

Geospatial inequality of anaemia among children in Ethiopia

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Abstract

Anaemia remains a severe public health problem among children in Ethiopia and targeted approaches, based on the distribution and specific risk factors for that setting are needed to efficiently target health interventions. An analysis was performed using Ethiopia Demographic and Health Survey 2016 data. Blood spec-

imens for anaemia testing were collected from 9268 children aged 6-59 months. A child was considered as anaemic if the blood-haemoglobin count was less than 11.0 g/dL. We applied Kulldorf's spatial scan statistics and used SaTScan™ to identify locations and estimate cluster sizes. In addition, we ran the local indicator of spatial association and the Getis-Ord G_i^* statistics to detect and locate hotspots and multilevel multivariable analysis to identify risk factors for anaemia clustering. More than half of children aged 6-59 months (57%) were found to be anaemic in Ethiopia. We found significant geospatial inequality of anaemia among children and identified clusters (hotspots) in the eastern part of Ethiopia. The odds of anaemia among children found within the identified cluster was 1.5 times higher than children found outside the cluster. Women anaemia, stunting and high fertility were associated with anaemia clustering.

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Ethical considerations: permission to use the data was obtained from DHS Program manager. The survey protocol, including biomarker collection was reviewed and approved by the Federal Democratic Republic of Ethiopia, Ministry of Science and Technology and the Institutional Review Board of ICF International. Verbal informed consent was sought from DHS respondents to the Questionnaire and for drawing blood in survey. The interviewer read a prescribed statement to the respondent and recording in the questionnaire whether or not the respondent consented (or provided assent on behalf of minors). Then the interviewer signs his or her name attesting to the fact that he/she read the consent statement to the respondent. The consent statements and procedures for recording consent and interviewers are part of the survey questionnaires (<https://dhsprogram.com/pubs/pdf/FR328/FR328.pdf>).

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Introduction

Anaemia is defined as a less than normal red blood cell count or haemoglobin (Hb) levels that are inadequate to meet the body's physiologic needs. For children 6 months to 5 years of age anaemia is defined according to the World Health Organization (WHO) as Hb levels less than 11g/dL (WHO, 2015). Globally, close to half of preschool children and pregnant women are anaemic (Stevens, 2013), and more than half of the world's population of preschool children and pregnant women live in countries where anaemia is a severe public health problem, Africa and Asia being the continents most affected (Thurnham and Northrop-Clewes, 2007). The consequences of anaemia include poor pregnancy outcome, poor motor and mental performance in children and low work productivity in adults (Horton and Ross, 2003; Noronha *et al.*, 2012). Furthermore, anaemia causes huge economic loss due to physical productivity loss and cognitive loss (Horton and Ross, 2003).

According to the Central Statistical Agency (CSA) in Ethiopia, the prevalence of anaemia remains a severe public health problem among preschool children in the country with no improvement for more than ten years; *i.e.* 54% in 2005 and 57% in 2016, 2005; CSA, 2016). The absence of any progress in this regard implies failure of anaemia prevention and control programmes. Although anaemia is a severe public health problem in all regions of Ethiopia, there is significant regional disparity (CSA, 2016).

The causes of anaemia are multi-factorial and vary across space. The most important causes of anaemia include nutritional deficiencies (iron, folate and vitamins B12, A and C), Infections, such as malaria, various helminthiasis and other acute and chronic inflammations plus genetic conditions, *e.g.*, thalassemia (Yip and Dallman, 1988; Thurnham and Northrop-Clewes, 2007; De la



Cruz-Góngora *et al.*, 2012). The causes and environmental drivers of anaemia show a high degree of geographic clustering (Magalhães and Clements, 2011). A growing body of evidence indicate that people with low Hb concentrations are geographically clustered (Magalhães and Clements, 2011; Gayawan *et al.*, 2014; Ejigu *et al.*, 2018; Habyarimana *et al.*, 2018; Kibret *et al.*, 2019). Studies on spatial heterogeneity of Hb concentration in sub Saharan Africa show that Hb concentration among preschool children is highly clustered geographically in both western and eastern Africa (Magalhães and Clements, 2011; Habyarimana *et al.*, 2018). Similarly, spatial analyses of Hb concentration of Nigerian children reveal that Northern Nigeria possess a higher risk of anaemia (Gayawan *et al.*, 2014). In a geo-spatial study of anaemia among adults in Ethiopia, hotspots were concentrated in the eastern parts of the country (in the Somali, Dire Dawa and Harari, Afar regions), while coldspots were observed in the North (in Tigray and Amhara), Centre (in Addis Ababa and Oromia) and West (in Benishangul-Gumuz and Gambella) (Ejigu *et al.*, 2018; Kibret *et al.*, 2019). In anaemia control, the use of national prevalence estimates of anaemia in the presence of sub-national variability is likely to hamper the efficient delivery of control programmes. Targeted approaches based on the geographical distribution of high-risk communities are needed to efficiently allocate health interventions and to attain an accelerated reduction of anaemia. In Ethiopia, given a high degree of agro-ecological and geographic variation, we hypothesize that there are anaemia clusters among preschool children. This study aimed to identify and locate such potential clusters (hotspots) by using multiple methods of geospatial analysis.

Materials and methods

Study settings

Ethiopia is the second most populous country in Africa and characterized by enormous diversity. The country has extensive altitudinal and geographic variations. The altitude ranges from 116 m below mean sea level in the Danakil Depression to the peak of 4620 m above at Mount Ras Dashen, the mean annual rainfall ranges from 500 mm to 2800 mm and the mean annual temperatures range from below 10 to above 30°C. Although there is opportunity for agricultural growth in the sub-humid highland areas, agricultural production can be low in lowlands of Ethiopia, which is characterized by a warm and a dry climate and this can lead to food insecurity. In addition, Ethiopia is gifted with diverse culture with more than 80 Ethnic groups. Despite being one of the world's poorest countries, Ethiopia's economic growth is one of the fastest globally (Hurni, 1998; Adamu, 2013).

Study design

Data covering the year 2016 were obtained from the Ethiopia Demographic and Health Survey (EDHS), which is carried out every five years to provide health and health-related indicators at the national and regional levels in Ethiopia. The data were downloaded from the Demographic and Health Survey (DHS) website (<http://dhsprogram.com>) after online permission had been secured. The data sample was selected using a stratified, two-stage cluster sampling design. In the first stage, 645 clusters of census enumeration areas (EAs), including 202 urban areas and 443 rural areas were selected. In the second stage, 18,008 households were selected using data from the 9268 children who had undergone anaemia testing. Due to the non-proportional allocation of the sample to dif-

ferent regions and their urban and rural areas, we applied sampling weights to ensure the actual representative of the survey results at both national and regional levels. We also applied a complex survey design to account for the stratified multistage sampling methods of EDHS. The detailed sampling procedure is presented in the EDHS 2016 report (CS, 2016). Potential predictor variables such as wealth index, educational level, body mass index (BMI), age, residence (urban vs rural), region and other variables were extracted from the dataset. In addition, ecologic level variables such as temperature, malaria incidence, rainfall and altitude were extracted from openly available DHS spatially interpolated datasets downloaded from DHS Program Spatial Data Repository (<http://spatialdata.dhsprogram.com>).

Measurements

Blood specimens for anaemia testing were collected from all children aged 6-59 months from whom consent had been obtained from parents or another responsible guardian. Blood samples were drawn from a drop of blood taken from the palm side of the end of a finger and in case of children aged 6-11 months, blood was taken from the heel prick. The blood samples were collected on a HemoCue (<https://www.hemocue.com/>) micro cuvette. Blood samples were placed in a HemoCue photometer, and the results recorded on site. The anaemia status was defined as follows: mild anaemia (10.0-10.9 g/dL), moderate anaemia (7.0-9.9 g/dL) and severe anaemia (≤ 7.0 g/dL). For the purpose of this study, the outcome variable anaemia was recorded into a dichotomous variable where a child was considered to be anaemic if the blood-Hb measurement was less than 11.0 g/dL (CSA, 2016).

Data analysis

The statistical analysis was performed using the software packages STATA 14 and SaTScanTM. Descriptive statistics were used to analyse baseline characteristics of children and their caregivers including sex, age, residence, mother's and father's education level and wealth index to provide an overall picture of the sample. The prevalence of each risk factor and the 95% confidence interval (CI) were also presented.

Spatial clustering analysis

We made an attribute table containing information for each EA such as EA number, the number of children less than 5 years of age in each EA (population), proportion of anaemia cases and EA coordinates. This file was imported into ArcGIS 10.1 (ESRI, Redlands, CA, USA) for visualization, which was based on EA median Hb. Concentrations less than 110 mg/dL was considered anaemic, while ≥ 110 mg/dL was accepted as normal. The coordinate projection was defined using the World Geodetic System (WGS) 1984, Universal Transverse Mercator (UTM) Zone 37°N. The shape file created was exported to the software SaTScanTM version 9.1.1 (<http://www.satscan.org>) for cluster analysis.

We conducted analysis of the spatial clustering of anaemia in two steps, the first of which examined the presence and locations of significant clusters of anaemia at the national level. For the national level, we used data from all regions (eleven) of Ethiopia. The second step aimed at detecting spatial clustering within each region separately. We used SaTScanTM version 9.1.1 to identify locations and estimate cluster sizes over the study area. This statistic evaluates whether the anaemia cases are distributed randomly over a defined space. If not, the scan statistics can identify significant spatial clusters (Kulldorff 1995; Kulldorff, 1997). A circular window is used to identify significant clusters with high cases of anaemia. The

statistical significance of this largest likelihood ratio was assessed through Monte Carlo simulation (1000 simulation performed). In order to detect both small and large clusters, we set the upper limit of the window size at 50% of the study population. The spatial relationships among EAs were conceptualized by calculating the spatial weights from the input file containing the proportion of anaemia for each EA (the number of anaemia cases divided by the total number of tested children in the EA) and the geo-coordinates data for each EA. We assumed that spatial autocorrelation for anaemia declined with distance and therefore a spatial weight matrix conceptualizing the spatial relationship between clusters was generated using an inverse distance approach. In addition to Kulldorf's spatial scan statistics, we applied the local indicator of spatial association (LISA) and the Getis-Ord G_i^* statistics to detect and locate clusters (hotspots) of anaemia. LISA indicates spatial autocorrelation for each location (Anselin, 1995). The Getis-Ord G_i^* statistics (Getis, 2010) was performed using ArcGIS 10.2 to identify the locations of clusters for high occurrence of anaemia. The Getis-Ord G_i^* statistics performs the spatial analysis by looking at each cluster within the context of neighbouring clusters.

Determinants of anaemia clustering

Although identifying the presence of clustering was our primary objective, we performed further analysis to help identify the underlying process that governs observed clustering, which might be due to underlying aggregation of known risk factors not randomly distributed geographically (or the presence of spatial dependency as stated in Tobler's first law of geography (Waters, 2017). We initially ran bivariate analyses to determine the potential risk factors of anaemia. We used both individual and ecologic level data such as: i) individual variables: socio-demographic (child age, sex), disease (fever, diarrhoea), food intake (dairy, vegetables and fruits), stunting and wasting, Maternal characteristics (age, anaemia, education, BMI, number of antenatal care (ANC) visits, iron consumption during pregnancy, number of births), household characteristics (water source, latrine, wealth status, residence); ii) ecologic level variables: rainfall, temperature, enhanced vegetation index and altitude. Multilevel multivariable logistic regression was used to select factors that were independently associated with anaemia. Regions and households were considered as levels. Variables at $P < 0.2$ in the multilevel multivariable model were used

Table 1. Anaemia among children aged 6-59 months, by background characteristics.

Background characteristics	Prevalence of anaemia			
	Children with Hb<11.0 g/dL (%)	95% CI	Number	Percent
Age in months				
6-11	77.1	(72.5-81.2)	1043	11.3
12-23	69.2	(65.7-72.5)	2022	21.8
24-35	59.0	(54.5-63.2)	1948	21.0
36-47	50.9	(46.9-54.9)	2019	21.8
8-59	40.0	(36.2-43.9)	2235	24.1
Sex				
Female	56.6	(53.8-59.3)	4455	48.0
Male	57.2	(54.1-60.3)	4812	52.0
Region				
Tigray	53.6	(49.0-58.1)	612	6.6
Afar	74.8	(70.4,78.6)	91	1.0
Amhara	42.2	(37.9-46.5)	1861	20.1
Oromia	65.5	(61.0-69.6)	4008	43.2
Somali	82.9	(79.6-85.8)	371	4.0
Benishangul-Gumuz	42.5	(37.6-47.6)	96	1.0
SNNPR	50.0	(45.0-54.9)	1992	21.5
Gambella	56.2	(47.8-64.2)	21	0.2
Harari	67.9	(63.1-72.3)	16	0.2
Addis Ababa	49.2	(43.4-55.0)	165	1.8
Dire Dawa	71.5	(66.0-76.5)	35	0.4
Household wealth quintile				
Poorest	67.8	(62.9-72.2)	2164	23.3
Poor	57.6	(53.5-61.7)	2166	23.4
Middle	52.6	(48.3-56.8)	1963	21.2
Well-off	54.0	(49.9-58.0)	1723	18.6
Affluent	47.9	(43.6-52.3)	1250	13.5
Mothers' education				
No education	58.5	(55.5-61.5)	5746	67.1
Primary education	56.8	(53.3-60.3)	2307	26.9
Secondary education	48.6	(41.7-55.6)	345	4.0
Higher education	49.1	(40.2-58.1)	170	2.0
Place of residence				
Rural	57.8	(55.1-60.5)	8330	90
Urban	49.3	(43.5-53.1)	937	10
Total	56.9	(54.4-59.4)	9267	100

Hb, haemoglobin; CI, confidence interval; SNNPR, Southern Nations, Nationalities and People Region.

for the analysis of anaemia clustering. In the final model, variables such as women anaemia, wealth, child stunting, child wasting, women, education, availability of improved toilet, number of births and amount of rainfall were included. We identified risk factors that varied across cases (anaemic children) identified within the cluster and cases (anaemic children) outside the cluster. A $P < 0.05$ was considered as significant.

Results

Characteristics of study participants

Table 1 describes the background characteristics of study participants. This study involved a total of 9267 children aged 6-59 month. Most children lived in rural area (90%). The majority of mothers had no formal education (67%). Only thirteen percent (13%) of children lived in the highest wealth quintile.

As shown in Table 1, nearly 57% of children were anaemic. In general, however, this prevalence decreased with increasing age; it ranged from 77% among 6-11 month old children to 40% among 48-59 month old children. A higher prevalence of anaemia was found among children who lived in Somali region of Ethiopia (83%), in the rural area (58%), among those living in the lowest wealth quintile (68%), and among children who had mothers with no education (59%).

Spatial distribution of anaemia

Figure 1 shows the distribution of Hb concentration across the EAs (clusters). Low median Hb concentration (Pronounced anaemia) was aggregated in the eastern part of Ethiopia. The geographic distribution of median Hb concentration varies over the country. The median Hb concentration was significantly lower in the north-eastern, south-eastern, south-central and south-western part of the country. High anaemia concentrations were found span-

ning the country's border to the East and Southwest. The geographic distribution of anaemia is shown in Figure 2. Using both LISA and Getis-Ord G_i^* statistics, we identified a significant geospatial inequality in the distribution of anaemia in Ethiopia. We identified statistically significant hotspots in the eastern part of Ethiopia and coldspots in the western part. We also identified hotspots in the south-western corner of the country (Gambella region).

Figure 3 shows the spatial SaTScan statistics result of anaemia clustering at the national level. The results indicated a most likely significant cluster located in the eastern part of Ethiopia. A single large cluster size of 2135 cases (1709 expected) in 215 EAs was identified ($RR=1.45$, $P < 0.01$). The odds of anaemia among children found within the cluster identified was 1.5 times more than the odds of anaemia among children found outside it. The sizes of the most likely significant clusters were within an area with a

Table 2. Distribution of the enumeration areas in cluster identified by SaTScan.

Region	Frequency	Percent
Afar	36	16.7
Amhara	10	4.6
Oromia	33	15.3
Somali	50	23.3
SNNPR	2	1.0
Harari	42	19.5
Addis Ababa	2	1.0
Dire Dawa	40	18.6
Total	215	100

SNNPR, Southern Nations, Nationalities and People Region.

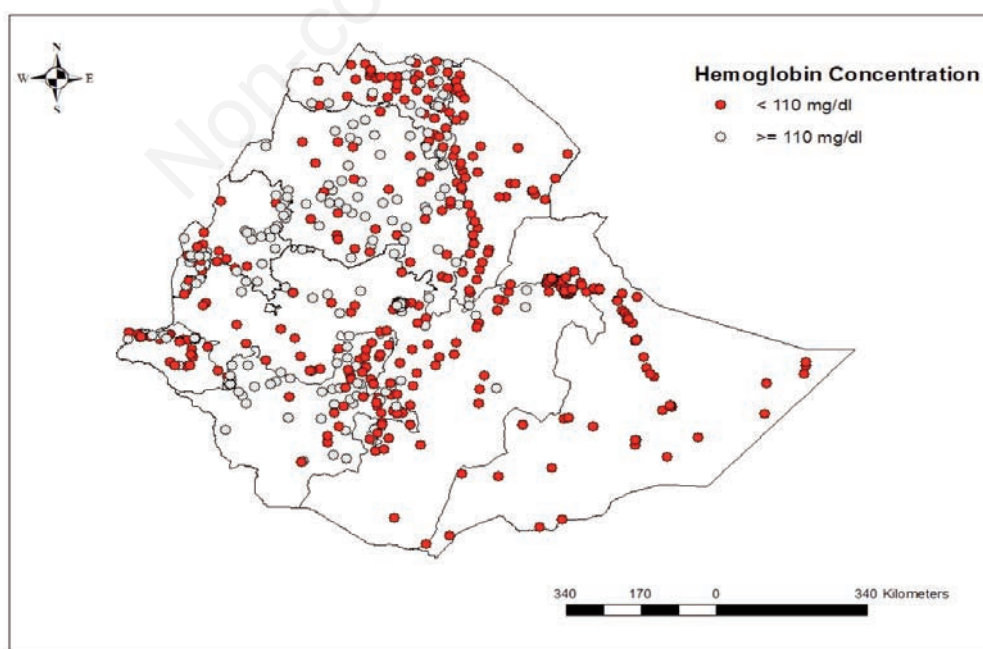


Figure 1. Visualization of haemoglobin concentration levels across Ethiopia.

radius of 8.3 km. We counted a total of 215 EAs in a cluster identified in the eastern part of the country. We further analysed the distribution of the 215 EAs within the regions (Table 2). Of the 215 EAs in this cluster, 201 (93%) were found in five regions of Ethiopia such as Somali (23.3%), Harari (19.5%), Dire Dawa (18.6%) Afar (16.7%) and Oromia 33 (15.3%).

We further applied spatial scan statistics separately for the 11 regions of Ethiopia to find out whether there was a distinct spatial cluster in the distribution of anaemia at the regional level. We found most likely significant clusters in four regions (Tables 3 and 4). In Oromia Region, a cluster of 106 cases (73 expected) was detected (blue) and the odds of anaemia among children within this cluster were 1.5 times higher than the odds of anaemia among children outside the cluster ($RR=1.52$, $P<0.021$). In the Southern Nations, Nationalities and People Region (SNNPR), a cluster of

317 cases (270 expected) was identified with the odds of anaemia within the cluster 1.4 times higher than that outside the cluster ($RR=1.42$, $P=0.013$). In Benishangul-Gumuz, we detected a cluster of 170 cases (140 expected) where the odds of anaemia among children within this cluster were 1.5 higher than that outside the cluster ($RR=1.52$, $P=0.046$), and in Gambella, a there was cluster of 196 cases (160 expected) with the odds of anaemia within were 1.6 higher than that outside the cluster ($RR=1.55$, $P=0.011$).

Risk for spatial clustering

This analysis was run to identify the risk factors for the clustering of anaemia and further to evaluate whether the observed clustering could be due to the distribution of various risk factors not randomly distributed geographically. For this we fitted a regression model and found no significant differences with respect

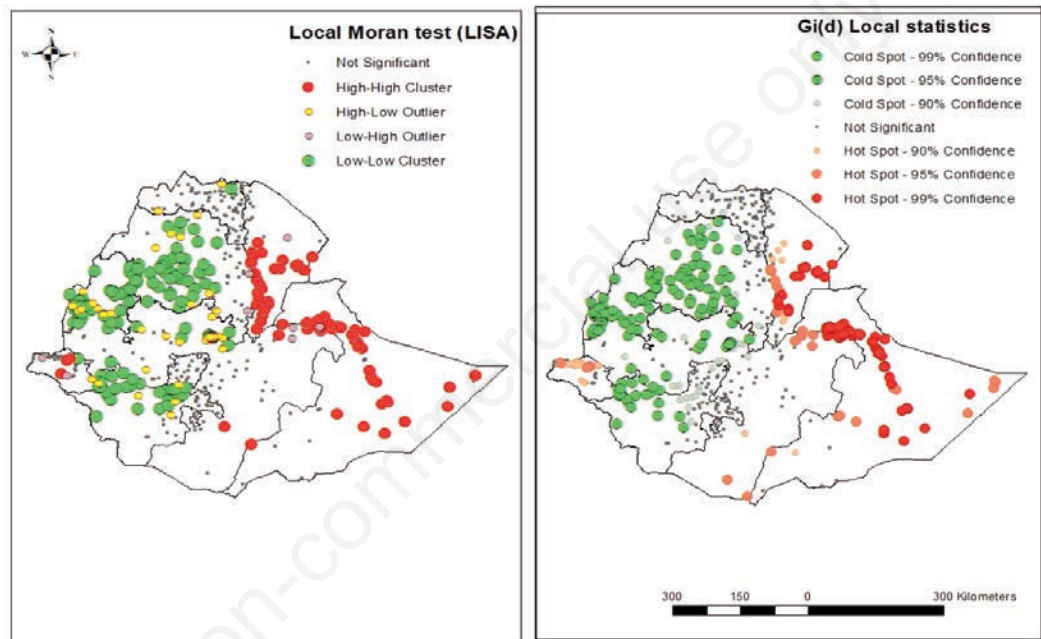


Figure 2. Geospatial distribution of anaemia in Ethiopia. Data based on LISA and Getis-Ord G_i^* statistics.

Table 3. Purely spatial scan statistics of the most likely significant clusters for anaemia at the national and regional levels.

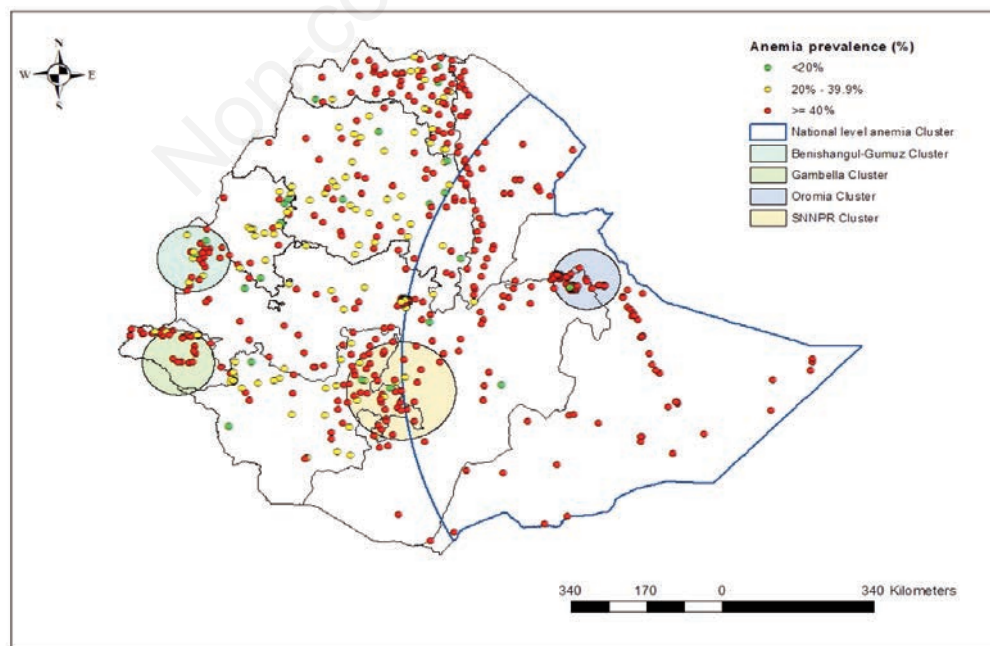
Characteristic	National	Oromia	SNNPR	Benishangul-Gumuz	Gambella
Number of clusters	622	72	71	49	49
Lat./Long. coordinates	(47.007-7.6506)	(42.438-9.5054)	(38.693-7.0033)	(34.503-9.9730)	(34.196-7.6374)
Radius	8.29	0.68	1.11	-	0.73
Population (children)	2891	114	542	331	273
Observed cases	2135	106	317	171	196
Expected cases	1708.77	72.94	269.52	140.35	160.05
Cases/100,000	73,697.0	92,790.0	58,366.0	51,554.7	71646.3
Observed/expected	1.25	1.45	1.18	1.22	1.22
Relative risk	1.45	1.52	1.42	1.52	1.55
Log likelihood ratio	80.160755	7.311074	8.254107	6.432496	7.790748
P-value	<0.001	0.021	0.013	0.046	0.011

SNNPR, Southern Nations, Nationalities and People Region.

Table 4. Risk factors for clustering of anaemia among children aged under five.

Explanatory variable	Cases in spatial cluster		COR (95% CI)	AOR (95% CI)
	Yes (No. %)	No (No. %)		
Mother				
Normal Hb	994 (32.1)	2106 (67.9)	1.00	1.00
Anaemic	773 (44.1)	979 (55.9)	1.31 (1.11-1.56)**	1.41 (1.11-1.79)***
Stunting				
Not stunted	1116 (39.1)	1739 (60.9)	1.00	1.00
Stunted	421 (36.4)	736 (63.6)	1.15 (0.93-1.41)	1.26 (0.95-1.69)**
Severely stunted	376 (32.9)	766 (67.1)	1.02 (0.83-1.26)	1.36 (1.01-1.82)*
Wasting				
Not wasted	1710 (37)	2914 (64)	1.00	-
Wasted	155 (37.2)	261 (62.8)	0.91	1.17 (0.79-1.73)
Severely wasted	69 (40.3)	102 (59.7)	0.89 (0.72-1.74)	1.14 (0.63-2.08)
Household wealth quintile				
Poorest	668 (45.5)	799 (54.5)	0.75 (0.56-1.01)*	1.36 (0.83-2.22)
Poor	509 (40.8)	739 (59.2)	0.86 (0.61-1.21)	1.20 (0.70-2.05)
Middle	342 (33.1)	690 (66.9)	0.59 (0.41-0.85)	1.12 (0.65-1.94)
Well-off	295 (31.7)	636 (68.3)	0.61 (0.43-0.88)***	1.40 (0.82-2.41)
Affluent	147 (24.6)	452 (75.4)	1.00	1.00
Mothers' education				
No education	1316 (38.3)	2124 (61.7)	0.62 (0.30-1.28)	0.54 (0.18-1.61)
Primary education	484 (36.4)	846 (63.6)	0.72 (0.34-1.50)	0.9 (0.31-2.69)
Secondary education	37 (21.3)	135 (78.7)	1.06 (0.44-2.52)	1.98 (0.59-6.57)
Higher education	24 (27.6%)	64 (72.4%)	1.00	1.00
Improved toilet				
No	1771 (36.9)	3023 (63.1)	1.00	1.00
Yes	190 (39.3)	293 (60.7)	0.83 (0.65-1.07)*	1.00 (0.64-1.57)*
Births				
1	537 (27.3)	1232 (72.7)	1.00	1.00
2	947 (39.8)	1432 (60.2)	1.28 (1.06-1.55)**	1.52 (1.17-1.99)**
3	270 (53.9)	231 (46.1)	1.19 (0.91-1.55)	1.05 (0.72-1.54)
4	69 (88.1)	9 (11.9)	2.26 (1.19-4.30)**	1.51 (0.52-4.40)*
Mean annual Rainfall_2015	764 SD (239.7)	-	1.00	1.00

COR, crude odds ratio; AOR, adjusted odds ratio; CI, confidence interval; Hb, haemoglobin; SD, standard deviation. ***P<0.01; **P<0.05; *P<0.1.

**Figure 3. Anaemia clustering among preschool children in Ethiopia. Data by SaTScan statistics.**

to household socio-economic status, latrine availability, wasting, and maternal education between anaemic children within the cluster and those outside. However, we found a statistically significant difference in mother's anaemia, stunting of children and the number of births between anaemic children within the cluster those outside. The odds of stunting were 1.3 times higher among children within the identified cluster compared to the odds for children outside ($P=0.041$). The odds of having anaemic mothers were 1.4 times higher among children within the identified cluster compared to those outside the cluster ($P<0.01$). The odds of having mothers who had two births in the last five years was 1.4 times higher with regard to children within the identified cluster compared to those outside ($P<0.01$).

Discussion

We assessed geospatial inequality of anemia among preschool children. We used multiple methods to detect spatial clustering of anemia and further locate hotspots of anemia. We found considerable geographical variation; hotspots (clusters) of anemia were concentrated in the eastern part of Ethiopia. Anaemic children identified within the cluster had higher odds of being stunted, living with anaemic women, and living with women with higher fertility.

We employed three types of local cluster techniques (Kulldorf spatial scan, local Moran's statistics, and Getis-Ord G_i^* statistics) to identify locations with elevated anemia prevalence. Each method has its own strength and limitation (Kiani *et al.*, 2021). However applying multiple techniques could offset some of the limitations. The shared advantage of the aforementioned local spatial statistics, over the global statistics, is its ability to quantify spatial autocorrelation and locate clusters. The main strength of Kulldorf spatial scan is its suitability to detect clusters of any size located anywhere in the study area. However, because of its fixed circular window, locations with low anemia prevalence surrounded by locations with high anemia prevalence could be wrongly included within the cluster extent (Selman *et al.*, 2015). Moreover, this fixed window decreases its ability to detect non-circular clusters. On the other hand, local Moran's statistics can detect high-high clusters, low-low clusters, and spatial outliers (high-low and low-high) (Chirenda *et al.*, 2010). However, the local Moran's results will be biased if the population at risk in each area has significant variation (Ward and Carpenter, 2000). Although the advantage of Getis-Ord G_i^* statistics for identifying disease hotspots is widely established, it has important limitations. Firstly, since the results are relative to global mean of the study area, less prominent clusters could be missed (Cohen *et al.*, 2011). Secondly, Getis-Ord G_i^* statistics cannot determine outliers such as high-low outlier (areas with high anemia prevalence surrounded by areas with low anemia prevalence) (Kiani *et al.*, 2021).

Our finding of geospatial inequality of anaemia affecting unduly the eastern part of Ethiopia is consistent with other similar studies (Ejigu *et al.*, 2018; Kibret *et al.*, 2019). The high anaemia cluster found in Somali, Afar and eastern Oromia regions can be partly explained by the low economic and human development in these regions, which are characterized as lowlands, pastoralist or agro pastoralist societies with chronic food insecurity, frequent droughts, poor infrastructure and poor access to health care and education. The human development index (HDI) for Ethiopia's regions indicate that these three regions have the lowest development score in Ethiopia (UNDP, 2018). Similarly, Afar and Somali

regions have poor maternal and child health service coverage and utilization (such as folic acid supplementation, institutional delivery, family planning) and vaccination (CSA, 2016). Furthermore, the highest proportions of women without education and poor households are concentrated in the same regions (CSA, 2016). A growing body of literature report that anaemia highly affect socio-economically disadvantaged groups (Kim *et al.*, 2014; CSA, 2016; Yang *et al.*, 2018) implying that ensuring equitable socioeconomic and human development of societies could play significant role in the prevention of anaemia.

The geospatial inequality of anaemia might also be due to variations in food consumption patterns. For example, the highest consumption of Teff (*Eragrostis tef*), a good source of iron (Baye, 2014), is reported from urban areas and highlands of Ethiopia, for example the Amhara region, while the lowest consumption is reported from the lowlands of eastern part of Ethiopia, e.g., the Somali region (Hurni, 1998; Taffesse, 2012; Berhane, 2012). Similarly, as given by the Ethiopian food consumption survey published by the Ethiopian Public Health Institute (EPHI) shows that the highest prevalence of inadequate dietary intake of iron (83%) is reported from the Somali region and the lowest from Amhara (6%) (EPHI, 2013). On the other hand, the proportion of the diet contributed by dairy products (iron absorption inhibitor) is higher among women in Somali, Afar and Gambella regions (EPHI, 2013). This implies the need to improve dietary diversification through improving access and utilization of iron rich food.

The prevalence of malaria, using the rapid diagnostic test, is 0.6% among children 6-59 months old (MoH, 2017). Somali, Dire Dawa, Afar and Oromia reported lower prevalence ($<0.2\%$) of malaria among children 6-59 month old (MoH, 2017). Using multiplex serology assays, a high malaria burden was observed in the Northwest compared to the eastern part of Ethiopia. The proportion of seropositivity for *P. falciparum* by region ranges from 11.0% in Somali to 65.0% (95% CI: 58.0-71.4) in Gambella Region (Assefa *et al.*, 2019). Given the lower prevalence of malaria in the anaemia hotspot areas (eastern Ethiopia), it is less likely that malaria is the cause for the geospatial inequality of anaemia noted in our research. Furthermore, several studies revealed that infections such as acute respiratory tract infection, diarrhoea and soil-transmitted worm infections are important contributors in the aetiology of anaemia (Alemu *et al.*, 2012; Reithinger *et al.*, 2013; Deribew *et al.*, 2013; Derege *et al.*, 2014; Mahmud *et al.*, 2015). However, these infections are not highly concentrated in the eastern part of compared to other parts of Ethiopia (CSA, 2016). According to a study conducted in different areas of the country, the prevalence of hookworm infections among school age children is 22% in north-western Ethiopia, 28.4% in the South, 6.7% in the East and 4.9% in the North (Samuel, 2015). These finding on the prevalence of malaria and other infections indicate that the geospatial inequality of anaemia is less likely to be due to acute infections.

The current study found that there is a higher odd of anaemia among women in the anaemia cluster (identified by SaTScan) than outside it. This in line was the finding of other studies (Pasricha, 2010; Ntenda, 2018). The possible explanation is that women with anaemia and anaemic children live in a similar socioeconomic, cultural and health related environments (Brooker, 2007; Samuel, 2015). There is also a high chance of an intergenerational cycle of anaemia involving mother and infant. Additionally, low levels of essential minerals, such as iron in the breast milk of the anaemic mother, could also affect the Hb levels (Wang, 2015). This implies that anaemia prevention and control strategies should be integrated



targeting both mothers and their children concurrently.

Our study should be interpreted in the context of the following strengths and limitations. The fact that we found similar area of high anaemia clustering using multiple methods of geospatial analysis makes the findings robust. In addition, use of nationally and regionally representative DHS data on Hb concentration and GPS coordinates, supports the possibility of reproducing our approach in other countries. However, measurement error and misclassification might have occurred because the locations of DHS clusters are randomly displaced to protect the confidentiality of survey respondents (Perez-Heydrich, 2013). The DHS data lacks comprehensive information on the risk factors of anaemia, such as malaria, intestinal parasite and nutrition for under-five children. This limited our analysis to determine the risk factors of anaemia clustering. Though we used the latest EDHS survey (EDHS, 2016), changes might occur after the survey and our finding may not reflect the current situation.

Conclusions

In conclusion, we found significant geospatial inequality of anaemia highly affecting the eastern part of Ethiopia. We recommend that policy makers and programmers especially target this area for accelerated reduction of anaemia. Programmes should target both women and children since we found strong association between maternal anaemia and childhood anaemia. Further research is needed to understand the risk factors and aetiologies of anaemia across the different setting of Ethiopia.

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