)	4,395(51.9)
Female	1,937(50.1)	4,358(48.7)	4,081(48.2)
Age of child in month			
6-11	418 (10.8)	1,029(11.5)	1,000(11.8)
12-23	842 (21.76)	1,804(20.14)	1,902(22.4)
24-35	825 (21.3)	1,895(21.2)	1,803(21.3)
36-47	919 (23.7)	2,184(24.4)	1,832(21.6)
48-59	864 (22.3)	2,047(22.9)	1,939(22.9)
Mean ± SD	**32.6 ±15.6**	**32.6±15.4**	**31.7±15.6**
Residence			
Urban	244 (6.3)	1,047(11.7)	857(10.1)
Rural	3,624 (93.7)	7,911(88.3)	7,619(89.9)
Religion			
Orthodox	1,624 (42.0)	3,416(38.1)	2,913(34.4)
Muslim	1,276 (33.0)	3,108(34.7)	3,432(40.5)
Protestant	836 (22.0)	2,151(24.0)	1,874(22.1)

Others	133 (3.0)	283(3.2)	258(3.0)
Women age			
15-29	1,930(49.9)	4,908(54.9)	4,356(51.4)
30-39	1,474(38.1)	3,223(36.0)	3,335(39.3)
40-49	464(12.0)	828(9.1)	785(9.3)
Women education			
No education	3,042 (78.6)	6,285(70.1)	5,685(67.1)
Primary	684 (17.7)	2,389(26.7)	2,275(26.8)
Secondary	136 (3.5)	168(1.9)	346(4.1)
Higher	7 (0.2)	117(1.3)	170(2.0)
Marital status			
Single	7(0.2)	50(0.6)	45(0.5)
Married	3,704(95.7)	8,425(94.0)	8,129(95.9)
Widowed	80(2.1)	178(2.0)	93(1.1)
Divorced	78(2.0)	306 (3.4)	210(2.5)
Husband education			
No-education	2,235 (58.0)	4,532(50.9)	4, 33(51.1)
Primary	1,233(32.0)	3,710(41.7)	3,273(38.6)
Secondary	362(9.0)	412(4.6)	572(6.8)
Higher education	31(1.0)	255 (2.8)	300(3.5)
Wealth index			
Poor	1,697(43.7)	4,048(45.2)	3,977(46.9)
Middle	854(22.1)	1,873(20.9)	1,821(21.5)

Rich	1,318(34.1)	3,038 (33.9)	2,678(31.6)
Women working status			
Not working	2,841(73.5)	5,793(64.7)	6,140(72.4)
Working	1,027(26. 5)	3,165(35.3)	2,336(27.6)
Total	3,868(100)	8,958(100)	8,476(100)

258

259 **Community-level characteristics of the study population**

260 Findings from this study revealed a regional variation of childhood anaemia, with 83.3% in
261 Somali, 75.5%, in Afar, 74.5% in Dire Dawa, and 68.8% in Harari. However, Amhara, and
262 Benishangul with 42.5%, which was relatively low compared to other regions.

263 Childhood anaemia varies by urban-rural of residence. Children residing in communities with
264 low women poverty level had a lower percent of anaemia (51.2%) than high community poverty
265 level (62.5%). Children from low community women education level (59.5%) were more
266 anaemic than children resided with high community women (53.6%) educational level (Table
267 2).

268 **Table 2: Community-level factors of under five children participated in EDHS (2016),**
269 **Ethiopia. (N, 8476)**

Community-level factors	Not-anaemic (%)	Anaemic (%)	Total (100%)
Residence			
Urban	435(50.6)	424(49.4)	857
Rural	3164(41.5)	4455(58.5)	7619
Region			
Tigray	263(46.0)	309(54.0)	572

Afar	21(25.3)	62(74.5)	83
Amhara	950(57.5)	703(42.5)	1653
Oromia	1273(34.2)	2446(65.8)	3719
Somali	58(16.7)	290(83.3)	348
Beneshangul	51(56.6)	39(43.4)	90
SNNPR	875(49.1)	906(50.9)	1781
Gambela	8(42.1)	11(57.9)	19
Harari	5(31.2)	11(68.8)	16
Addis Ababa	82(50.9)	79(49.1)	161
Dire Dawa	9(28.1)	23(71.9)	32
Community women education			
Low	2281(40.5)	3358(59.5)	5639
High	1315(46.4)	1520(53.6)	2837
Community women poverty			
Low	1815(48.8)	1905(51.2)	3719
High	1782(37.5)	2974(62.5)	4756

Spatio-temporal distribution of anaemia among children age 6-59 months in Ethiopia

The spatial distribution of childhood anaemia varied across regions in all surveys. The spatial autocorrelation analysis result indicated that childhood anaemia had spatial dependency in 2005, 2011 and 2016 (Moran's I: 0.176, 0.18, and 0.09, respectively at P-value < 0.01).

Hot spot analysis of the three surveys

The spatial distribution of childhood anaemia in Ethiopia was different in all the three survey periods. In EDHS 2005, a high proportion of childhood anaemia was detected in Dire Dawa, Harari, eastern Oromia, Beneshangul in Metekel zone, Gambela, southern and eastern Tigray, and Somali region mainly Liben, Afdar, and Fafna zone which was hotspot area within 95% confidence level. On the counterpart, GamoGofa, Wolayita, Hadiya, Southern Omo, and Segen zone of SNNPR, Addis Ababa, central Oromia, Jima, north Shewa zone were cold spot area. In EDHS 2011, a highly significant clustering of childhood anaemia was detected in Somali, Dire Dawa, Harari, Afar, Gambela, Beneshangul, eastern Oromia, Bale, Arsi zone were the hotspot areas within 95% level of confidence. The low hotspot area of childhood anaemia was detected in central Tigray, East and West Gojam, North Gondar, a central part of Oromia, Addis Ababa and SNNPR were areas identified as the low percentage of childhood anaemia in the 2011 EDHS survey.

In EDHS-2016 sampled data, hot spot (high risk) regions for childhood anaemia were observed in Somali, Dire Dawa, Harari, Gambela, eastern, and Southern part of Oromia. However, Amhara, Beneshangul, and SNNPR were identified as cold spot (low risk) regions for childhood anaemia within a 95% confidence interval (**Fig.2**)

Spatial interpolation

Based on EDHS-2005 sampled data, the geostatistical analysis predicts that the highest prevalence of childhood anaemia (65.75%-88.89%) was detected in east Oromia, Ilubabur, Arsi, some parts of Beneshangul, Agnuak zone in Gambela, north Shewa Amhara region, south and central Tigray, Afar in zone2, some parts of Dire Dawa and Somali. In EDHS-2011 Geostatistical analysis, a high percentage of anaemia was detected in Afar, most parts of Somali, Oromia in east Harerge and Borena, some part of Dire Dawa, and the Meketel zone in Beneshangul. In 2016 EDHS most of Somali, some parts of Gambela, Guji and some parts of Borena, ast Shewa, East Harerge and Arsi in Oromia and part of Dire Dawa were highly prevalent areas in childhood anaemia **(Fig.3)**

Spatial scan statistics

In 2005 EDHS, a total of 3 significant clusters were identified, one most likely (primary) cluster and two were secondary clusters of spatial scan analysis. The primary cluster spatial window was located in Somali, which was centered at (9.018373 N, 43.110635 E) of geographic location with a 97.93 km radius, and Log-Likelihood ratio (LLR) of 20.03, at p < 0.01 which was detected as the most likely cluster with maximum likelihood. It showed that children within the spatial window had 1.5 times more likely a higher risk of anaemia than the children outside the spatial window areas. The secondary clusters scanning window was located in the southern part of Somali region, which was centered at (3.998656 N, 41.240691 E) with a 92.08 km radius and LLR of 1.7 at p-value < 0.01. It showed that children within the spatial window had a 1.7 times higher risk of anaemia than children outside the window.

In 2011 EDHS, 10 clusters were identified and five of them were significant clusters with a p-value <0.05. A total of 180 locations/spots with a total sampled population of 2478 were found in the primary cluster spatial window with a significant p-value < 0.01. The primary cluster spatial window was located mainly in Somali, Afar, eastern Oromia, Dire Dawa, and Harari. The primary cluster spatial window was centered at (8.975207 N, 43.790264 E) / 540.29 km, with a relative risk (RR) of 1.4 and a log-likelihood ratio (LLR) of 127.79. It showed that children within the spatial window had 1.4 times more likely a higher risk of anaemia than the children outside the spatial window areas. The secondary cluster spatial window was located mainly in Afar region. The secondary cluster spatial window was centered at (12.758587 N, 40.175990 E) / 39.58 km, with a relative risk (RR) of 1.7 and a log-likelihood ratio (LLR) of 21.5 P-value<0.01.

In 2016 EDHS, 7 clusters (one most likely cluster) were located in Somali, Afar, eastern Oromia, Dire Dawa, and Harari. The cluster window was centered with a radius at (7.650693 N, 47.007920 E) / 912.19 km with a relative risk (RR) of 1.4. The Log-Likelihood ratio (LLR) for the most likely cluster was 182.86, P-value<0.01. It showed that children within the spatial window had a 1.4 times higher risk of anaemia than outside the window. Secondary clusters were located in Gambela which was centered at (8.195862 N, 34.289837 E) with a radius of 29.01 km, and LLR of 18.80 at p-value < 0.01**(Fig.4)**.

Multilevel Analysis

The intra-cluster correlation coefficient (ICC) in the empty model indicated that 19% of the total variability for childhood anaemia was due to differences between clusters. The remaining unexplained 81% were attributable to individual differences. The median odds ratio for anaemia was 2.3 in the null model, indicating variation between clusters. If we randomly select children from two different clusters children at the cluster with a higher risk of anaemia had 2.3 times higher odds of experiencing anaemia than children at the cluster with a lower risk of anaemia.

Bi-variable multilevel logistic regression analysis was done to identify variables for multivariable multilevel logistic analysis, and variable with a p-value less than 0.25 were considered for multivariable analysis.

Individual-level predictors for anaemia

In multivariable multilevel mixed-effect logistic regression analysis, individual-level factors such as the age of the child, wealth index, mother age, maternal anaemia status, birth order, fever, stunting, and wasting status were significant predictor of childhood anaemia.

Children age between 12–23 months (AOR = 0.66, 95%CI = 0.53-0.81), between 24–35 months (AOR= 0.35, 95% CI = 0.28-0.43), between 36–47 months (AOR = 0.23-95%CI = 0.19-0.29), and between 48–59 months (AOR = 0.15, 95%CI = 0.12-0.19) were less likely to develop anaemia compared with children age between 6–11 months.

The likelihood of developing anaemia for those children residing with the family wealth index of middle and rich were lower by 21% (AOR=0.79, 95%CI = 0.67-0.94), and 23% (AOR=0.77, 95%CI = 0.65-0.91), respectively as compared with children with low wealth index. Children whose mother's age were between 40-49 had 25% decreased odds of developing childhood anaemia compared to age 15-29, (AOR=0.75, 95%CI = 0.59-0.95).

The odds of experiencing anaemia for those birth orders 4-5, six and above six were 1.22 times (AOR=1.22, 95%CI = 1.01-1.47) and, 1.35 times (AOR=1.35, 95%CI = 1.08-1.67) higher as compared with first-order respectively. The odds of developing anaemia of children born from anaemia history mother were 1.39 higher more elevated than those born from not anaemic history before. Children who had fever were 39% (AOR =1.39, 95% CI: 1.24-1.58) more likely to develop anaemia than their counterparts. Children with moderate and severe stunting status were 35% (AOR=1.35, 95% CI: 1.17-1.54) and, 96% (AOR=1.95, 95% CI: 1.68-2.28), more likely to develop anaemia respectively, compared to no stunting status. Similarly, children who had to sever wasting status were 51% more (AOR =1.51, 95% CI: 1.07-2.12) likely to develop anaemia compared with those children who had no wasting.

Community-level predictors for anaemia

The multivariable multilevel logistic regression analysis region was significantly associated with community-level factors for childhood anaemia.

Odds of children live in Somali were 5.65 times (AOR=5.65, 95% CI: 3.92-8.16), Dire Dawa 3.45 times (AOR=3.45, 95% CI: 2.27-5.26), Afar 3 times (AOR=3.00, 95% CI: 2.09-4.34), and

Oromia 2.34 times (AOR=2.34, 95% CI: 1.73-3.18) had more likely to develop childhood anaemia compared to Amhara region. Similarly, the odds of developing anaemia in Addis Ababa were 2 times (AOR=2.00, 95% CI: 1.40-3.16), Gambella 1.94 times (AOR=1.94, 95% CI: 1.32-2.84), and Tigray 1.46 times (AOR=1.46, 95% CI: 1.08-1.98), more likely as compared to Amhara region. Beneshangul and SNNPR had not significantly different in the prevalence of anaemia than the reference region Amhara (Table 3).

Table 3: Multilevel logistic regression analysis result of both individual and community-level factors associated with anaemia in Ethiopia, EDHS 2016

Variables	Null Model	Model I AOR (95% CI)	Model II AOR (95% CI)	Model III AOR (95% CI)
Individual-level factors				
Age of child in month				
6-11	-	1	-	1
12-23	-	0.66[0.54-0.82] **	-	0.66 [0.53-0.81] **
24-35	-	0.35[0.28-0.44] **	-	0.35 [0.28-0.43] **
36-47	-	0.23[0.18-0.28] **	-	0.23 [0.19-0.29] **
48-59	-	0.15[0.12-0.19] **	-	0.15 [0.12-0.19] **
Religion				
Orthodox	-	1	-	1
Muslim	-	2.07[1.77-2.47] **	-	1.21 [0.97-1.46]
Protestant		1.20 [1.00-1.48] *		1.10 [0.86-1.37]
Others	-	1.55[1.07-2.32] *	-	1.44[0.96-2.13]
Wealth status				
Poor	-	1	-	1

Middle	-	0.71[0.61-0.84] **	-	0.79 [0.67-0.94] *
Rich	-	0.72[0.63-0.85] **	-	0.77 [0.65-0.91] *
Child size at birth				
Small	-	1	-	1
Average	-	0.96[0.84-1.09]	-	0.93 [0.80-1.07]
Large	-	0.94[0.81-1.08]	-	0.96 [0.84-1.10]
Birth order			-	
1st	-	1	-	1
2-3	-	1.09[0.94-1.28]	-	1.13[0.97-1.32]
4-5	-	1.17[0.97-1.40]	-	1.22 [1.01-1.47] *
6 and above	-	1.30[1.05-1.62]	-	1.35 [1.08-1.67] **
No of children under 5				
1-2 children	-	1	-	1
≥ 3 children	-	1.22[1.1-1.4] *	-	1.09 [0.94-1.27]
Maternal anaemia				
Not anaemic	-	1	-	1
Anaemic	-	1.51[1.34, 1.72] **	-	1.39 [1.24-1.58] **
Maternal BMI				
≥18.5 kg/m2	-	1	-	1
<18.5 kg/m2	-	1.12[0.97-1.26]	-	1.05 [0.92-1.19]
Women working status				
Not-working	-	1	-	1
Working	-	0.88[0.77-0.99] *	-	0.92 [0.81-1.04]

Women age				
15-29	-	1		1
30-39	-	0.91[0.71-1.06]	-	0.90 [0.78-1.04]
40-49	-	0.75[0.59-1.12] *	-	0.75 [0.59-0.95] *
Breastfeeding				
No	-	1	-	
Yes	-	0.92[0.81-1.04]	-	0.98 [0.87-1.12]
Vitamins in last 6 month				
No	-	1	-	
Yes	-	0.90[0.81-1.09]	-	0.93 [0.84-1.05]
Diarrhea last 2 week				
No	-	1	-	1
Yes	-	0.88[0.73, 1.04]	-	0.90 [0.76-1.07]
Fever in last 2 weeks				
No	-	1	-	1
Yes	-	1.35[1.15-1.59] **	-	1.32 [1.13-1.56] *
Stunting status				
No-stunting	-	1	-	1
Moderate stunting	-	1.27[1.10-1.46] **	-	1.35 [1.17-1.54] **
Severely stunting	-	1.81[1.55-2.11] **	-	1.96 [1.68-2.28] **
Wasting status				
No-wasting	-	1	-	1
Moderate wasting	-	1.27[1.11-1.45]	-	0.98 [0.80-1.19]

Severe wasting	-	1.68[1.55-2.10] *	-	1.51 [1.07-2.12] *
Community/cluster-level factors				
Region				
Amhara	-	-	1	**1**
Tigray	-	-	1.46[1.09-1.97] **	1.46 [1.08-1.98] **
Afar	-	-	3.90 [2.84-5.35] **	3.00 [2.09-4.34] **
Oromia	-	-	2.48 [1.89-3.25] **	2.34 [1.73-3.18] **
Somali	-	-	6.34[4.65-8.63]	5.65 [3.92-8.16] **
Beneshangul	-	-	0.86 [0.62-1.17]	0.81 [0.58-1.15]
SNNPR	-	-	1.33 [1.00-1.76]	1.30 [0.94-1.80]
Gambela	-	-	1.93 [1.38-2.69] **	1.94 [1.32-2.84] **
Harari	-	-	3.08 [2.15-4.43] **	2.98 [1.99-4.46] **
Addis Ababa	-	-	1.91[1.29-2.83] **	2.10 [1.40-3.16] **
Dire dawa	-	-	3.92 [2.67-5.77] **	3.45 [2.27-5.26] **
Residence				
Urban	-	-	**1**	**1**
Rural	-	-	1.40[1.12-1.78]	1.28 [0.99-1.64]
Community women education				
Low	-	-	1	1
High	-	-	1.07[0.90-1.26]	1.13[0.94-1.34]
Community women poverty				
Low	-	-	1	1
High	-	-	1.41[1.17-1.68] *	1.15[0.94-1.40]

Model comparison and random effect				
ICC	0.19	0.12	0.08	0.07
Log-likelihood	-4981.63	-4513.17	-4836.83	-4436.60
Deviance	9963.26	9026.34	9673.66	8873.20
MOR	2.30	1.72	1.42	1.38
PVC (%)	Ref	41.20	60.10	62.59

Key: 1: reference group; p-value 0.05-0.01 *: p-value < 0.01 *

Multicollinearity

Multicollinearity was checked for those variables included in the final model using VIF. Accordingly, the VIF for all predictor variables included in the final model was below 10 indicating the absence of multicollinearity among the predictor variables.

Comparison of models

Deviance was used to compare the models, and the lowest value of deviance (Model III) was considered the better mode.

Discussion

This study tried to identify spatio-temporal distribution and predictors of childhood anaemia across the regions in Ethiopia. The 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used. In this study, anaemia trend was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL: 0.56-0.59] of children were anaemic in 2016, preceding the survey. This finding was in line with a study done in Gondar, Northwest Ethiopia 58.6%(22), whereas higher than the study done in cape Verde, west Africa 51.8%(23), and southern Ethiopia(24). Among children of 6–59 months, anaemia is still considered a significant public health problem in Ethiopia. Though the levels of anaemia among children vary by background characteristics like region and lowest household wealth index and maternal related factors, more of the children in Ethiopia were suffering anaemia.

The spatial pattern shows the geographical inequality of anaemia by using different spatial analysis techniques like cluster mapping tools and interpolation techniques. The spatial analysis indicates that the distribution of childhood anaemia was non-random across the country with a global Moran's I index of 0.176 in 2005, 0.18 in 2011, and 0.09 in 2016 with a significant p-value <0.01, which indicates substantial-considerable clustering areas. This findings were in line with a study done in Nigeria, Malawi, Tanzania, and Uganda (25,26).

The spatial pattern of scan statistical analysis showed that Eastern Somali region were primary (most likely) cluster and secondary cluster also located in the southern part of Somali in 2005 sat scan analysis. In 2011 Somali, Afar, Eastern Oromia, Dire Dawa, and Harari were located in the primary window and centered at (8.975207 N, 43.790264 E/ 540.29 km with a significant p-value. Similarly, spatial sat scan analysis showed that Somali, Afar, Eastern Oromia, Dire Dawa, Harari were hotspot areas in the 2016 EDHS spatial analysis. In addition, this study revealed that eastern parts of the country had similar spatiotemporal trend over the study periods.

The spatial analysis indicated the hotspots areas of anaemia were situated in the East, Northeast, and Western parts, whereas, Central area, and South, and Northwest parts were cold spot parts of Ethiopia. The observed variability of childhood anaemia might be attributed to the regional deference of economy, healthcare facility and food availability(27).

This study indicated that children age 12-59 months were less affected by childhood anaemia. This finding was consistent with studies conducted in Ethiopia and Togo (28–30). This could be explained by the fact that children who are getting older receive a richer and complete diet, with a sufficient intake of iron which could prevent the occurrence of iron deficiency anaemia. The deficiency may result from inadequate dietary intake of iron, malabsorption of iron an increased iron demand during rapid growth might it be the possible reason (31). The finding of this study indicated that children whose women age was between 40-49 were less anaemic as compared to age 15-29. This finding was consistent with other studies conducted in Sub-Saharan Africa and Ghana (12,32).

This group consists of more at-risk population segments (Adolescent) for anaemia. They are vulnerable to malnutrition because they are growing faster than at any time after their first year of life which contributes to the intergenerational cycle of malnutrition and most common forms of malnutrition among Ethiopian adolescent girls is iron deficiency anaemia. Aside from, growing adolescent mother and her baby's bodies may compete for nutrients, raising the infant's risk of low birth weight; however, the lack of such nutrients might lead to anaemia.

Children from households of middle and rich wealth indexes were less affected by childhood anaemia as compared to children from a poor household. This finding in line with similar studies in Nigeria and Northern Ethiopia (25,33). This is due to the reason that children from poor households are less likely to get iron-rich foods like animal foods and vitamin-rich foods especially vitamins A and C which are very important for iron absorption.

Maternal anaemia was highly associated with the occurrence of childhood anaemia. This finding was in line with a study done in South Africa, Haiti, and India(34–36).

This might be explained that mothers and children share a common home environment, socioeconomic, and dietary conditions, and maternal and child anaemia may reflect the household common nutritional status, and poor maternal iron intake during pregnancy, reduce breast milk might be the possible reason.

The EDHS data set indicated that the incidence of fever had an impact on childhood anaemia. This is in line with studies done in Ghana and South Ethiopia Wolaita (24,37). This result showed that children who had a fever in the last two weeks before the survey had had a higher likelihood of anaemia than the counterpart. This could be attributed to the infectious cause of childhood fever mainly malaria, tuberculosis, and Leishmaniasis which cause anaemia by destructing red blood cells or other related mechanisms.

The nutritional status of children had a significant association with childhood anaemia. The stunting status of children had significant association with childhood anaemia. This finding in line with previous similar finding conducted in South Africa(36), Bangladesh(38,39), and Ethiopia(40,41). This might be explained that children suffering from nutritional deficiency were more likely to have weak immune systems, making them vulnerable to various illnesses and healthiness such as parasitic infections or chronic inflammation; many of these conditions reduce the haemoglobin level in the blood leading to increased childhood anaemia(42)

Furthermore, severely wasting children were more likely to be anaemic than their counterpart. Consistent with other previous studies(43,44). This is due to the fact that malnutrition leads to both macronutrient and micronutrient deficiencies, such as protein, iron, and vitamin A, which are responsible for iron deficiency. Odds of experiencing anaemia for those birth order four up to five and six and greater than six were higher than those of the first order. This finding was similar to a studies done in Indian(12,45). This could be due to the distribution of scarce resources within the family and related to the maternal exhaustion of micronutrient feeding practices.

In a multivariable multilevel analysis, the odds of developing childhood anaemia were higher among children who lived in Somali, Dire Dawa, Afar, and Gambela compared to Amhara region. This might be due to the unavailability and inaccessibility of health facilities as compared to the regions. Regional variation in the nutrient intake can cause significant health disparity, and this variability may be mediated by factors such as food availability, food customs, and culture.

This study, used different methodologies; spatial pattern, trends, and a multilevel regression model because of nested or cluster samples to show the effect of individual predictors and community-level variables on the outcome variable. The study was based on a large dataset representing the whole country of Ethiopia and which was weighted to make it nationally representative and adjusted for the design to get a reliable estimate. However, there were some limitations to this study. The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables. Also, respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the overall result and the generalizability of the findings.

Conclusion

through declining prevalence of childhood anaemia was observed from 2005 to 2011, it increases from 2011-2016 survey. Besides, it was spatially clustered across regions in Ethiopia. The most prominent risk areas of anaemia were detected in Afar, Somali, Dire Dawa and Oromia regions more or less consistently overtime in the last one and half-decade. Child age, women age, wealth index, maternal anaemia, fever, birth order, stunting, wasting and region were significant predictors among 6-59 months. Therefore, public health intervention actions intended in a targeted approach to bearing high-risk populations as well as geographic regions were vital to reduce childhood anaemia in Ethiopia.

Abbreviations

AOR-Adjusted Odds Ratio, CSA-Central Statics Agency, CI-Confidence Interval, CMHS-College of Medicine and Health Science COR-Crude Odds Ratio, EDHS-Ethiopia Demographic and Health Survey, GPS-Global Positioning System, ICC-Intra Class Correlation Coefficient, LLR-Log-Likelihood Ratio, MOR-Median odds ratio, OR-Odds Ratio, RR-Relative Risk, PVC-Proportional Change in Variance, SNNPR- Southern Nations, Nationalities, and Peoples' Region.

Declarations

Onset to participate

The institutional ethical review committee board approved the study. Ethical clearance was obtained from ethical review board of the University of Gondar. Upon this clearance, the study was conducted. The congeniality of the data was maintained by using the extracted data only for the study purpose and keeping the data from a third party.

Consent for publication

Not-applicable

Data sharing statement

The data in which the authors used to produce this manuscript are available upon reasonable request

Competing interests

The authors declare that they have no competing interests.

Funding

No funding

Contributors

Proposal preparation, acquisition of data, analysis, and interpretation of data was done by SH, AM, ZM and BF guided the study design data collection and analysis. SH drafted the manuscript and all authors have a substantial contribution in revising and finalizing the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors gratefully acknowledge the support received from the University of Gondar. We also thank the Ethiopian Central Statistics Agency for providing us with the data and shape files for this study.

References

1. WHO. Nutritional Anaemias : Tools for Effective Prevention. World Health Organization. 2017. 1–83 p.
2. WHO. Global estimates of the prevalence of anaemia in infants and children aged 6 – 59 months , 2011 Global estimates of the prevalence of anaemia , all women of reproductive age , 15 – 49 years , 2011. Scaling Up Nutr [Internet]. 2015; Available from: http://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011_maps.pdf?ua=1
3. WHO. The global prevalence of anaemia in 2011. Who [Internet]. 2011;1–48. Available from: https://apps.who.int?iris/hendle/10665/177094
4. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005. Public Health Nutr. 2009;12(4):444–54.
5. Malkanthi RLDK, Silva KDRR, Jayasinghe-Mudalige UK. Risk Factors Associated with High Prevalence of Anemia among Children under 5 Years of Age in Paddy-Farming Households in Sri Lanka. Food Nutr Bull. 2010;31(4):475–82.
6. Olivares M, Walter T, Hertrampf E, Pizarro F. Anaemia and iron deficiency disease in children. Br Med Bull [Internet]. 1999 Sep 1;55(3):534–43. Available from: https://doi.org/10.1258/0007142991902600
7. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993-2005. Public Health Nutr. 2009;12(4):444–54.
8. Leal LP, Batista Filho M, de Lira PIC, Figueiroa JN, Osório MM. Temporal trends and anaemia-associated factors in 6- to 59-month-old children in Northeast Brazil. Public Health Nutr. 2012;15(9):1645–52.
9. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: a cross-sectional study. BMJ Open [Internet]. 2018 May 1;8(5):e019654. Available from: http://bmjopen.bmj.com/content/8/5/e019654.abstract
10. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health. 2019;19(1):1–9.
11. Malako BG, Teshome MS, Belachew T. Anemia and associated factors among children aged 6-23 months in Damot Sore District, Wolaita Zone, South Ethiopia. BMC Hematol. 2018;18(1):1–9.
12. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: A cross-sectional study. BMJ Open. 2018;8(5):1–14.
13. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in nigeria: A bayesian semi-parametric modelling. Int Health. 2014;6(1):35–45.
14. Desalegn A, Mossie A, Gedefaw L. Nutritional Iron Deficiency Anemia: Magnitude and Its Predictors among School Age Children, Southwest Ethiopia: A Community Based Cross-Sectional Study. PLoS One [Internet]. 2014 Dec 1;9(12):e114059. Available

from: https://doi.org/10.1371/journal.pone.0114059
15. Guerra CA, Snow RW, Hay SI. Defining the global spatial limits of malaria transmission in 2005. Adv Parasitol. 2006;62:157–79.
16. Central Statistical Agency, ORC Macro. Ethiopia Demographic and Health Survey 2005. Heal San Fr [Internet]. 2006;(September):[446]. Available from: http://www.measuredhs.com/pubs/pdf/FR179/FR179[23June2011].pdf
17. Central Statistical Agency [Ethiopia], ICF International. Ethiopia Demographic and Health Survey 2011. 2012;1–452.
18. ECSA. Ethiopian Demographic Health Survey 2016. 2016. 161 p.
19. Kulldorff M. SatScan user guide 2006. 2018;
20. Bartko JJ. The Intraclass Correlation Coefficient as a Measure of Reliability. Psychol Rep. 1966 Aug;19(1):3–11.
21. Assessment IS. Understanding Variability in Multilevel Models Sophia Rabe-Hesketh Example : PISA (Programme for International Student Assessment) PISA : Distribution of SES.
22. Enawgaw B, Workineh Y, Tadesse S, Mekuria E, Addisu A, Genetu M. Prevalence of anemia and associated factors among hospitalized children attending the University of Gondar Hospital, Northwest Ethiopia. Electron J Int Fed Clin Chem Lab Med. 2019;30(1):35–47.
23. Semedo RML, Santos MMAS, Baião MR, Luiz RR, Da Veiga G V. Prevalence of Anaemia and Associated Factors among Children below Five Years of Age in Cape Verde, West Africa. J Heal Popul Nutr. 2014;32(4):646–57.
24. Tiku YS, Mekonnen TC, Workie SB, Amare E. Does Anaemia Have Major Public Health Importance in Children Aged 6–59 Months in the Duggina Fanigo District of Wolaita Zone, Southern Ethiopia? Ann Nutr Metab [Internet]. 2018;72(1):3–11. Available from: https://www.karger.com/DOI/10.1159/000484324
25. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in Nigeria: a Bayesian semi-parametric modelling. Int Health [Internet]. 2014 Jan 31;6(1):35–45. Available from: https://doi.org/10.1093/inthealth/iht034
26. Roberts DJ, Matthews G, Snow RW, Zewotir T, Sartorius B. Investigating the spatial variation and risk factors of childhood anaemia in four sub-Saharan African countries. BMC Public Health. 2020;20(1):126.
27. Diao X, Taffesse AS, Thurlow J, Pratt AN, Yu B, Orkin K, et al. NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Highlights of Presentations Summer – Fall 2010 : h NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Capacity Building Initiatives 2010 : 2010;(December).
28. Gebreweld A, Ali N, Ali R, Fisha T. Prevalence of anemia and its associated factors among children under five years of age attending at Guguftu health center, South Wollo, Northeast Ethiopia. PLoS One [Internet]. 2019 Jul 5;14(7):e0218961. Available from: https://doi.org/10.1371/journal.pone.0218961
29. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health [Internet]. 2019;19(1):215. Available from: https://doi.org/10.1186/s12889-019-6547-1
30. Mohammed SH, Habtewold TD, Esmaillzadeh A. Household, maternal, and child related determinants of hemoglobin levels of Ethiopian children: Hierarchical regression analysis. BMC Pediatr. 2019;19(1):1–10.
31. Keikhaei B, Zandian K, Ghasemi A, Tabibi R. Iron-Deficiency Anemia among Children

in Southwest Iran. Food Nutr Bull. 2007 Dec;28(4):406–11.
32. Campbell JR, Holland J. Development research. Focaal. 2007;2005(45):3–17.
33. Gebreegziabiher G, Etana B, Niggusie D. Determinants of Anemia among Children Aged 6–59 Months Living in Kilte Awulaelo Woreda, Northern Ethiopia. Benz EJ, editor. Anemia [Internet]. 2014;2014:245870. Available from: https://doi.org/10.1155/2014/245870
34. Ayoya MA, Ngnie-Teta I, Séraphin MN, Mamadoultaibou A, Boldon E, Saint-Fleur JE, et al. Prevalence and risk factors of anemia among children 6-59 months old in Haiti. Anemia. 2013;2013:2–5.
35. Pasricha SR, Black J, Muthayya S, Shet A, Bhat V, Nagaraj S, et al. Determinants of anemia among young children in rural India. Pediatrics. 2010;126(1).
36. Ntenda PAM, Nkoka O, Bass P, Senghore T. Maternal anemia is a potential risk factor for anemia in children aged 6–59 months in Southern Africa: a multilevel analysis. BMC Public Health [Internet]. 2018;18(1):650. Available from: https://doi.org/10.1186/s12889-018-5568-5
37. Shenton LM, Jones AD, Wilson ML. Factors Associated with Anemia Status Among Children Aged 6–59 months in Ghana, 2003–2014. Matern Child Health J. 2020;24(4):483–502.
38. Khan JR, Awan N, Misu F. Determinants of anemia among 6–59 months aged children in Bangladesh: evidence from nationally representative data. BMC Pediatr [Internet]. 2016;16(1):3. Available from: https://doi.org/10.1186/s12887-015-0536-z
39. Rahman MS, Mushfiquee M, Masud MS, Howlader T. Association between malnutrition and anemia in under-five children and women of reproductive age: Evidence from Bangladesh Demographic and Health Survey 2011. PLoS One. 2019 Jul;14(7):e0219170–e0219170.
40. Belachew A, Tewabe T. Under-five anemia and its associated factors with dietary diversity, food security, stunted, and deworming in Ethiopia: systematic review and meta-analysis. Syst Rev. 2020 Feb;9(1):31.
41. Malako BG, Asamoah BO, Tadesse M, Hussen R, Gebre MT. Stunting and anemia among children 6–23 months old in Damot Sore district, Southern Ethiopia. BMC Nutr. 2019;5(1):1–11.
42. Pelletier DL, Frongillo Jr EA, Schroeder DG, Habicht JP. The effects of malnutrition on child mortality in developing countries. Bull World Health Organ. 1995;73(4):443–8.
43. Takele WW, Baraki AG, Wolde HF, Desyibelew HD, Derseh BT, Dadi AF, et al. Anemia and Contributing Factors in Severely Malnourished Infants and Children Aged between 0 and 59 Months Admitted to the Treatment Centers of the Amhara Region, Ethiopia: A Multicenter Chart Review Study. Hassen K, editor. Anemia [Internet]. 2021;2021:6636043. Available from: https://doi.org/10.1155/2021/6636043
44. Caulfield LE, Richard SA, Rivera JA, Musgrove P, Black RE. Chapter 28. Stunting,Wasting, and Micronutrient Deficiency Disorders. Dis Control Priorities Dev Ctries (2nd Ed. 2006;551–68.
45. Goswmai S, Das KK. Socio-economic and demographic determinants of childhood anemia. J Pediatr (Rio J). 2015;91(5):471–7.

Figure legend/caption

Figure 1: Trends in anaemia overtime across the regions in Ethiopia, EDHS 2005 to 2016

682 Figure 2: Hot spot and cold spot analysis of anaemia in Ethiopian, EDHS 2005 to 20016

683 Figure 3: Ordinary Kriging interpolation of anaemia in Ethiopia, EDHS 2005 to 2016

684 Figure 4: Spatial scan statistics analysis of anaemia in Ethiopia, EDHS, 2005-2016

685

686

687

688

689

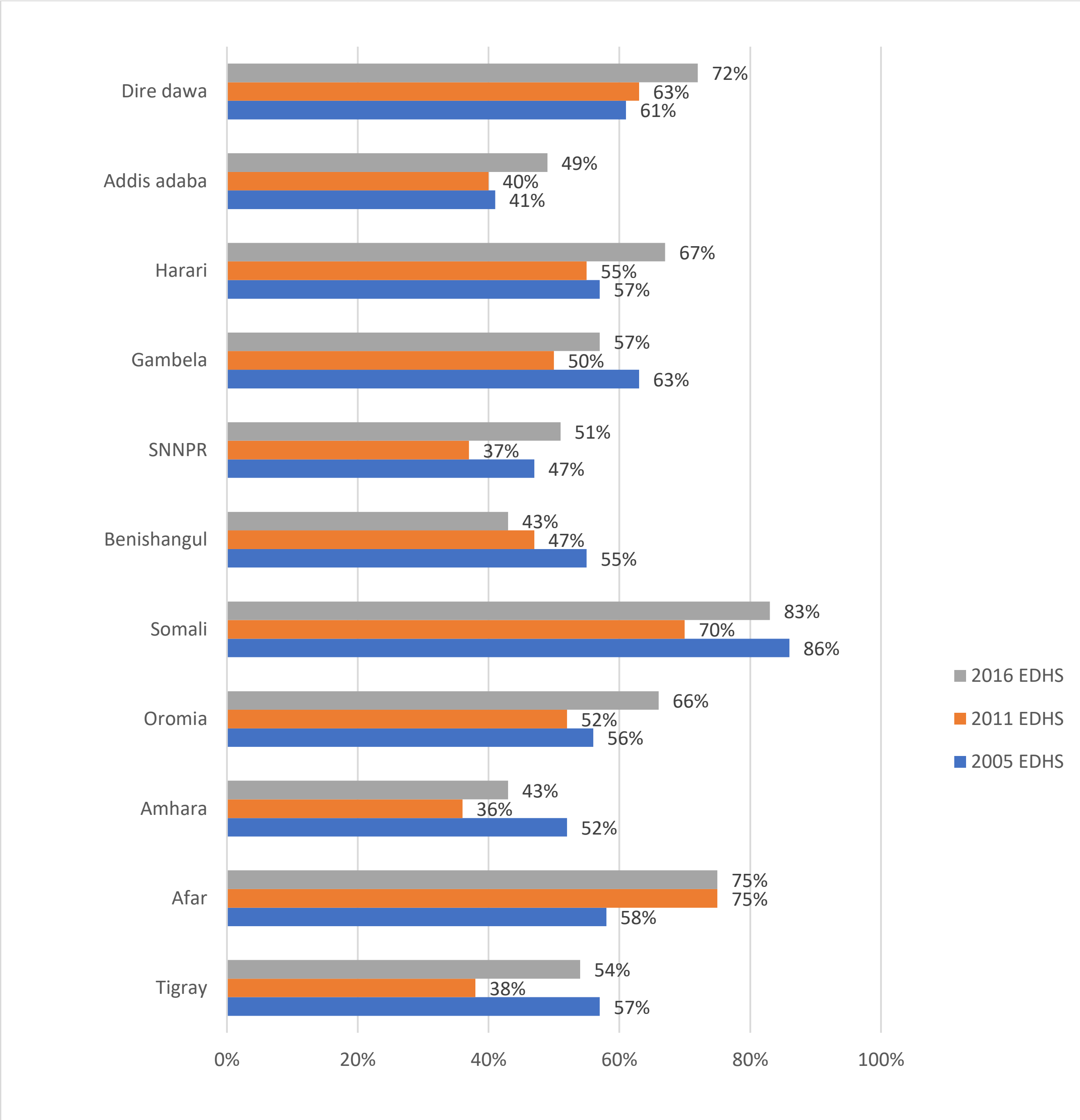


Figure 1: Trends in anaemia overtime across the regions in Ethiopia, EDHS 2005 to 2016

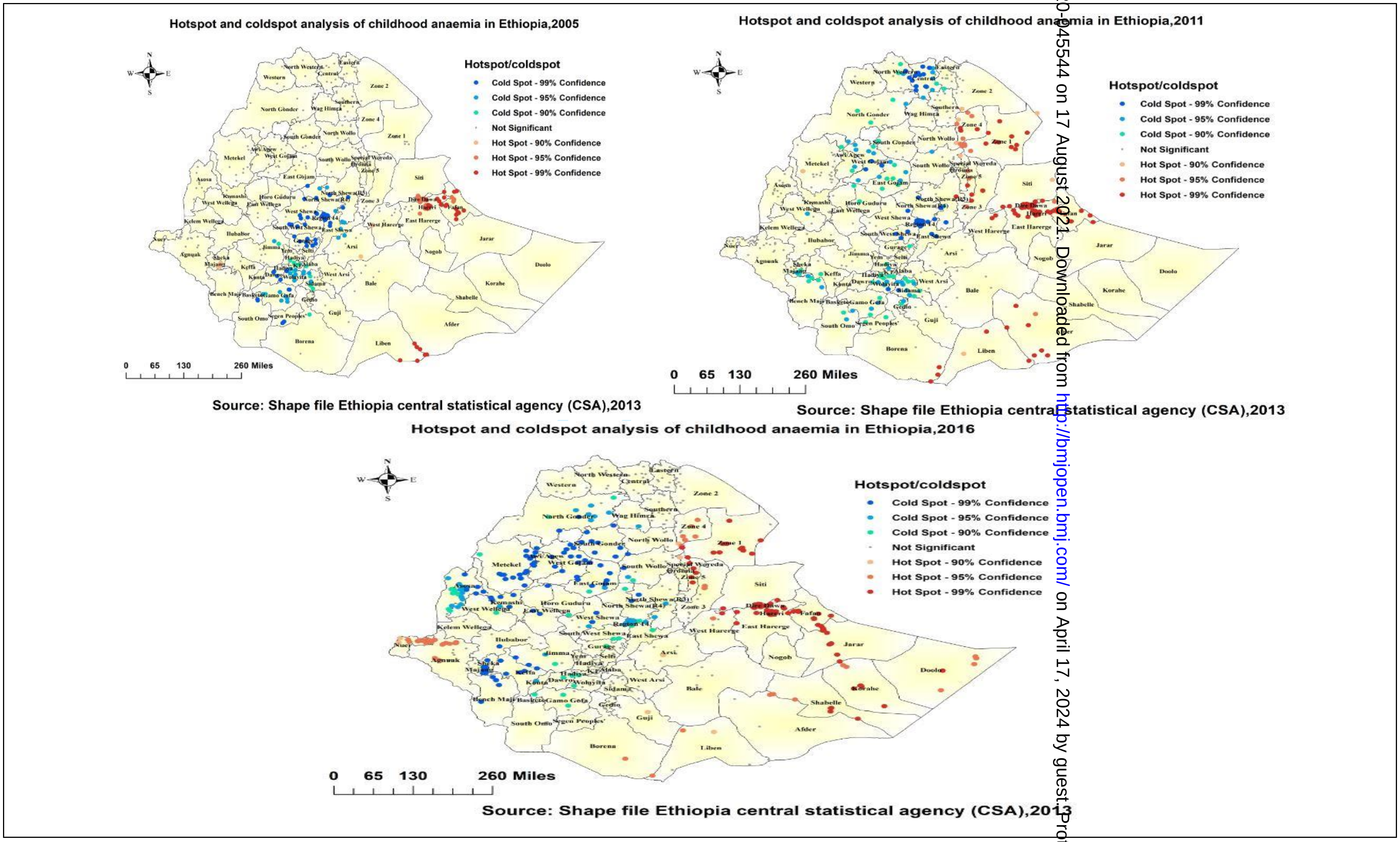


Figure 2: Hot spot and cold spot analysis of anaemia in Ethiopian, EDHS 2005 to 20016

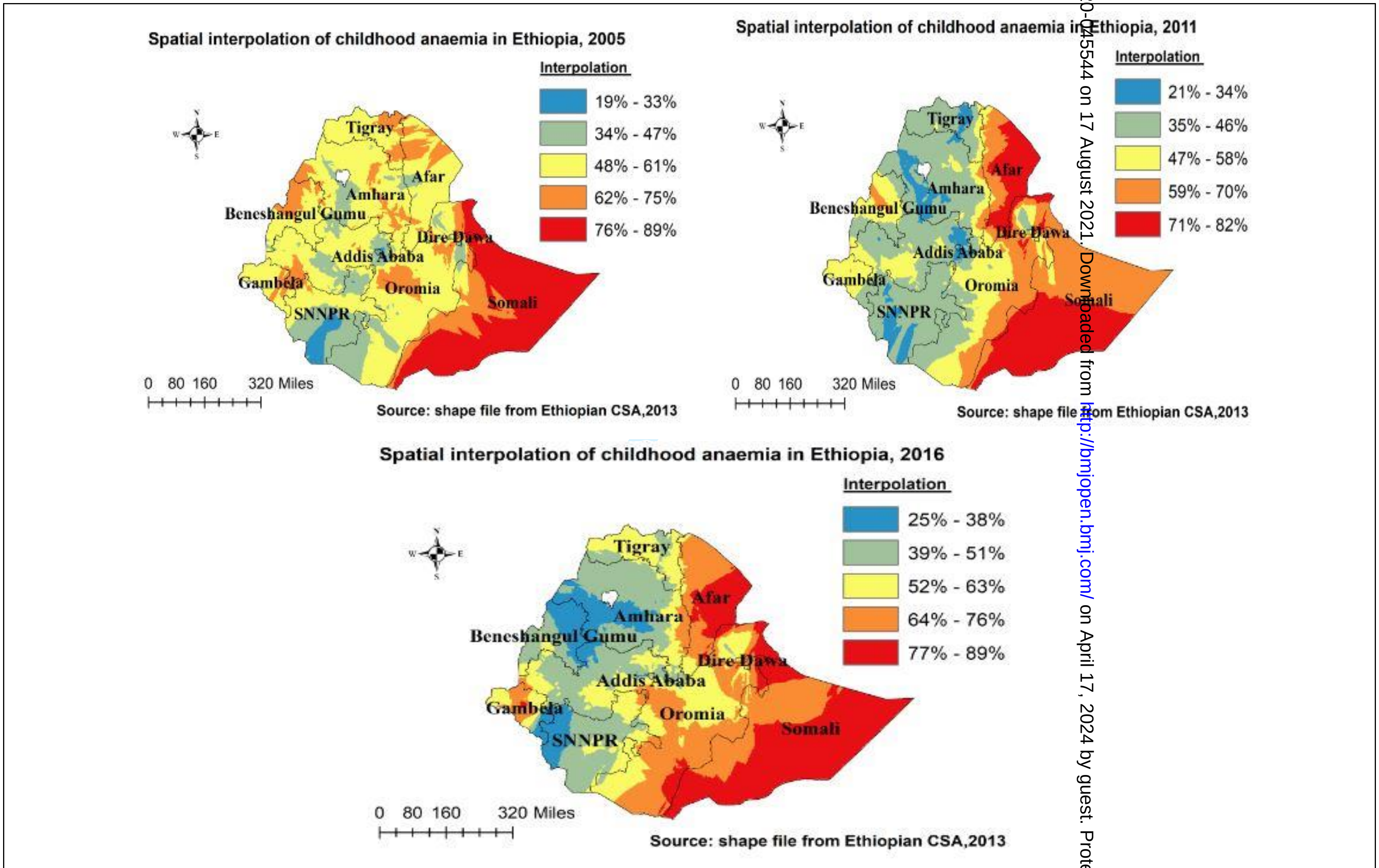


Figure 3: Ordinary Kriging spatial interpolation of anaemia in Ethiopia, EDHS 2005 to 2016

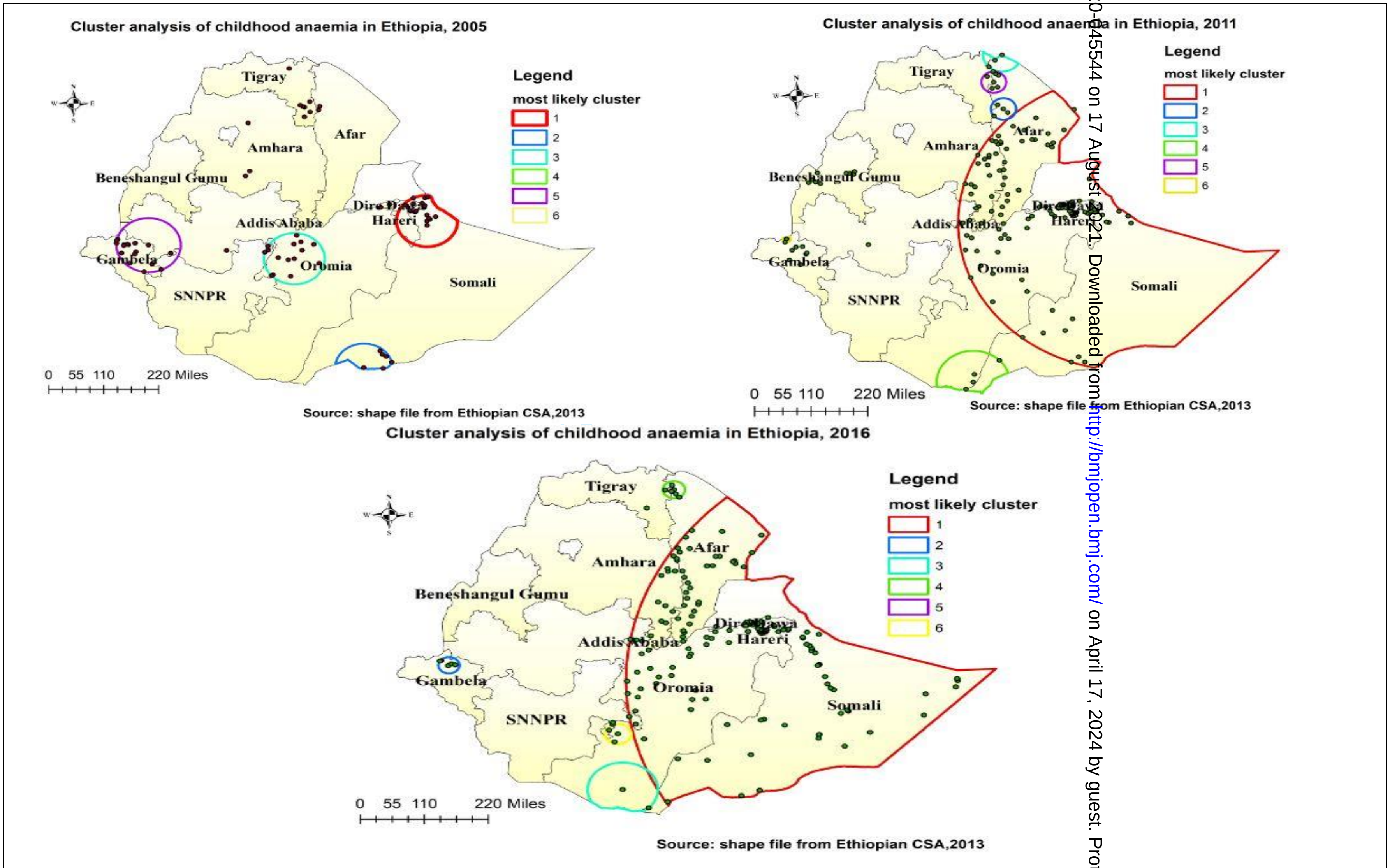


Figure 4: Spatial scan statistics analysis of anaemia in Ethiopia, EDHS, 2005-2016

BMJ Open

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: a spatial and multilevel analysis based on the EDHS 2005-2016

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-045544.R3
Article Type:	Original research
Date Submitted by the Author:	20-Jul-2021
Complete List of Authors:	Samuel, Hailegebreal; Arba Minch University, Department of Health Informatics Nigatu, Araya; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia Mekonnen, Zeleke; Ethiopia Ministry of Health, Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia; Endehabtu, Berhanu; University of Gondar, Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia
Primary Subject Heading:	Public health
Secondary Subject Heading:	Public health, Health informatics
Keywords:	PAEDIATRICS, Community child health < PAEDIATRICS, Anaemia < HAEMATOLOGY, EPIDEMIOLOGY

SCHOLARONE™ Manuscripts

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: a spatial and multilevel analysis based on the EDHS 2005- 2016

Samuel Hailegebreal[1*], Araya Mesfin Nigatu[2], Zeleke Abebaw Mekonnen[2,3], Berhanu Fikadie Endehabtu[2]

Affiliation

[1]Arba Minch University, College of Medicine and Health Sciences, School of Public Health Department of Health Informatics, Ethiopia

[2]Department of Health Informatics, Institute of Public Health, University of Gondar, Ethiopia

[3]Health System Directorate, Ministry of Health, Addis Ababa, Ethiopia

Corresponding author

Samuel Hailegebreal

Email: samuastd@gmail.com

Abstract

Objectives: Anaemia is a global public health problem with major health and socio-economic consequences. Though childhood anaemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anaemia over time in the country. Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and Health Survey (EDHS) data from 2005-2016.

Design: Survey-based cross-sectional study design was employed for the EDHS.

Setting: Data were collected in all nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.

Participants: The source population for this study was all 6–59 months of children in Ethiopia. A total of 21,302 children aged 6-59 months were included in this study.

Outcome measure: The outcome variable was child anaemia status.

Results: The prevalence of anaemia declined from 53.9% in 2005 to 44.6% in 2011, but it showed an increase in 2016 to 57.6%. The spatial analysis revealed that the spatial distribution of anaemia varied across the regions. The spatial scan statistics analysis indicated a total of 22 clusters (RR= 1.5, P-value < 0.01) in 2005, 180 clusters (RR = 1.4, P-value < 0.01) in 2011, and 219 clusters (RR = 1.4, P-value < 0. 0.01) in 2016 significant primary clusters were identified. The child's age, age of the mother, maternal anaemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anaemia.

Conclusions: In this study, childhood anaemia remains a public health problem. The spatial distribution of childhood anaemia varied significantly across the country. Individual-level and

community-level factors were associated with childhood anaemia. Therefore, in regions with a high risk of childhood anaemia, individual and community level factors should be intensified by allocating additional resources and providing appropriate and tailored strategies.

Keywords*:* Anaemia, Childhood, EDHS, Spatial, Multilevel, Ethiopia

Strengths and limitations of this study

- This study applied different methods to analyses spatial patterns, trends, and used multilevel logistic regression models, accounting for the nested nature of EDHS data
- The study was based on three consecutive EDHS datasets representing the whole country of Ethiopia
- The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables
- Respondents without coordinate (longitude and latitude) were excluded from the spatial analysis, which could affect the generalizability of the findings

Background

Anaemia is a condition characterized by a low level of haemoglobin in the blood(1). Over 273 million children age under five years suffer from anaemia worldwide(2). Sub-Saharan Africa is one of the most affected regions, accounting for 53.8% of childhood anaemia(2). World Health Organization (WHO) had developed a classification system to facilitate international comparisons of anaemia as public health crises. The problem is considered severe if anaemia prevalence is ≥40%, moderate from 20% to 39.9%, and mild from 5% to 19.9%(3). The high prevalence of anaemia and its consequences for child health, especially on their growth and development, have made it an important public health problem. Anaemia also increases the risk of mortality and morbidity that come from other diseases(4,5).

Anaemia is a public health problem that affects populations in both industrialized and non-industrialized countries which touches all segments of the population. It is frequently observed among children and pregnant women who are the most vulnerable group because their iron requirements are higher than any other group(6). Anaemia is defined as a haemoglobin level below 11.0 g/dl for children age 6-59 months. Childhood anaemia is mainly caused by dietary iron deficiency, foliate, vitamin B12, vitamin A deficiencies, chronic inflammation, parasitic infections, nutritional deficiencies, hemoglobinopathies and inherited disorders (7,8).

A report from WHO in 2015 regarding global anaemia prevalence, using data for 2011, has shown that prevalence for Africa, southeast Asia, America and the European regions was 62.3%,53.8%,23.3%, and 22.9% respectively(3). In Sub-Saharan Africa, anaemia is a significant public health problem associated with an increased risk of death and impaired cognitive development(9).

Various studies showed that the prevalence of anaemia among children aged 6-59-months was high and a severe public health problem. Evidence from various studies indicated that age of the mother , residence, maternal education status(10), an introduction of complementary foods, poor breastfeeding practice, poor utilization of folic acid by mothers(11), maternal anaemia(12), unemployment of the parent, and presence of sickle haemoglobin, household wealth index, and sex of the child were associated with childhood anaemia(13) . Few studies have been done on factors associated with anaemia in Ethiopia, to date; the risk areas (hot spot) of anaemia among children are not identified. Thus, this study aimed to assess the spatiotemporal patterns of anaemia among children aged under five years in Ethiopia over the last 15 years to evaluate whether there have been improvements in anaemia risk areas following intervention programs in between the survey periods in Ethiopia. Geographical differences in the causes of anaemia can be partially explained by large-scale variability in environmental drivers, particularly nutritional and infectious causes(14). The risk of malaria is known to be associated with elevation and land surface temperature(15). Environmental drivers of anaemia tend to show a high degree of spatial dependency. Therefore, detecting the geographic variation of anaemia during childhood is important to prioritize and design targeted intervention programs to reduce anaemia especially in those areas with a consistently higher risk of anaemia over time. Therefore, this study attempts to fill the gap by investigating the spatio-temporal distribution of anaemia and its associated factors using multilevel model analysis in Ethiopia using the EDHS survey between 2005-2016 data.

Methods and materials

Study design, setting and period

A cross sectional survey data from three consecutive EDHS (2005, 2011 and 2016) were used for this study. The surveys were conducted at 5-year interval at the national level. Ethiopia is situated in the Horn of Africa (3^{o}-14^{o}N and 33^{o} – 48^{o}E). Administratively, the country is divided into nine regions (Afar, Amhara, Benishangul-Gumuz, Gambela, Harari, Oromia, Somali, Southern Nations, Nationalities, and People's Region (SNNPR), and Tigray) and two cities administration (Addis Ababa and Dire-Dawa). Each region is sub-divided into zones, districts, towns, and kebeles (the smallest administrative units).

Source and study population

All children aged 6-59-months in Ethiopia were the source population for this study whereas all children aged 6-59 months in the selected enumeration areas within five years before the survey were the study population.

Sample size and sampling technique

For the current study, a total of 21,302 children aged 6-59-months were extracted from three surveys and included in the analysis. Children's record (KR) datasets were used for this analysis. The survey covered all nine regions and the two city administrations of Ethiopia. Participants were selected based on a stratified two-stage cluster sampling technique in each survey year. After excluding clusters with zero coordinates and missing information, a total of 503 clusters in 2005, 569 clusters in 2011, and 615 clusters in 2016 were used for analysis. The detailed sampling procedure was available in each survey years report(16–18)

Data collection tools and procedures

The data for this analysis were extracted from Demographic and Health Survey (DHS) program website (www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses. Similarly, spatial location data (latitude and longitudinal) were extracted from the DHS website. After extraction, the missing values for the significant independent variables were excluded and the analysis was undertaken using a complete data set. Blood specimens for anaemia testing were collected from all children age 6-59 months for whom consent was obtained from their parents or other adults responsible for them. Blood samples were drawn from a drop of blood taken from a finger prick or a heel prick in the case of children age 6-11 months and collected in a microcuvette. Haemoglobin analysis was carried out on-site using a battery-operated portable HemoCue analyser.

Key variables and measurements

Dependent variable: The study variables were grouped into dependent and independent variables. The dependent variable is childhood anaemia status, categorized as "anaemic or not-anaemic". Children whose haemoglobin level was less than 11g/dl were considered anaemic and not anaemic otherwise.

Independent variables:

sociodemographic (religion, age of mother, marital status, educational status, husband education, wealth index, mothers working status, numbers of under five children) Maternal and Child- related (child's sex, child's age, birth size, birth order, maternal BMI, maternal anaemia status, breastfeeding, fever, diarrhoea, vitamin supplement, stunting status and wasting status). Community-level variables (residence, region, community women education and community women poverty).

We created community women education and community women poverty variables by aggregating the individual characteristics within their clusters. The aggregates were computed using the median values of the proportions of women in each category of a given variable. We categorized the aggregate values of a cluster into groups based on national median values, since all aggregates were not normally distributed.

Community women education: was defined as the proportion of women who attended primary, secondary, and higher education within the cluster. The aggregate of individual primary, secondary, and higher educational attainment can show the overall educational and academic status of women within the cluster. They were categorized into two categories a higher proportion of women education within the cluster and a lower proportion of women education based on the national median value.

Community women poverty status: defined as the proportion of poor and poorest mothers within the cluster. For each cluster, the proportion of poor and poorest as-was aggregated and show overall poverty status within the cluster. It was categorized into two categories based on national median value as higher proportion of poor/poorest mother's and lower proportion of mothers within a cluster.

Data management and analysis

The data were cleaned using STATA version 14.1 software and microsoft excel. The data were weighted using sampling weight, primary sampling unit, and strata before any statistical analysis to restore the representativeness of the survey and take into account the sampling design to obtain reliable statistical estimates.

Spatial analysis

For the spatial analysis, ArcGIS V.10.7 software, and SaTScan V.9.6 software were used.

The spatial scan statistics uses a circular scanning window that moves across the study area to identify a significant spatial clustering of childhood anaemia.

Spatial autocorrelation analysis

The spatial autocorrelation (Global Moran's I) statistic measures whether childhood anaemia patterns were dispersed, clustered or randomly distributed in the study area. Moran's I is a spatial statistic used to measure spatial autocorrelation by taking the entire dataset and produce a single output value that ranges from −1 to +1. Moran's I values close to −1 indicate the spatial distribution of anaemia was dispersed, whereas Moran's I close to +1 indicate the spatial distribution of anaemia was clustered, and an I value of 0 means anaemia is distributed randomly. Anselin's Local Moran's *I* (ALM*I)* identifies High-High clusters, Low-Low clusters, and spatial outliers (High-Low and Low-High).

Hot spot analysis (Getis-Ord Gi* statistic)

Local Moran's I, Gettis-OrdGi* statistics was computed to measure how spatial autocorrelation of anaemia among children age under five years varies across the regions. In this analysis, Z-score and p-value were computes to determine the statistical significance of the clustering. Statistical output with high GI* indicates 'hotspot' (high-risk areas) of childhood anaemia, whereas low GI* shows a 'cold spot' (low-risk areas) of anaemia in Ethiopia.

Spatial interpolation

The unsampled areas of Ethiopia were also predicted by using data from sampled locations through the spatial interpolation technique. There are various deterministic and geostatistical interpolation methods. Among all of the methods, ordinary Kriging and empirical Bayesian Kriging are considered the best methods since they incorporate spatial autocorrelation and statistically optimize the weight. Ordinary Kriging spatial interpolation method was used for this study for predictions of childhood anaemia in unobserved areas of Ethiopia since it had low mean square error and residual as compared to the other interpolation techniques.

Spatial scan statistical analysis

Spatial scan statistical analysis was employed to Identifying most likely(primary) and secondary spatial clusters of childhood anaemia. This method is widely recommended as it is very important in detecting local clusters and has higher power than other available spatial statistical methods. Bernoulli based model was employed to test for statistically significant spatial clusters of anaemia using Kulldorff's SaTScan V.9.6 software. Children age under five years with anaemia were taken as cases, and those who are not-anaemic as controls to fit the Bernoulli model. The default maximum spatial cluster size of <50% of the population was used.

The scanning window with maximum likelihood was the most likely cluster, and the p-value was assigned to each cluster based on Monte Carlo hypothesis testing(19).

Associated factors of anaemia

Four models were constructed for multilevel logistic regression analysis using **melogit** STATA command**.** The first model (a random intercept model) was null model without predictors to determine the extent of cluster variations in anaemia. The second model (model I) was adjusted with individual-level variables. The third model (model II) was adjusted for community-level variables, while the fourth model (model III) was fitted with both individual-level and community-level variables simultaneously. For model comparison, we used Log-Likelihood Ratio (LLR) and deviance.

Intra-class correlation (ICC), median odds ratio (MOR), and proportional change in variance (PCV) were computed to measure the variation between clusters. The intra-class correlation coefficient (ICC) quantifies the degree of heterogeneity of childhood anaemia between clusters (the proportion of the total observed individual variation in anaemia that is attributable between cluster variations) calculated as

$ICC = \frac{\sigma^2}{(\sigma^2 + \sigma^2{}_b)}$ (20) , where, σ^2 is the community level variance and $\sigma^2{}_b$ indicates individual level variance. The individual variance ($\sigma^2{}_b$) equal to $\pi^2/3$.

Median Odds Ratio (MOR) is quantifying the variation of the odds ratio between the cluster at high risk of anaemia and cluster at lower risk when randomly picking out two clusters (EAs).

$MOR = e^{(0.95 * \text{sqrt}(\sigma^2)}$(21) where, σ^2 indicates that cluster level variance.

Proportional Change in Variance (PCV) the proportion of the total observed individual variation of childhood anaemia that is attributable to between cluster variations. In the multivariable multilevel logistic regression analysis variables with a p-value of <0.05 were considered as statistically significant. Adjusted Odds Ratio (AOR) with their corresponding 95% confidence interval was determined to identify factors associated with anaemia. Multicollinearity was checked using the variance inflation factor (VIF), which indicates that there is no multicollinearity because all variables have VIF less than 10%. The final model was the best fitted model since it had the highest log-likelihood and the lowest deviance value.

Patient and public involvement

This study did not involve patients and the public

Results

Descriptive characteristics of the study population

A total of 21,302 children with known haemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anaemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively. The majority of the participants were in the age group of 36-47 (23.7%), 36-47 (24.4%), and, 48-59 (22.9%) in EDHS 2005, 2011, and 2016 survey respectively. The mean age of children was 32.6 ±15.6-SD, 32.6±15.4-SD, and 31.7±15.6-SD in 2005, 2011, and 2016 respectively. Among the three survey, male participants were higher in 2011 and 2016 compared to 2005 EDHS survey. The majority of children were from rural resident in three surveys. The educational status of women was 78.6%, 70.1%, and 67.1% were unable to read and write in 2005, 2011, and 2016 survey years respectively. Children from poor and middle class wealth index families were more anaemic than children from rich families across the three EDHS survey years (Table 1). In this study, the trends in the childhood anaemia rate were fluctuates across regions **(Fig.1)**.

256 **Table 1: Descriptive characteristics of study participants included in the analysis for**
257 **childhood anaemia five years preceding the survey from EDHS 2005-2016 in Ethiopia**

Variables	2005 (N, 3868)	2011 (N, 8958)	2016 (N, 8476)
	Frequency (%)	Frequency (%)	Frequency (%)
Sex of child			
Male	1,931(49.9)	4,500(51.4)	4,395(51.9)
Female	1,937(50.1)	4,358(48.7)	4,081(48.2)
Age of child in month			
6-11	418 (10.8)	1,029(11.5)	1,000(11.8)
12-23	842 (21.76)	1,804(20.14)	1,902(22.4)
24-35	825 (21.3)	1,895(21.2)	1,803(21.3)
36-47	919 (23.7)	2,184(24.4)	1,832(21.6)
48-59	864 (22.3)	2,047(22.9)	1,939(22.9)
Mean ± SD	**32.6 ±15.6**	**32.6±15.4**	**31.7±15.6**
Residence			
Urban	244 (6.3)	1,047(11.7)	857(10.1)
Rural	3,624 (93.7)	7,911(88.3)	7,619(89.9)
Religion			
Orthodox	1,624 (42.0)	3,416(38.1)	2,913(34.4)
Muslim	1,276 (33.0)	3,108(34.7)	3,432(40.5)
Protestant	836 (22.0)	2,151(24.0)	1,874(22.1)
Others	133 (3.0)	283(3.2)	258(3.0)
Women age			
15-29	1,930(49.9)	4,908(54.9)	4,356(51.4)

30-39	1,474(38.1)	3,223(36.0)	3,335(39.3)
40-49	464(12.0)	828(9.1)	785(9.3)
Women education			
No education	3,042 (78.6)	6,285(70.1)	5,685(67.1)
Primary	684 (17.7)	2,389(26.7)	2,275(26.8)
Secondary	136 (3.5)	168(1.9)	346(4.1)
Higher	7 (0.2)	117(1.3)	170(2.0)
Marital status			
Single	7(0.2)	50(0.6)	45(0.5)
Married	3,704(95.7)	8,425(94.0)	8,129(95.9)
Widowed	80(2.1)	178(2.0)	93(1.1)
Divorced	78(2.0)	306 (3.4)	210(2.5)
Husband education			
No-education	2,235 (58.0)	4,532(50.9)	4, 33(51.1)
Primary	1,233(32.0)	3,710(41.7)	3,273(38.6)
Secondary	362(9.0)	412(4.6)	572(6.8)
Higher education	31(1.0)	255 (2.8)	300(3.5)
Wealth index			
Poor	1,697(43.7)	4,048(45.2)	3,977(46.9)
Middle	854(22.1)	1,873(20.9)	1,821(21.5)
Rich	1,318(34.1)	3,038 (33.9)	2,678(31.6)
Women working status			
Not working	2,841(73.5)	5,793(64.7)	6,140(72.4)

Working	1,027(26. 5)	3,165(35.3)	2,336(27.6)
Total	3,868(100)	8,958(100)	8,476(100)

Community-level characteristics of the study population This study revealed that there was a significant regional variation of childhood anaemia, with 83.3%, 75.5%,74.5%, and 68.8% in Somali, Afar, Dire Dawa and Harari respectively. However, Amhara, and Benishangul regions were relatively low compared to other regions.

Also, childhood anaemia varies by place of residence. Children residing in communities with low women poverty level had a lower percent of anaemia (51.2%) than high community poverty level (62.5%). Children from low community women education (59.5%) were more anaemic than children resided from high community women educational (53.6%) (Table 2).

Table 2: Community-level factors of under five children participated in EDHS (2016), Ethiopia. (N, 8476)

Community-level factors	Not-anaemic (%)	Anaemic (%)	Total (100%)
Residence			
Urban	435(50.6)	424(49.4)	857
Rural	3164(41.5)	4455(58.5)	7619
Region			
Tigray	263(46.0)	309(54.0)	572
Afar	21(25.3)	62(74.5)	83
Amhara	950(57.5)	703(42.5)	1653
Oromia	1273(34.2)	2446(65.8)	3719
Somali	58(16.7)	290(83.3)	348

Beneshangul	51(56.6)	39(43.4)	90
SNNPR	875(49.1)	906(50.9)	1781
Gambela	8(42.1)	11(57.9)	19
Harari	5(31.2)	11(68.8)	16
Addis Ababa	82(50.9)	79(49.1)	161
Dire Dawa	9(28.1)	23(71.9)	32
Community women education			
Low	2281(40.5)	3358(59.5)	5639
High	1315(46.4)	1520(53.6)	2837
Community women poverty			
Low	1815(48.8)	1905(51.2)	3719
High	1782(37.5)	2974(62.5)	4756

Spatio-temporal distribution of anaemia among children age 6-59 months in Ethiopia

The spatial distribution of childhood anaemia varied across regions in all surveys. The spatial autocorrelation analysis result indicated that childhood anaemia had spatial dependency in 2005, 2011, and 2016 (Moran's I: 0.176, 0.18, and 0.09, respectively at P-value < 0.01).

Hot spot analysis of the three surveys

The spatial distribution of childhood anaemia in Ethiopia was different in all the three survey periods. In EDHS 2005, a high proportion of childhood anaemia was detected in Dire Dawa, Harari, eastern Oromia, Beneshangul in Metekel zone, Gambela, southern and eastern Tigray, and Somali region mainly Liben, Afdar, and Fafna zone which was hotspot area within 95% confidence level. On the counterpart, GamoGofa, Wolayita, Hadiya, Southern Omo, and

Segen zone of SNNPR, Addis Ababa, central Oromia, Jima, north Shewa zone were cold spot area. In EDHS 2011, a highly significant clustering of childhood anaemia was detected in Somali, Dire Dawa, Harari, Afar, Gambela, Beneshangul, eastern Oromia, Bale, Arsi zone were the hotspot areas within 95% level of confidence. The low hotspot area of childhood anaemia was detected in central Tigray, East and West Gojam, North Gondar, a central part of Oromia, Addis Ababa and SNNPR were areas identified as the low percentage of childhood anaemia in the 2011 EDHS survey.

In2016 EDHS sampled data, hot spot (high risk) regions for childhood anaemia were observed in Somali, Dire Dawa, Harari, Gambela, eastern, and Southern part of Oromia. However, Amhara, Beneshangul, and SNNPR were identified as cold spot (low risk) regions for childhood anaemia within a 95% confidence interval (**Fig.2**)

Spatial interpolation

Based on 2005 EDHS sampled data, the geostatistical analysis predicts that the highest prevalence of childhood anaemia (65.75%-88.89%) was detected in east Oromia, Ilubabur, Arsi, some parts of Beneshangul, Agnuak zone in Gambela, north Shewa Amhara region, south and central Tigray, Afar in zone2, some parts of Dire Dawa and Somali. In EDHS-2011 Geostatistical analysis, a high percentage of anaemia was detected in Afar, most parts of Somali, Oromia in east Harerge and Borena, some part of Dire Dawa, and the Meketel zone in Beneshangul. In 2016 EDHS most of Somali, some parts of Gambela, Guji and some parts of Borena, ast Shewa, East Harerge and Arsi in Oromia and part of Dire Dawa were highly prevalent areas in childhood anaemia **(Fig.3)**

Spatial scan statistics

In 2005 EDHS, a total of 3 significant (one most likely/primary and two secondary) clusters were identified in spatial scan analysis. The primary cluster spatial window was located in

Somali. it was centered at (9.018373 N, 43.110635 E) with a radius of 97.93 km, a relative risk (RR) of 1.5, a Log-Likelihood ratio (LLR) of 20.03, at p < 0. 01. It showed that children within the spatial window had 1.5 times more likely a higher risk of anaemia than thechildren outside the spatial window areas. The secondary clusters scanning window was located in the southern part of Somali region. It was centered at (3.998656 N, 41.240691 E) with a radius of 92.08 km, a relative risk (RR) of 1.7 at p-value < 0.01. It showed that children within the spatial window had a 1.7 times higher risk of anaemia than children outside the window.

In 2011 EDHS, 10 clusters were identified and five of them were significant clusters at a p-value <0.05. A total of 180 locations/spots with a total sampled population of 2478 were found in the primary cluster spatial window with a significant p-value < 0.01. The primary cluster spatial window was located mainly in Somali, Afar, eastern Oromia, Dire Dawa, and Harari. It was centered at (8.975207 N, 43.790264 E) with a radius of 540.29 km, a relative risk (RR) of 1.4, a log-likelihood ratio (LLR) of 127.79 at p-value < 0.01. It showed that children within the spatial window had 1.4 times more likely a higher risk of anaemia than the children outside the spatial window areas. The secondary cluster spatial window was located mainly in Afar region. It was centered at (12.758587 N, 40.175990 E) with a radius of 39.58 km,a relative risk (RR) of 1.7,a log-likelihood ratio (LLR) of 21.5 at P-value<0.01.

In 2016 EDHS, 7 clusters (one most likely cluster) located in Somali, Afar, eastern Oromia, Dire Dawa, and Harari. It was centered at (7.650693 N, 47.007920 E) with a radius 912.19 km, a relative risk (RR) of 1.4 and a Log-Likelihood ratio (LLR) of 182.86 at P-value<0.01. It showed that children within the spatial window had a 1.4 times higher risk of anaemia than outside the window. Secondary clusters spatial window was located in Gambela. It was centered at (8.195862 N, 34.289837 E) with a radius of 29.01 km, a log-likelihood ratio (LLR) of 18.80 at p-value < 0.01**(Fig.4)**.

Multilevel Analysis

The intra-cluster correlation coefficient (ICC) in the null model indicated that 19% of the total variability for childhood anaemia was due to differences between clusters. The remaining unexplained 81% were attributable to individual differences. The median odds ratio for anaemia was 2.3 in the null model, indicating variation between clusters. If we randomly select children from two different clusters children at the cluster with a higher risk of anaemia had 2.3 times higher odds of experiencing anaemia than children at the cluster with a lower risk of anaemia. A bivariable analysis was done to identify variables for multivariable multilevel logistic analysis. A variable with a p-value < 0.25 were considered for multivariable logistic regression analysis.

Individual-level predictors for anaemia

In multivariable multilevel mixed-effect logistic regression analysis child's age, wealth index, age of mother, maternal anaemia status, birth order, fever, stunting, and wasting status were significant predictor of childhood anaemia.

Children age between 12–23 months (AOR = 0.66, 95%CI = 0.53-0.81), between 24–35 months (AOR= 0.35, 95% CI = 0.28-0.43), between 36–47 months (AOR = 0.23-95%CI = 0.19-0.29), and between 48–59 months (AOR = 0.15, 95%CI = 0.12-0.19) were less likely to develop anaemia compared with children age between 6–11 months.

The likelihood of developing anaemia for those children residing with the family wealth index of middle and rich were lower by 21% (AOR=0.79, 95%CI = 0.67-0.94), and 23% (AOR=0.77, 95%CI = 0.65-0.91), respectively as compared with children with low wealth index. Children whose mother age were between 40-49 had 25% decreased odds of developing childhood anaemia compared to age 15-29, (AOR=0.75, 95%CI = 0.59-0.95).

The odds of experiencing anaemia for those birth orders 4-5, six and above six were 1.22 times (AOR=1.22, 95%CI = 1.01-1.47) and, 1.35 times (AOR=1.35, 95%CI = 1.08-1.67) higher as compared with first-order respectively. The odds of developing anaemia of children born from anaemia history mother were 1.39 higher more elevated than those born from not anaemic history before. Children who had fever were 39% (AOR =1.39, 95% CI: 1.24-1.58) more likely to develop anaemia than their counterparts. Children with moderate and severe stunting status were 35% (AOR=1.35, 95% CI: 1.17-1.54) and, 96% (AOR=1.95, 95% CI: 1.68-2.28), more likely to develop anaemia respectively, compared to no stunting status. Similarly, children who had to sever wasting status were 51% more (AOR =1.51, 95% CI: 1.07-2.12) likely to develop anaemia compared with those children who had no wasting.

Community-level predictors for anaemia

The multivariable multilevel logistic regression analysis region was significantly associated with community-level factors for childhood anaemia.

Odds of children live in Somali were 5.65 times (AOR=5.65, 95% CI: 3.92-8.16), Dire Dawa 3.45 times (AOR=3.45, 95% CI: 2.27-5.26), Afar 3 times (AOR=3.00, 95% CI: 2.09-4.34), and Oromia 2.34 times (AOR=2.34, 95% CI: 1.73-3.18) had more likely to develop childhood anaemia compared to Amhara region. Similarly, the odds of developing anaemia in Addis Ababa were 2 times (AOR=2.00, 95% CI: 1.40-3.16), Gambella 1.94 times (AOR=1.94, 95% CI: 1.32-2.84), and Tigray 1.46 times (AOR=1.46, 95% CI: 1.08-1.98), more likely as compared to Amhara region. Beneshangul and SNNPR had not significantly different in the prevalence of anaemia than the reference region Amhara (Table 3).

Table 3: Multilevel logistic regression analysis result of both individual and community-level factors associated with anaemia in Ethiopia, EDHS 2016

Variables	Null Model	Model I AOR (95% CI)	Model II AOR (95% CI)	Model III AOR (95% CI)
		Individual-level factors		
Age of child in month				
6-11	-	1	-	1
12-23	-	0.66[0.54-0.82] **	-	0.66 [0.53-0.81] **
24-35	-	0.35[0.28-0.44] **	-	0.35 [0.28-0.43] **
36-47	-	0.23[0.18-0.28] **	-	0.23 [0.19-0.29] **
48-59	-	0.15[0.12-0.19] **	-	0.15 [0.12-0.19] **
Religion				
Orthodox	-	1	-	1
Muslim	-	2.07[1.77-2.47] **	-	1.21 [0.97-1.46]
Protestant		1.20 [1.00-1.48] *		1.10 [0.86-1.37]
Others	-	1.55[1.07-2.32] *	-	1.44[0.96-2.13]
Wealth status				
Poor	-	1	-	1
Middle	-	0.71[0.61-0.84] **	-	0.79 [0.67-0.94] *
Rich	-	0.72[0.63-0.85] **	-	0.77 [0.65-0.91] *
Child size at birth				
Small	-	1	-	1
Average	-	0.96[0.84-1.09]	-	0.93 [0.80-1.07]
Large	-	0.94[0.81-1.08]	-	0.96 [0.84-1.10]
Birth order			-	
1st	-	1	-	1
2-3	-	1.09[0.94-1.28]	-	1.13[0.97-1.32]
4-5	-	1.17[0.97-1.40]	-	1.22 [1.01-1.47] *
6 and above	-	1.30[1.05-1.62]	-	1.35 [1.08-1.67] **
No of children under 5				
1-2 children	-	1	-	1
≥ 3 children	-	1.22[1.1-1.4] *	-	1.09 [0.94-1.27]
Maternal anaemia				
Not anaemic	-	1	-	1
Anaemic	-	1.51[1.34, 1.72] **	-	1.39 [1.24-1.58] **

Maternal BMI				
≥18.5 kg/m2	-	1	-	1
<18.5 kg/m2	-	1.12[0.97-1.26]	-	1.05 [0.92-1.19]
Women working status				
Not-working	-	1	-	1
Working	-	0.88[0.77-0.99] *	-	0.92 [0.81-1.04]
Women age				
15-29	-	1		1
30-39	-	0.91[0.71-1.06]	-	0.90 [0.78-1.04]
40-49	-	0.75[0.59-1.12] *	-	0.75 [0.59-0.95] *
Breastfeeding				
No	-	1	-	
Yes	-	0.92[0.81-1.04]	-	0.98 [0.87-1.12]
Vitamins in last 6 month				
No	-	1	-	
Yes	-	0.90[0.81-1.09]	-	0.93 [0.84-1.05]
Diarrhea last 2 week				
No	-	1	-	1
Yes	-	0.88[0.73, 1.04]	-	0.90 [0.76-1.07]
Fever in last 2 weeks				
No	-	1	-	1
Yes	-	1.35[1.15-1.59] **	-	1.32 [1.13-1.56] *
Stunting status				
No-stunting	-	1	-	1
Moderate stunting	-	1.27[1.10-1.46] **	-	1.35 [1.17-1.54] **
Severely stunting	-	1.81[1.55-2.11] **	-	1.96 [1.68-2.28] **
Wasting status				
No-wasting	-	1	-	1
Moderate wasting	-	1.27[1.11-1.45]	-	0.98 [0.80-1.19]

Severe wasting	-	1.68[1.55-2.10] *	-	1.51 [1.07-2.12] *
Community/cluster-level factors				
Region				
Amhara	-	-	1	**1**
Tigray	-	-	1.46[1.09-1.97] **	1.46 [1.08-1.98] **
Afar	-	-	3.90 [2.84-5.35] **	3.00 [2.09-4.34] **
Oromia	-	-	2.48 [1.89-3.25] **	2.34 [1.73-3.18] **
Somali	-	-	6.34[4.65-8.63]	5.65 [3.92-8.16] **
Beneshangul	-	-	0.86 [0.62-1.17]	0.81 [0.58-1.15]
SNNPR	-	-	1.33 [1.00-1.76]	1.30 [0.94-1.80]
Gambela	-	-	1.93 [1.38-2.69] **	1.94 [1.32-2.84] **
Harari	-	-	3.08 [2.15-4.43] **	2.98 [1.99-4.46] **
Addis Ababa	-	-	1.91[1.29-2.83] **	2.10 [1.40-3.16] **
Dire dawa	-	-	3.92 [2.67-5.77] **	3.45 [2.27-5.26] **
Residence				
Urban	-	-	**1**	**1**
Rural	-	-	1.40[1.12-1.78]	1.28 [0.99-1.64]
Community women education				
Low	-	-	1	1
High	-	-	1.07[0.90-1.26]	1.13[0.94-1.34]
Community women poverty				
Low	-	-	1	1
High	-	-	1.41[1.17-1.68] *	1.15[0.94-1.40]
Model comparison and random effect				
ICC	0.19	0.12	0.08	0.07
Log-likelihood	-4981.63	-4513.17	-4836.83	-4436.60
Deviance	9963.26	9026.34	9673.66	8873.20
MOR	2.30	1.72	1.42	1.38
PVC (%)	Ref	41.20	60.10	62.59

Key: 1: reference group; p-value 0.05-0.01 *: p-value < 0.01 *

Discussion

This study tried to identify spatio-temporal distribution and predictors of childhood anaemia across the regions in Ethiopia. The 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used for this analysis. The anaemia trend over these years was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL: 0.56-0.59] of children were anaemic in 2016. This finding is in line with a study done in Gondar, Northwest Ethiopia 58.6%(22), higher than the study done in cape Verde, west Africa 51.8%(23), and southern Ethiopia(24). Among children aged 6-59-months, anaemia is still considered as a significant public health problem in Ethiopia, and consequent by various factors. Childhood anaemia in this study was influenced by background characteristics such as child's age, age of the mother, region, wealth status, and maternal related factors.

The spatial analysis found that the spatial pattern of childhood anaemia across the country was substantially varied. The spatial autocorrelation analysis result indicated that childhood anaemia had spatial dependency in 2005, 2011, and 2016 (Moran's I: 0.176, 0.18, and 0.09, respectively at P-value < 0.01). These findings are in line with a studies done in Nigeria, Malawi, Tanzania, and Uganda (25,26).

Scan statistical analysis showed that Eastern Somali and the southern part of Somali region were primary (most likely) and secondary clusters in 2005 respectively. Whereas, in 2011 the spatial window was located in Somali, Afar, Eastern Oromia, Dire Dawa, and Harari region. It was centered at (8.975207 N, 43.790264 Ewith radius of 540.29 km with a significant p-value. Similarly, spatial sat scan analysis showed that Somali, Afar, Eastern Oromia, Dire Dawa, and Harari regions were hotspot areas in the 2016 EDHS survey. In addition, this study revealed that eastern parts of the country had similar spatiotemporal trend over the study periods.

The spatial analysis indicated the hotspots areas of anaemia were situated in the East, Northeast, and Western parts, whereas, Central area, and South, and Northwest parts were cold spot parts of Ethiopia. The observed variability of childhood anaemia might be attributed to the regional deference of economy, healthcare facility and food availability(27).

This study indicated that children age 12-59 months were less affected by childhood anaemia. This finding was consistent with studies conducted in Ethiopia and Togo (28–30)(31). This could be explained by the fact that children who are getting older receive a richer and complete diet, with a sufficient intake of iron which could prevent the occurrence of iron deficiency anaemia. The finding of this study indicated that children whose women age was between 40-49 were less anaemic as compared to age 15-29. This finding was consistent with other studies conducted in Sub-Saharan Africa and Ghana (12,32).

Women with the age group of 15-29 are consists adolescent population group who are more at-risk population segments for anaemia. They are vulnerable to malnutrition because they are growing faster than at any time after their first year of life which contributes to the intergenerational cycle of malnutrition. Iron deficiency is one of the most common forms of malnutrition among Ethiopian adolescent girls that result iron deficiency anaemia. Aside from, growing adolescent mother and her baby's bodies may compete for nutrients, raising the infant's risk of low birth weight; however, the lack of such nutrients might lead to anaemia.

Children from households of middle and rich wealth indexes were less affected by childhood anaemia as compared to children from a poor household. This finding is in line with studies in Nigeria and Northern Ethiopia (25,33). This is due to the reason that children from poor households are less likely to get iron-rich foods like animal foods and vitamin-rich foods especially vitamins A and C which are very important for iron absorption.

Maternal anaemia was highly associated with the occurrence of childhood anaemia. This finding was in line with a study done in South Africa, Haiti, and India(34–36). This might be explained that mothers and children share a common home environment, socioeconomic, and dietary conditions, and maternal and child anaemia may reflect the household common nutritional status, and poor maternal iron intake during pregnancy, reduce breast milk might be the possible reason.

The findings from this study data set indicated that the incidence of fever had an impact on childhood anaemia. This is in line with studies done in Ghana and South Ethiopia Wolaita (24,37). This could be attributed to the infectious cause of childhood fever mainly malaria, tuberculosis, and Leishmaniasis which cause anaemia by destructing red blood cells or other related mechanisms.

The nutritional status of children had a significant association with childhood anaemia. The stunting status of children had significant association with childhood anaemia. This finding is in line with previous studies conducted in South Africa(36), Bangladesh(38,39), and Ethiopia(40,41). This might be explained that children suffering from nutritional deficiency were more likely to have weak immune systems, making them vulnerable to various illnesses and healthiness such as parasitic infections or chronic inflammation; many of these conditions reduce the haemoglobin level in the blood leading to increased childhood anaemia(42)

Furthermore, severely wasting children were more likely to be anaemic than their counterpart. This finding is consistent with previous studies(43,44). This is due to the fact that malnutrition leads to both macronutrient and micronutrient deficiencies, such as protein, iron, and vitamin A, which are responsible for iron deficiency anaemia. Birth order of four up to five and six and greater than six were higher than those of the first order. This finding was similar to a studies done in Indian(12,45). This could be due to the distribution of scarce resources within the family and related to the maternal exhaustion of micronutrient feeding practices.

In the multilevel analysis, different individual and community factors were significantly associated with anaemia. Among the community-level variables, it was found that the odds of anaemia among children lived in the Somali, Dire Dawa, Afar, and Gambela were higher than in the Amhara region. This might be due to the regional variation in the nutrient intake can cause significant health disparity, and this variability may be mediated by factors such as food availability, food customs, and culture.

The potential strength of our study is the use of different methodologies spatial pattern, trends, and a multilevel regression model because of nested or cluster samples to show the effect of individual predictors and community-level variables on the outcome variable. The study was based on a large dataset representing the whole country of Ethiopia and which was weighted to make it nationally representative and adjusted for the design to get a reliable estimate. However, there were some limitations to this study. The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables. Also, respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the overall result and the generalizability of the findings.

Conclusion

Though, declining prevalence of childhood anaemia was observed from 2005 to 2011, it increases from 2011-2016 survey. Besides, it was spatially clustered across regions in Ethiopia. The most prominent risk areas of anaemia were detected in Afar, Somali, Dire Dawa and Oromia regions more or less consistently over the last 15 years. child's age, age of the mother, wealth index, maternal anaemia, fever, birth order, stunting, wasting and region were significant predictors among 6-59 months. Therefore, public health intervention actions intended in a targeted approach to bearing high-risk populations as well as geographic regions were vital to reduce childhood anaemia in Ethiopia.

Abbreviations

AOR-Adjusted Odds Ratio, CSA-Central Statics Agency, CI-Confidence Interval, CMHS-College of Medicine and Health Science COR-Crude Odds Ratio, EDHS-Ethiopia Demographic and Health Survey, GPS-Global Positioning System, ICC-Intra Class Correlation Coefficient, LLR-Log-Likelihood Ratio, MOR-Median odds ratio, OR-Odds Ratio, RR-Relative Risk, PVC-Proportional Change in Variance, SNNPR- Southern Nations, Nationalities, and Peoples' Region.

Declarations

Ethics statements

Patient consent for publication

Not required.

Ethics approval

Permission for data access was obtained from a major Demographic and Health Survey through an online request at (http://www.dhsprogram.com). The data used for this study were publicly available with no personal identifier. Our study was based on secondary data from Ethiopian Demographic and Health Survey and we have secured the permission letter from the main Demographic Health and Survey.

Consent for publication

Not-applicable

Data sharing statement

The data in which the authors used to produce this manuscript are available upon reasonable request

Competing interests

The authors declare that they have no competing interests.

Funding

No funding

Contributors

Proposal preparation, acquisition of data, analysis, and interpretation of data was done by SH, AM, ZM and BF guided the study design data collection and analysis. SH drafted the manuscript and all authors have a substantial contribution in revising and finalizing the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors gratefully acknowledge the support received from the University of Gondar. We also thank the Ethiopian Central Statistics Agency for providing us with the data and shape files for this study.

References

1. WHO. Nutritional Anaemias : Tools for Effective Prevention. World Health Organization. 2017. 1–83 p.
2. WHO. Global estimates of the prevalence of anaemia in infants and children aged 6 – 59 months , 2011 Global estimates of the prevalence of anaemia , all women of reproductive age , 15 – 49 years , 2011. Scaling Up Nutr [Internet]. 2015; Available from: http://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011_maps.pdf?ua=1
3. WHO. The global prevalence of anaemia in 2011. Who [Internet]. 2011;1–48. Available from: https://apps.who.int?iris/hendle/10665/177094
4. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005. Public Health Nutr. 2009;12(4):444–54.
5. Malkanthi RLDK, Silva KDRR, Jayasinghe-Mudalige UK. Risk Factors Associated with High Prevalence of Anemia among Children under 5 Years of Age in Paddy-Farming Households in Sri Lanka. Food Nutr Bull. 2010;31(4):475–82.
6. Olivares M, Walter T, Hertrampf E, Pizarro F. Anaemia and iron deficiency disease in children. Br Med Bull [Internet]. 1999 Sep 1;55(3):534–43. Available from: https://doi.org/10.1258/0007142991902600
7. McLean E, Cogswell M, Egli I, Wojdyla D, De Benoist B. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993-2005. Public Health Nutr. 2009;12(4):444–54.
8. Leal LP, Batista Filho M, de Lira PIC, Figueiroa JN, Osório MM. Temporal trends and anaemia-associated factors in 6- to 59-month-old children in Northeast Brazil. Public Health Nutr. 2012;15(9):1645–52.
9. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: a cross-sectional study. BMJ Open [Internet]. 2018 May 1;8(5):e019654. Available from: http://bmjopen.bmj.com/content/8/5/e019654.abstract
10. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health. 2019;19(1):1–9.
11. Malako BG, Teshome MS, Belachew T. Anemia and associated factors among children aged 6-23 months in Damot Sore District, Wolaita Zone, South Ethiopia. BMC Hematol. 2018;18(1):1–9.
12. Moschovis PP, Wiens MO, Arlington L, Antsygina O, Hayden D, Dzik W, et al. Individual, maternal and household risk factors for anaemia among young children in sub-Saharan Africa: A cross-sectional study. BMJ Open. 2018;8(5):1–14.
13. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in nigeria: A bayesian semi-parametric modelling. Int Health. 2014;6(1):35–45.
14. Desalegn A, Mossie A, Gedefaw L. Nutritional Iron Deficiency Anemia: Magnitude and Its Predictors among School Age Children, Southwest Ethiopia: A Community Based Cross-Sectional Study. PLoS One [Internet]. 2014 Dec 1;9(12):e114059. Available from: https://doi.org/10.1371/journal.pone.0114059
15. Guerra CA, Snow RW, Hay SI. Defining the global spatial limits of malaria transmission in 2005. Adv Parasitol. 2006;62:157–79.
16. Central Statistical Agency, ORC Macro. Ethiopia Demographic and Health Survey

2005. Heal San Fr [Internet]. 2006;(September):[446]. Available from: http://www.measuredhs.com/pubs/pdf/FR179/FR179[23June2011].pdf
17. Central Statistical Agency [Ethiopia], ICF International. Ethiopia Demographic and Health Survey 2011. 2012;1–452.
18. ECSA. Ethiopian Demographic Health Survey 2016. 2016. 161 p.
19. Kulldorff M. SatScan user guide 2006. 2018;
20. Bartko JJ. The Intraclass Correlation Coefficient as a Measure of Reliability. Psychol Rep. 1966 Aug;19(1):3–11.
21. Assessment IS. Understanding Variability in Multilevel Models Sophia Rabe-Hesketh Example : PISA (Programme for International Student Assessment) PISA : Distribution of SES.
22. Enawgaw B, Workineh Y, Tadesse S, Mekuria E, Addisu A, Genetu M. Prevalence of anemia and associated factors among hospitalized children attending the University of Gondar Hospital, Northwest Ethiopia. Electron J Int Fed Clin Chem Lab Med. 2019;30(1):35–47.
23. Semedo RML, Santos MMAS, Baião MR, Luiz RR, Da Veiga G V. Prevalence of Anaemia and Associated Factors among Children below Five Years of Age in Cape Verde, West Africa. J Heal Popul Nutr. 2014;32(4):646–57.
24. Tiku YS, Mekonnen TC, Workie SB, Amare E. Does Anaemia Have Major Public Health Importance in Children Aged 6–59 Months in the Duggina Fanigo District of Wolaita Zone, Southern Ethiopia? Ann Nutr Metab [Internet]. 2018;72(1):3–11. Available from: https://www.karger.com/DOI/10.1159/000484324
25. Gayawan E, Arogundade ED, Adebayo SB. Possible determinants and spatial patterns of anaemia among young children in Nigeria: a Bayesian semi-parametric modelling. Int Health [Internet]. 2014 Jan 31;6(1):35–45. Available from: https://doi.org/10.1093/inthealth/iht034
26. Roberts DJ, Matthews G, Snow RW, Zewotir T, Sartorius B. Investigating the spatial variation and risk factors of childhood anaemia in four sub-Saharan African countries. BMC Public Health. 2020;20(1):126.
27. Diao X, Taffesse AS, Thurlow J, Pratt AN, Yu B, Orkin K, et al. NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Highlights of Presentations Summer – Fall 2010 : h NEWSLETTER - Ethiopia Strategy Support Program II (ESSP-II) Capacity Building Initiatives 2010 : 2010;(December).
28. Gebreweld A, Ali N, Ali R, Fisha T. Prevalence of anemia and its associated factors among children under five years of age attending at Guguftu health center, South Wollo, Northeast Ethiopia. PLoS One [Internet]. 2019 Jul 5;14(7):e0218961. Available from: https://doi.org/10.1371/journal.pone.0218961
29. Nambiema A, Robert A, Yaya I. Prevalence and risk factors of anemia in children aged from 6 to 59 months in Togo: analysis from Togo demographic and health survey data, 2013–2014. BMC Public Health [Internet]. 2019;19(1):215. Available from: https://doi.org/10.1186/s12889-019-6547-1
30. Mohammed SH, Habtewold TD, Esmaillzadeh A. Household, maternal, and child related determinants of hemoglobin levels of Ethiopian children: Hierarchical regression analysis. BMC Pediatr. 2019;19(1):1–10.
31. Keikhaei B, Zandian K, Ghasemi A, Tabibi R. Iron-Deficiency Anemia among Children in Southwest Iran. Food Nutr Bull. 2007 Dec;28(4):406–11.
32. Campbell JR, Holland J. Development research. Focaal. 2007;2005(45):3–17.
33. Gebreegziabiher G, Etana B, Niggusie D. Determinants of Anemia among Children Aged 6–59 Months Living in Kilte Awulaelo Woreda, Northern Ethiopia. Benz EJ,

editor. Anemia [Internet]. 2014;2014:245870. Available from: https://doi.org/10.1155/2014/245870

34. Ayoya MA, Ngnie-Teta I, Séraphin MN, Mamadoultaibou A, Boldon E, Saint-Fleur JE, et al. Prevalence and risk factors of anemia among children 6-59 months old in Haiti. Anemia. 2013;2013:2–5.

35. Pasricha SR, Black J, Muthayya S, Shet A, Bhat V, Nagaraj S, et al. Determinants of anemia among young children in rural India. Pediatrics. 2010;126(1).

36. Ntenda PAM, Nkoka O, Bass P, Senghore T. Maternal anemia is a potential risk factor for anemia in children aged 6–59 months in Southern Africa: a multilevel analysis. BMC Public Health [Internet]. 2018;18(1):650. Available from: https://doi.org/10.1186/s12889-018-5568-5

37. Shenton LM, Jones AD, Wilson ML. Factors Associated with Anemia Status Among Children Aged 6–59 months in Ghana, 2003–2014. Matern Child Health J. 2020;24(4):483–502.

38. Khan JR, Awan N, Misu F. Determinants of anemia among 6–59 months aged children in Bangladesh: evidence from nationally representative data. BMC Pediatr [Internet]. 2016;16(1):3. Available from: https://doi.org/10.1186/s12887-015-0536-z

39. Rahman MS, Mushfiquee M, Masud MS, Howlader T. Association between malnutrition and anemia in under-five children and women of reproductive age: Evidence from Bangladesh Demographic and Health Survey 2011. PLoS One. 2019 Jul;14(7):e0219170–e0219170.

40. Belachew A, Tewabe T. Under-five anemia and its associated factors with dietary diversity, food security, stunted, and deworming in Ethiopia: systematic review and meta-analysis. Syst Rev. 2020 Feb;9(1):31.

41. Malako BG, Asamoah BO, Tadesse M, Hussen R, Gebre MT. Stunting and anemia among children 6–23 months old in Damot Sore district, Southern Ethiopia. BMC Nutr. 2019;5(1):1–11.

42. Pelletier DL, Frongillo Jr EA, Schroeder DG, Habicht JP. The effects of malnutrition on child mortality in developing countries. Bull World Health Organ. 1995;73(4):443–8.

43. Takele WW, Baraki AG, Wolde HF, Desyibelew HD, Derseh BT, Dadi AF, et al. Anemia and Contributing Factors in Severely Malnourished Infants and Children Aged between 0 and 59 Months Admitted to the Treatment Centers of the Amhara Region, Ethiopia: A Multicenter Chart Review Study. Hassen K, editor. Anemia [Internet]. 2021;2021:6636043. Available from: https://doi.org/10.1155/2021/6636043

44. Caulfield LE, Richard SA, Rivera JA, Musgrove P, Black RE. Chapter 28. Stunting,Wasting, and Micronutrient Deficiency Disorders. Dis Control Priorities Dev Ctries (2nd Ed. 2006;551–68.

45. Goswmai S, Das KK. Socio-economic and demographic determinants of childhood anemia. J Pediatr (Rio J). 2015;91(5):471–7.

Figure legend/caption

Figure 1: Trends in anaemia overtime across the regions in Ethiopia, EDHS 2005 to 2016

Figure 2: Hot spot and cold spot analysis of anaemia in Ethiopian, EDHS 2005 to 20016

Figure 3: Ordinary Kriging interpolation of anaemia in Ethiopia, EDHS 2005 to 2016

Figure 4: Spatial scan statistics analysis of anaemia in Ethiopia, EDHS, 2005-2016

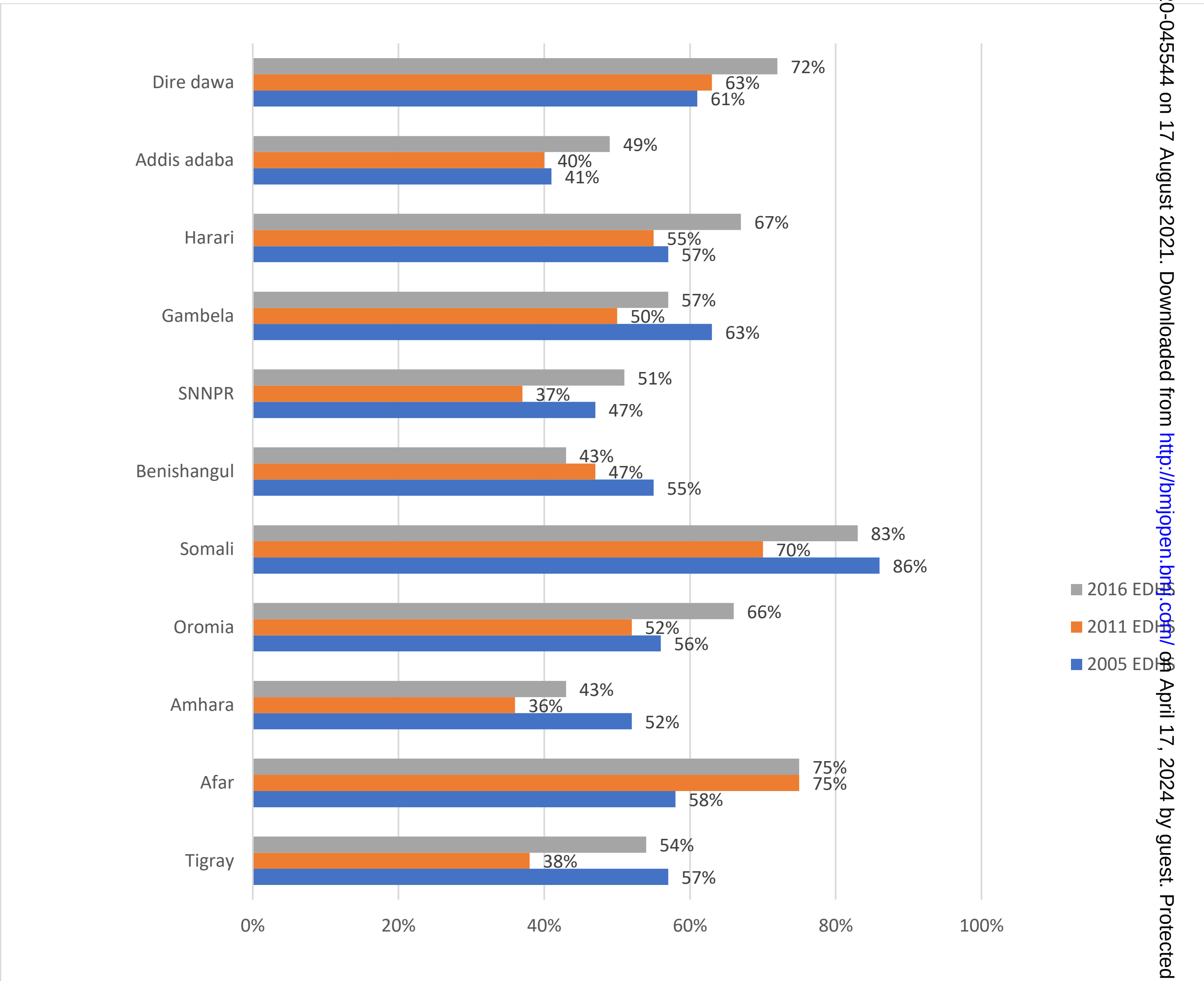


Figure 1: Trends in anaemia over time across the regions in Ethiopia, EDHS 2005 to 2016

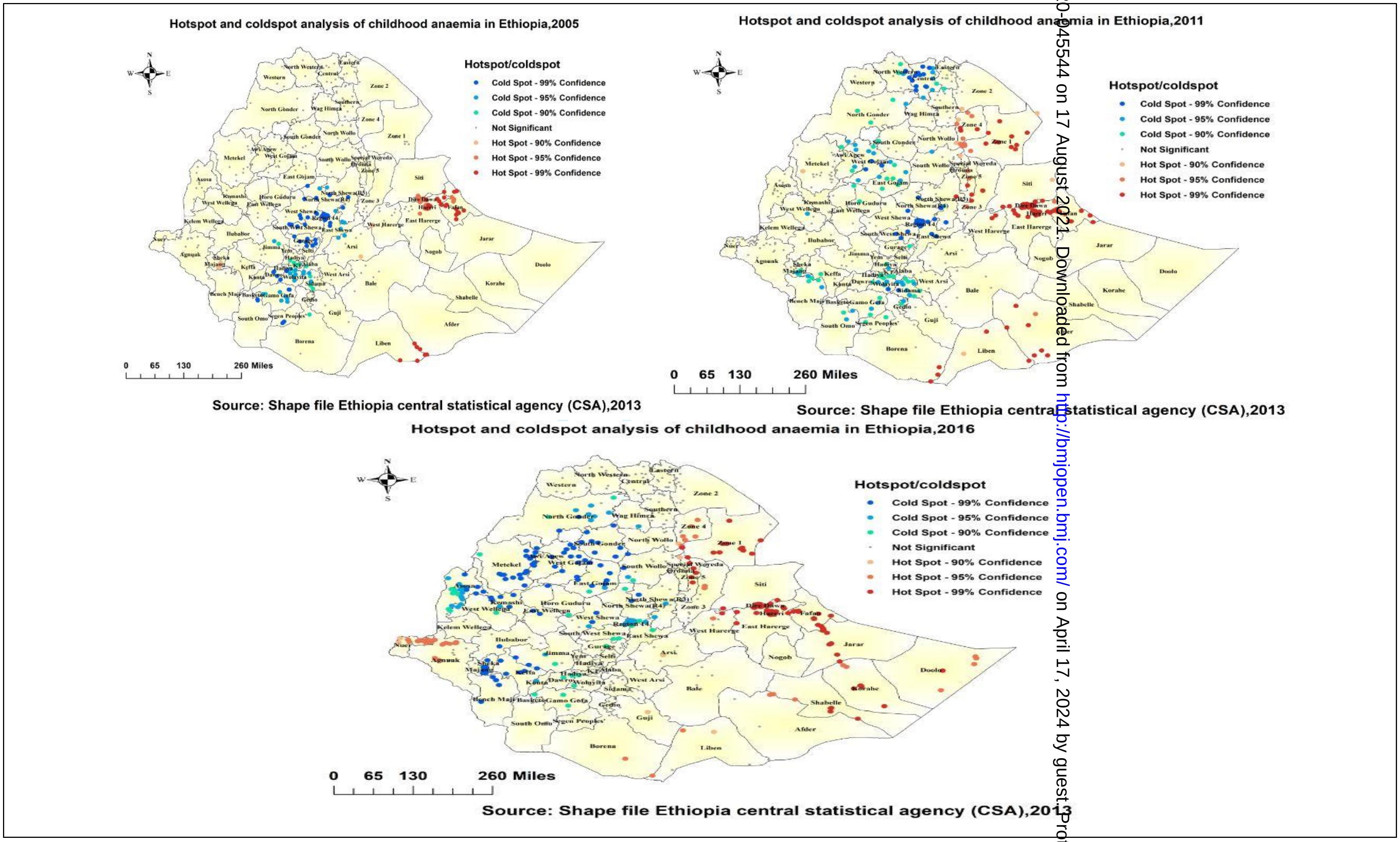


Figure 2: Hot spot and cold spot analysis of anaemia in Ethiopian, EDHS 2005 to 20016

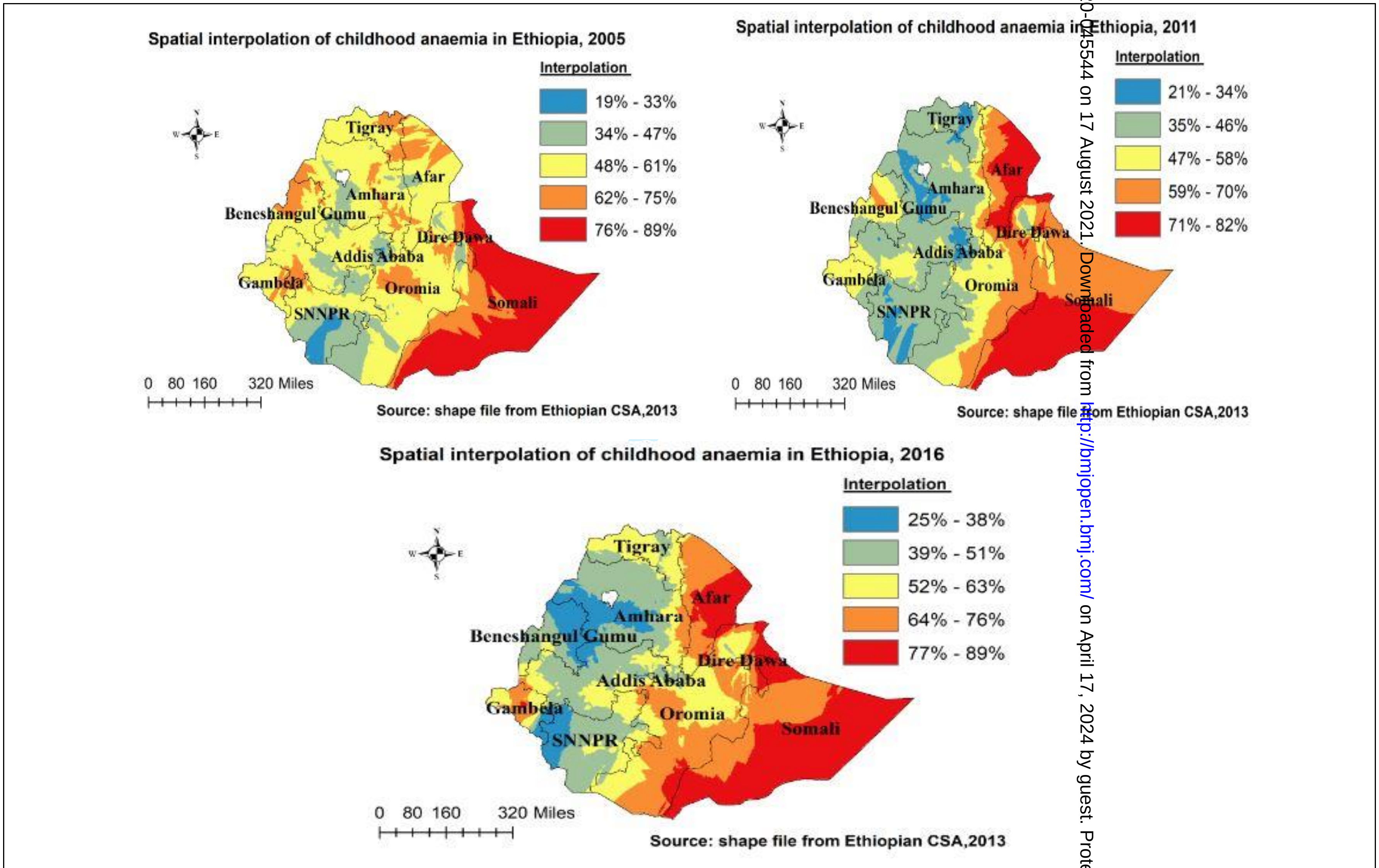


Figure 3: Ordinary Kriging spatial interpolation of anaemia in Ethiopia, EDHS 2005 to 2016

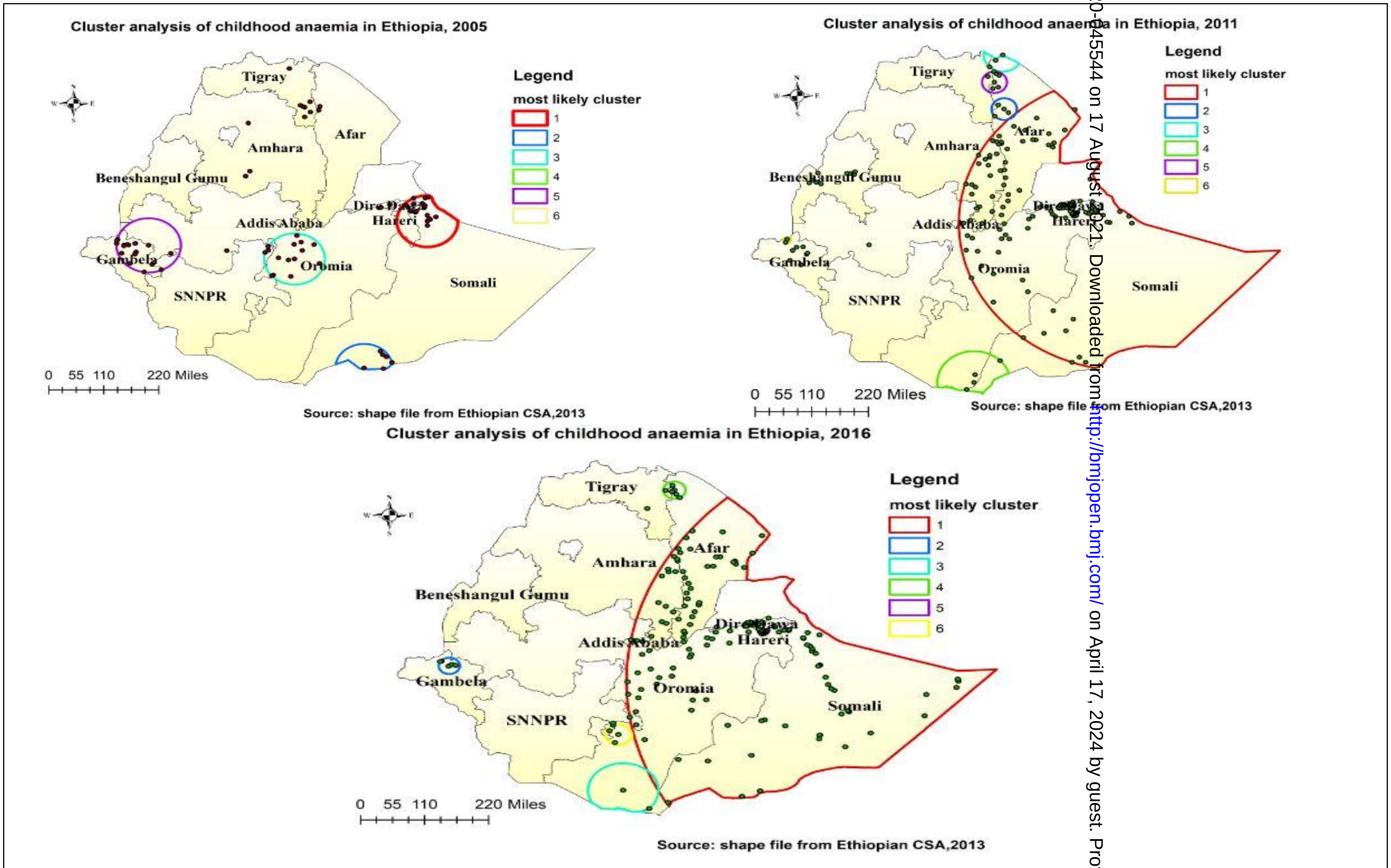


Figure 4: Spatial scan statistics analysis of anaemia in Ethiopia, EDHS, 2005-2016

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	
Title and abstract	1	Spatio-temporal distribution and associated factors of anaemia among children aged 6–59 months in Ethiopia: a spatial and multilevel analysis based on the EDHS 2005- 2016	Page1
		Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and Health Survey (EDHS) data from 2005-2016. In mixed effect model Child age, age of mother, maternal anaemia status, wealth index, birth order, fever, stunting, wasting status, and region were significant predictors of childhood anaemia.	Page2
Introduction			
Background/rationale	2	Childhood anaemia is a major public health problem in Ethiopia, there is limited evidence on the spatio-temporal variability of childhood anaemia over time. study attempts to fill the gap by investigating the spatio-temporal distribution of anaemia and its associated factors using multilevel model, since its hierarchical nature.	Page 5
Objectives	3	Therefore, this study aimed to assess the spatio-temporal distribution and associated factors of childhood anaemia using the Ethiopian Demographic and health survey (EDHS) data from 2005-2016	Page 5
Methods			
Study design	4	Survey-based cross-sectional study design was employed for the EDHS	Page 5
Setting	5	All nine regions and two city administrations of Ethiopia in 2005, 2011 and 2016.	Page 5-6
Participants	6	The source population for this study was among children aged 6–59 months in Ethiopia. A total of 21,302 children aged 6-59 months were included in this study.	Page 6
Variables	7	**Outcome measure:** The outcome variable was child anaemia status **Independent:** sociodemographic (religion, mother age, marital status, educational status, husband education, wealth index, mothers working status, numbers of under five children) Maternal and Child- related (child sex, age, birth size, birth order, maternal BMI, maternal anaemia, breastfeeding, fever, diarrhoea, vitamin supplement, stunting and wasting). Community-level (residence, region, community women education and community women poverty).	**Page 7**
Data sources/ measurement	8*	DHS program (Demographic and Health Survey) website(www.measuredhsprogram.com) after obtaining the necessary permissions for the download and further analyses.	Page 6
Bias	9	Cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables	Page 26
Study size	10	A total of 21,302 children (3,868 in 2005, 8,958 - in 2011, and 8476 in 2016)	Page 11

		were included in this study	
Quantitative variables	11	Quantitative variables were handled in three level Four models were constructed for multilevel logistic regression analysis using **melogit** STATA command**.** The first model (a random intercept model) was null model without predictors to determine the extent of cluster variations in anaemia. The second model (model I) was adjusted with individual-level variables. The third model (model II) was adjusted for community-level variables, while the fourth model (model III) was fitted with both individual-level and community-level variables simultaneously.	Page 10
Statistical methods	12	Multilevel model for associated factors, we use mixed effect to control confounding than traditional regression model.	Page 10-11
		Spatial analysis was performed	
		For associated factor predictors with missing dropped and for spatial analysis without spatial information was dropped	
		Secondary data analysis and participants were selected based on a stratified two-stage cluster sampling technique	
		Spatiotemporal pattern analysis was done for three-year data	
Results			
Participants	13*	A total of 21,302 children Secondary data analysis, simply we take from EDHS	Page 11
Descriptive data	14*	A total of 21,302 children with known haemoglobin levels (3,868 in 2005, 8,958 in 2011, and 8467 in 2016) were included in this study. The prevalence of anaemia for the three consecutive surveys was 53.9%, 44.6%, and 57.6% in 2005, 2011, and 2016 EDHS data respectively The majority of children were from rural residency in five years preceding the survey in three surveys. About 78.6%, 70%, and 67% of women were unable to read and write in 2005, 2011, and 2016 survey respectively. Children from poor and middle-class families were more anaemic than children from rich families across the three EDHS survey	Page 11-12
		Husband educational level was missing data	
Outcome data	15*	The dependent variable was child anaemia status, categorized as "anaemic/not-anaemic" for this study.	Page 7
Main results	16	The spatial distribution of childhood anaemia varied across regions in all surveys. The spatial autocorrelation analysis result indicated that childhood anaemia had spatial dependency in 2005, 2011, and 2016 (Moran's I: 0.176, 0.18, and 0.09, respectively at P-value <0.01). In multivariable multilevel mixed-effect logistic regression analysis, individual-level factors such as the age of the child, wealth index, mother age, maternal anaemic status, birth order, fever, stunting, and wasting status were significant predictor of childhood anaemia.	Page 15-17
		Not-applicable	
		Not-applicable	
Other analyses	17	Different spatial technique spatial autocreation, hotspot/cold spot analysis, interpolation, and sat scan analysis	Page 15

Discussion			
Key results	18	This study tried to identify spatio-temporal distribution and predictors of childhood anaemia across the regions in Ethiopia. 2005, 2011, and, 2016 Ethiopian Demographic and Health Survey data were used. In this study, anaemia's trend was decreased from 2005 to 2011, while the rate significantly increased from 2011 to 2016. The study revealed that 57.56% [CL: 0.56-0.59] of children were anaemic in 2016, preceding the survey. This finding was in line with a study done in Gondar, Northwest Ethiopia 58.6% The spatial pattern shows the geographical inequality of anaemia by using sat scan and GIS spatial techniques like cluster mapping tools and interpolation techniques. The spatial analysis indicates that the distribution of childhood anaemia was non-random across the country with a global Moran's I index of 0.176 in 2005, 0.18 in 2011, and 0.09 in 2016 with a significant p-value, which indicates substantial-considerable clustering areas. This study's findings were in line with a study done in Nigeria, Malawi, Tanzania, and Uganda	Page 23-26
Limitations	19	The cross-sectional nature of the data prevents causality from being inferred between the independent and dependent variables. Also, respondents' data that didn't have files (longitude and latitude) were excluded from the spatial analysis which could affect the overall result and the generalizability of the findings.	Page 26
Interpretation	20	Prevalence of childhood anaemia decreased between the 2005-2011 survey while the prevalence increased from 2011-2016 EDHS. The spatial pattern of child anaemia in Ethiopia was non-random among the three consecutive surveys with the global Moran's I value of 0.176, 0.18, and 0.09 in EDHS 2005, 2011, and 2016. In line study done Cape Verde, west Africa, Nigeria, Malawi, Tanzania, and Uganda	Page 26
Generalisability	21	Policymakers and health planners should design effective intervention strategies for the identified hot spot areas and individual and community-level factors to anaemia. For health care community, and researcher to alleviate the problem.	Page 26
Other information			
Funding	22	No funding	

*Give information separately for exposed and unexposed groups.

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