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Spatial variation and clustering of anaemia prevalence in school-aged children in Western Kenya

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Abstract

Anaemia surveillance has overlooked school-aged children (SAC), hence information on this age group is scarce. This study examined the spatial variation of anaemia prevalence among SAC (5–14 years) in western Kenya, a region associated with high malaria infection rates. A total of 8051 SAC were examined from 82 schools across eight counties in Western Kenya in February 2022. Haemoglobin (Hb) concentrations were assessed at the school and village level and anaemia defined as Hb<11.5g/dl for age 5-11yrs and Hb <12.0g/dl for 12-14yrs after adjusting for altitude. Moran's I analysis was used to measure spatial autocorrelation, and local clusters of anaemia were mapped using spatial scan statistics and local indices of spatial association (LISA). The prevalence of anaemia among SAC was 27.8%. The spatial variation of anaemia was non-random, with Global Moran's I 0.2 (p-value < 0.002). Two significant anaemia cluster windows were identified: Cluster 1 (LLR = 38.9, RR = 1.4, prevalence = 32.0%) and cluster 2 (LLR = 23.6, RR = 1.6, prevalence = 45.5%) at schools and cluster 1 (LLR = 41.3, RR = 1.4, prevalence = 33.3%) and cluster 2 (LLR = 24.5, RR = 1.6, prevalence = 36.8%) at villages. Additionally, LISA analysis identified ten school catchments as anaemia hotspots corresponding geographically to SatScan clusters. Anaemia in the SAC is a public health problem in the Western region of Kenya with some localised areas presenting greater risk relative to others. Increasing coverage of interventions, geographically targeting the prevention of anaemia in the SAC, including malaria, is required to alleviate the burden among children attending school in Western Kenya.

Introduction

Anaemia is a global public health problem, affecting approximately 1.8 billion people worldwide in 2019, and is a leading cause of morbidity and mortality among pregnant women and

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young children [1,2]. Sub-Saharan Africa (SSA) bears the greatest burden of anaemia [2,3]. The World Health Organization (WHO) defines anaemia as a condition in which the number of red blood cells (oxygen-carrying capacity) is inadequate to meet the body's physiological needs [4]. Iron deficiency is the main cause of anaemia. However, other factors leading to anaemia include malnutrition, inherited red blood cell disorders, infections from intestinal parasites, schistosomiasis, malaria, and human immunodeficiency virus (HIV) [5,6]. The risk factors associated with anaemia vary according to geography, age, and gender [1,7]. Therefore, it is important to understand the complex epidemiology of anaemia to successfully develop appropriate targeted, context-specific interventions [7,8].

However, population surveys and monitoring of anaemia have mainly focused on women of reproductive age (WRA) (15–49 years) and children under 5 years of age. This aligns with global targets for maternal, infant, and young child nutrition, which is committed to halve anaemia prevalence in WRA by 2025 [7]. Furthermore, the prevalence of anaemia in WRA was added as indicator 2.2.3 of the Sustainable Development Goals (SDGs) [9]. Despite the existence of important global health milestones, they overlook other vulnerable populations, particularly school-aged children (SAC) and the elderly (60+ years).

Owing to their rapid physical and physiological growth, SAC are more susceptible to anaemia [10–14]. There are limited national and global reports on the prevalence of anaemia among SAC [12,15,16], largely due to insufficient data in this age group [7,17]. Despite limited data, a review in 2008 suggested that as many as 64–71% of SAC could be anaemic in Africa [15]. SAC anaemia burden and its spatial patterns within countries remain poorly defined. Therefore, the purpose of this study was to determine the spatial distribution of anaemia at school level, among SAC in Western Kenya, specifically examining whether there were clusters of anaemia and identifying their location.

Methodology

Study context

This study was conducted across eight counties in Western Kenya: Bungoma, Busia, Kakamega, Vihiga, Siaya, Kisumu, Homa Bay and Migori. These counties represent the devolved system of governance in Kenya responsible for decision-making at the subnational level and are further divided into 62 sub-counties (Fig 1). This area, in the Lake Victoria Basin, is characterised by a high population density, representing 19.4% (9.4 million) of Kenya's population [18]. The area was chosen because it experiences stable malaria transmission [19,20] and until recently was endemic to hookworms [21].

Data

In February 2022, a survey was conducted on children attending 82 public primary schools in eight counties within a high malaria transmission region, where school surveys are frequently carried out. A sampling frame of all primary schools in the Western region was used to select the schools, and one school was randomly chosen from each sub-county in the eight selected counties (Fig 1). Approximately 100 children aged 5–14 years were randomly sampled from Classes 2 to 6 at each school. Selected children were asked to provide a finger-prick blood sample, which was used to assess their haemoglobin concentration using a portable photometer (HemoCue AB, Ängelholm, Sweden). The location of each sampled school was recorded using a hand-held Global Positioning System (GPS). The children provided information on their village of residence with the help of their teachers. Village coordinates were geolocated using Google Earth/Maps and digital place-name gazetteers, including Geonames, Encarta, and
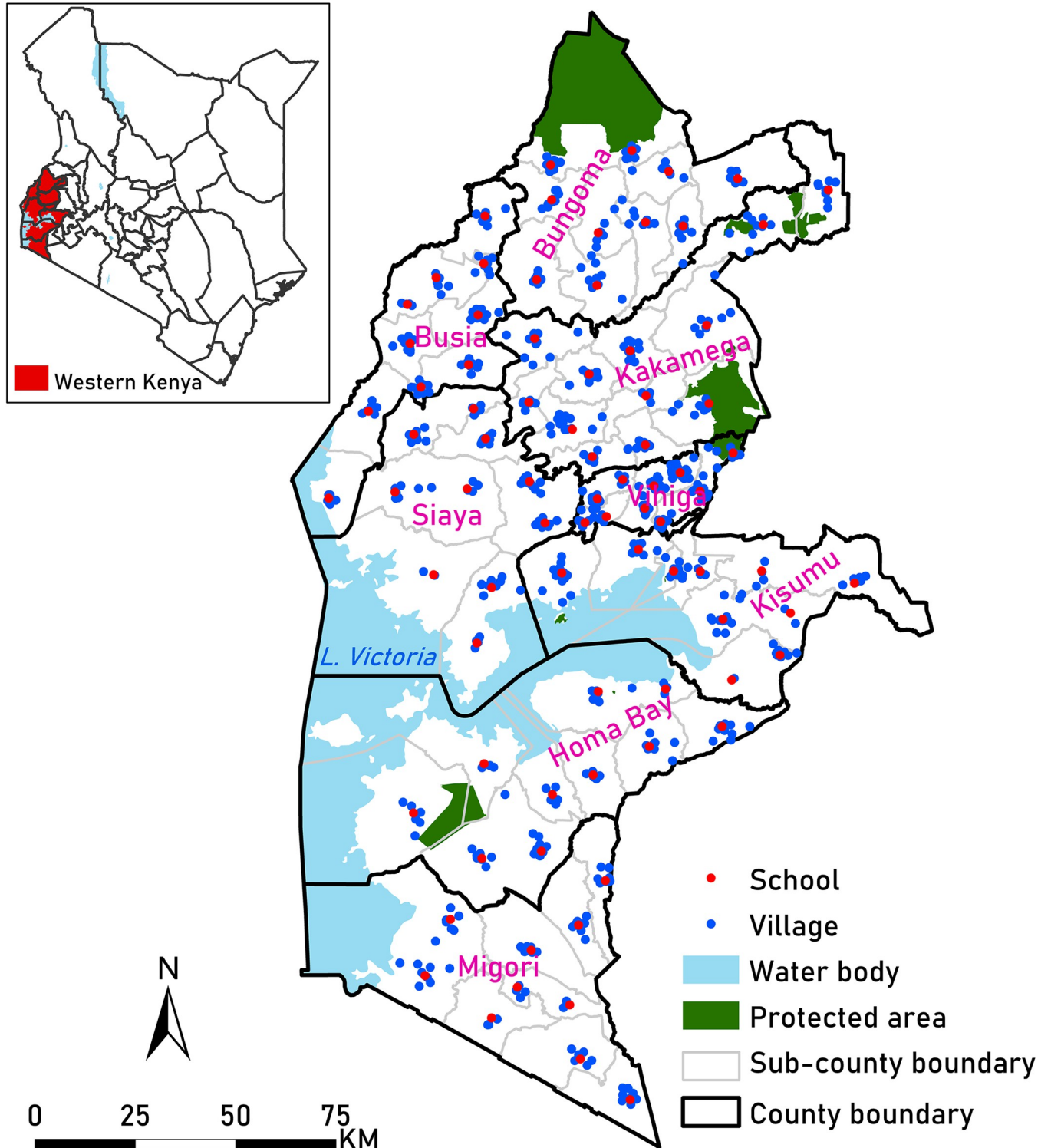
Fig 1. Study area map. Map of Western Kenya showing the distribution of schools and villages across the eight counties. The Western Kenya county and sub-county level shapefile was based on the County Integrated Development Plans 2021 [22].

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OpenStreetMap. The village locations were validated in ArcMap version 10.5 (ESRI Inc., Red-lands, CA, USA) using the approximate travel time to schools reported by the children.

Altitude was extracted from the shuttle radar topographic mission digital elevation models (SRTM) at the 30m x 30m spatial resolution downloaded from Regional Centre for Mapping of Resources for Development [23]. Data on protected areas were based on Biodiversity and Protected Areas Management Reference Information System (RIS) [24] and waterbodies downloaded from the Humanitarian Data Exchange website [25].

Anaemia prevalence

Hb measurements were adjusted for altitude according to the Centers for Disease Control and Prevention recommendations ($Hb = -0.32 \times [altitude\ in\ metres \times 0.0033] + 0.22 \times [altitude\ in\ metres \times 0.0033]$) [26]. No adjustment was made for altitudes below 1000 m. Anaemia was defined using the following age-specific thresholds: <11 g/dl for children aged <5 years, <11.5 g/dl for children aged 5–11 years, and <12 g/dl for children aged 12–14 years. The prevalence of anaemia at school was calculated as the proportion of children with anaemia out of those sampled in each school. A test of proportions was conducted to evaluate whether there was a significant difference between the proportion of children with anaemia by gender. The prevalence value from the school was then adopted to the school catchment area, derived using spatial techniques explained in the next section (School catchment area). Anaemia prevalence was also estimated at the village-level address, to assess clusters based on the area of residence.

School catchment area

The school catchment area, a geographical area around a school, was defined as the adjacent area representing most SAC that attended that school. The schools were mapped to the villages of each child (S1 Fig) using the children's geolocated residential addresses and the catchment was delineated by creating Thiessen Polygons in ArcMap V.10.5. This approach divides the area covered by point features (schools) into proximal zones such that any location within the zone is closer to its associated school than to any other school within the study area [27–29].

Spatial analysis

The geographical patterns of anaemia prevalence were assessed within the study area using local and global spatial autocorrelation measures to identify hotspots and outliers. First, the existence of clusters was determined using Global Moran's I spatial statistic, where values range from − 1 (negative spatial association) to + 1 (event\disease is clustered), with 0 indicating no spatial autocorrelation (uniform distribution of disease\event). A ($p < 0.05$) was used to define significant spatial autocorrelation.

Next, the locations of the clusters were identified using a circular spatial window. The presence of statistically significant spatial hotspots/clusters of anaemia was tested using a Bernoulli model using Kuldorff's SaTScan (v.10.0.2) software. SACs with anaemia at each school location were considered cases and those without were considered controls to fit the Bernoulli model. The default maximum spatial cluster size of <50% of the at-risk population was used [30]. The significance of each potential cluster was evaluated using a likelihood ratio test statistic, and a p-value of 0.05 was considered significant. The scanning window with the maximum likelihood was the most likely cluster (primary cluster), and a p-value was assigned based on Monte Carlo hypothesis testing. Secondary clusters were only reported if they did not overlap with a primary cluster or a previously reported cluster [30]. Cluster analysis was repeated at the

village to assess differences in spatial patterns in areas of residence where risk factors of the disease are and at school sampling sites.

Cluster detection was also undertaken at the areal level (school catchments) to identify anaemia hotspots across catchment areas and as a sensitivity analysis, given the assumption that the prevalence estimated at school is represented in the school catchment. Geoda v 1.20.0.10, was used to generate Anselin's local indicator of spatial association (LISA) test statistic that identifies neighbouring geographical units (catchments) with statistically similar disease rates [31]. The statistical significance level for each spatial unit was computed and mapped onto a LISA significance map.

The distribution of anaemia prevalence across counties and within the identified SatScan and LISA clusters was summarised using box plots. In addition, the Kruskal-Wallis rank sum test was employed to assess whether there were significant differences in anaemia prevalence values between schools and villages and LISA clusters.

Software

SaTScan™ software (v. 10.0.2, Kulldorff and Information Management Services, Inc.) and Geoda software (v. 1.20.0.10) were used for the cluster analysis. ArcMap (v10.5; ESRI Inc., Redlands, CA, USA) was used for geoprocessing and mapping. Data analysis and management were performed using R software (Version 4.2) and StataCorp. 2021 [Stata Statistical Software, Release 17. College Station, TX: StataCorp LP]

Ethical approval and consent to participate

Ethical review approval was obtained from the Kenya Medical Research Institute Scientific Ethics Review Unit SERU (#2801; #3822; #3832), Ministry of Education (MOE/ECD/VoII/37/ 35), and Ministry of Health (MOH/ADM/1/1/2). At the school level, parental consent was based on passive, opt-out consent rather than written opt-in consent owing to the low risk and routine nature of the study procedures. Individual assent was obtained from each child before participating in the survey. The data analysed here did not include individual identification variables hence confidentiality was maintained.

Results

Socio-demographic characteristics

A total of 8085 children were sampled across 82 schools:4030 females and 4055 males. Each county had ten sampled schools, except for Kakamega, where 12 schools were sampled (Fig 1). Most (76%) of the children sampled were between 5 and 11 years of age. Data on Hb concentration were available for 8051 (99.6%) children out of 8085 who were sampled. Children with missing Hb concentration data were excluded from the analysis. Seventy-five percent of the villages were geocoded and included in the analysis (Fig 1).

Anaemia prevalence among SAC

Overall, 27.8% of SAC were classified as anaemic. There was no statistically significant difference in anaemia prevalence between males (28.5%) and females (27.2%) (chi = 1.5913, p = 0.207). The prevalence of anaemia varied with age (Fig 2). The 5 to 6 years age group had the highest prevalence at 40.8% (Fig 2), and the adjusted Hb concentration among children ranged between 2.0 to 19.6 g/dl, with a mean value of 12.3 g/dl (95% CI:26.8–28.8%) (Table 1). The mean Hb increased steadily with age; however, there was a slight drop (12.6 g/dl to 12.4 g/
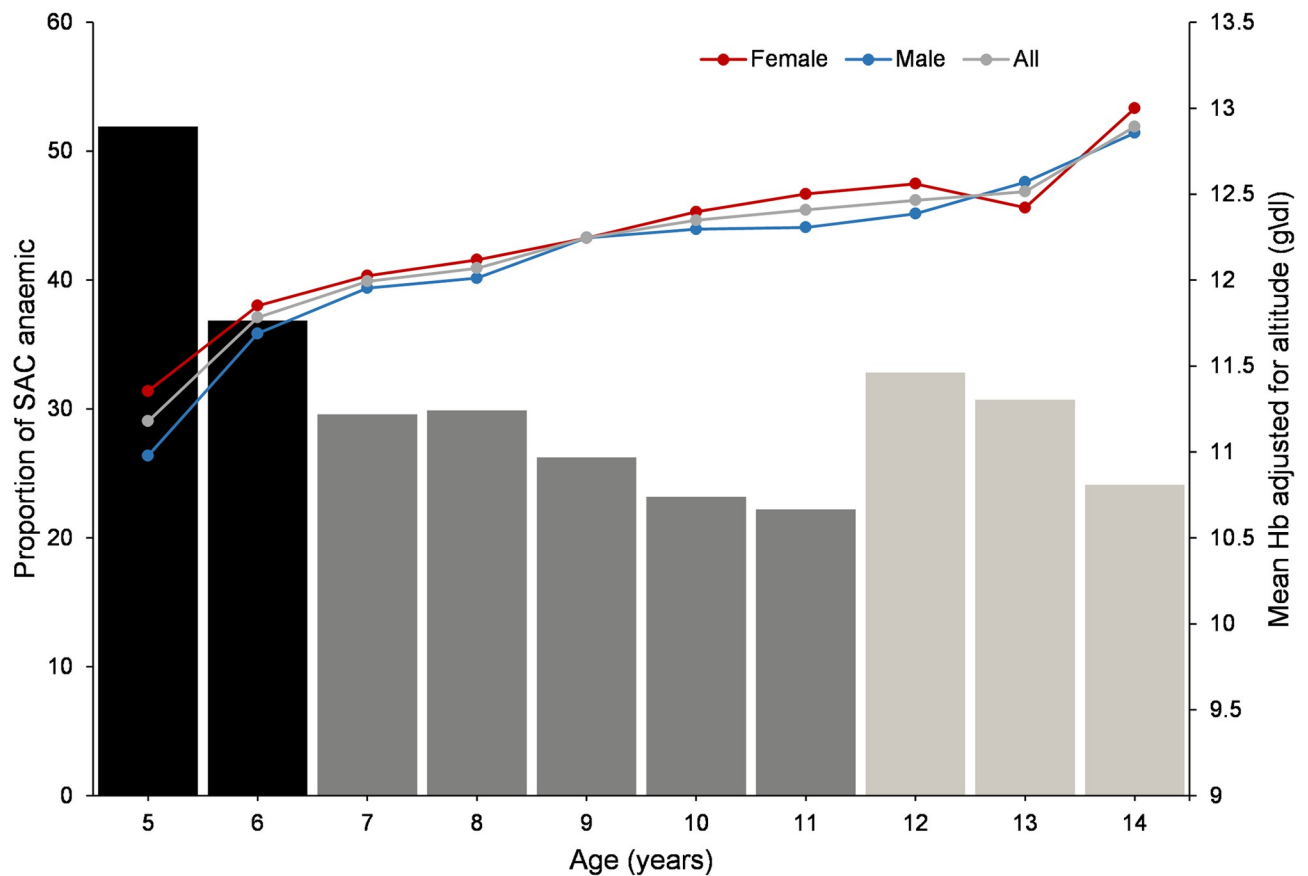
Fig 2. Combined bar and line charts. The bar chart shows the variation in anaemia prevalence by age (5–14 yrs) and the line graph shows mean Hb (adjusted for altitude) by gender across all age groups (5–14 yrs).

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dl) in females between ages 12 and 13 (Fig 2). There was minimal variation in mean Hb by age across schools as shown in Fig 3A.

Spatial distribution of anaemia prevalence

The empirical prevalence of anaemia varied across schools (Fig 3B), ranging from 7.1% to 59.2%. The prevalence value at each school was adopted for the corresponding school catchment areas (Fig 4A). Counties with the highest (>40%) prevalence of school catchment anaemia included Kakamega, Siaya, Migori, and Kisumu. At the county level, Siaya had the highest mean prevalence of anaemia (36.7%) and Bungoma had the lowest (20.6%). Siaya, Migori and Vihiga showed the greatest variability in prevalence values across schools compared to other counties with median prevalence values of 35.5% (30.7–40.6), 27.8% (24.8–36.7) and 22.1% (16.4–31.0) respectively (Fig 3B). In contrast, the distribution of anaemia prevalence in Bungoma 18.9% (16.3–23.2), Busia 27.3% (22.8–31.1), Homa Bay 25.9% (21.0–28.2) and Kisumu 24.8% (19.6–28.7) appeared to be relatively symmetrical. However, the distribution of anaemia prevalence in Kakamega skewed towards lower prevalence values of 29.5% (23.9–32.1), while Migori displayed skewness towards higher prevalence values.

Table 1. Summary statistics of Hb concentration (g/dl) by age category and sex across counties.

| County	Gender	Age Categories	Hb Concentration (Adjusted for altitude)					
			min	max	sd	mean	median	n
Bungoma	Female	12–14 yrs	7.7	15.4	1.3	12.9	12.9	106
		5–11 yrs	5.1	16.6	1.4	12.6	12.7	368
	Male	12–14 yrs	7.0	16.3	1.4	12.8	12.8	160
		5–11 yrs	7.2	16.2	1.5	12.4	12.5	319
	Total	**5–14 yrs**	**5.1**	**16.6**	**1.4**	**12.6**	**12.7**	**953**
Busia	Female	12–14 yrs	9.7	16.7	1.4	12.8	12.9	111
		5–11 yrs	7.7	16.8	1.4	12.3	12.3	382
	Male	12–14 yrs	8.8	16.4	1.3	12.7	12.8	160
		5–11 yrs	8.2	15.7	1.3	12.4	12.5	335
	Total	**5–14 yrs**	**7.7**	**16.8**	**1.3**	**12.5**	**12.5**	**988**
Homa Bay	Female	12–14 yrs	6.7	15.5	1.5	12.4	12.5	100
		5–11 yrs	2.0	15.9	1.5	12.4	12.5	387
	Male	12–14 yrs	7.8	15.6	1.5	12.7	12.8	135
		5–11 yrs	4.8	16.3	1.5	12.3	12.4	357
	Total	**5–14 yrs**	**2.0**	**16.3**	**1.5**	**12.4**	**12.5**	**979**
Kakamega	Female	12–14 yrs	7.5	16.7	1.6	12.3	12.2	101
		5–11 yrs	6.4	16.1	1.4	12.2	12.2	494
	Male	12–14 yrs	5.5	15.1	1.4	12.3	12.4	174
		5–11 yrs	5.2	19.5	1.6	12.0	12.2	426
	Total	**5–14 yrs**	**5.2**	**19.5**	**1.5**	**12.2**	**12.3**	**1195**
Kisumu	Female	12–14 yrs	6.2	16.5	1.5	12.3	12.1	86
		5–11 yrs	4.0	16.0	1.5	12.2	12.3	397
	Male	12–14 yrs	7.9	15.3	1.4	12.6	12.8	121
		5–11 yrs	5.3	16.0	1.4	12.1	12.2	363
	Total	**5–14 yrs**	**4.0**	**16.5**	**1.4**	**12.2**	**12.3**	**967**
Migori	Female	12–14 yrs	6.4	18.0	1.6	12.5	12.6	106
		5–11 yrs	3.1	16.3	1.8	12.0	12.3	387
	Male	12–14 yrs	3.2	16.2	1.8	12.2	12.3	151
		5–11 yrs	4.6	19.6	1.7	11.9	12.1	337
	Total	**5–14 yrs**	**3.1**	**19.6**	**1.7**	**12.1**	**12.2**	**981**
Siaya	Female	12–14 yrs	8.6	15.5	1.5	12.5	12.9	111
		5–11 yrs	6.1	17.0	1.6	12.0	12.1	382
	Male	12–14 yrs	5.1	16.6	1.7	12.3	12.5	151
		5–11 yrs	6.3	16.1	1.6	11.8	11.9	348
	Total	**5–14 yrs**	**5.1**	**17.0**	**1.7**	**12.0**	**12.1**	**992**
Vihiga	Female	12–14 yrs	10.5	15.7	1.3	12.8	12.9	69
		5–11 yrs	8.0	16.8	1.3	12.4	12.5	429
	Male	12–14 yrs	7.4	15.2	1.4	12.5	12.6	112
		5–11 yrs	4.9	16.5	1.5	12.3	12.4	386
	Total	**5–14 yrs**	**4.9**	**16.8**	**1.4**	**12.4**	**12.5**	**996**
Western Region	Female	12–14 yrs	6.2	18.0	1.5	12.6	12.6	790
		5–11 yrs	2.0	17.0	1.5	12.3	12.4	3226
	Male	12–14 yrs	3.2	16.6	1.5	12.5	12.6	1164
		5–11 yrs	4.6	19.6	1.5	12.2	12.3	2871
	Total	**5–14 yrs**	**2.0**	**19.6**	**1.5**	**12.3**	**12.4**	**8051**
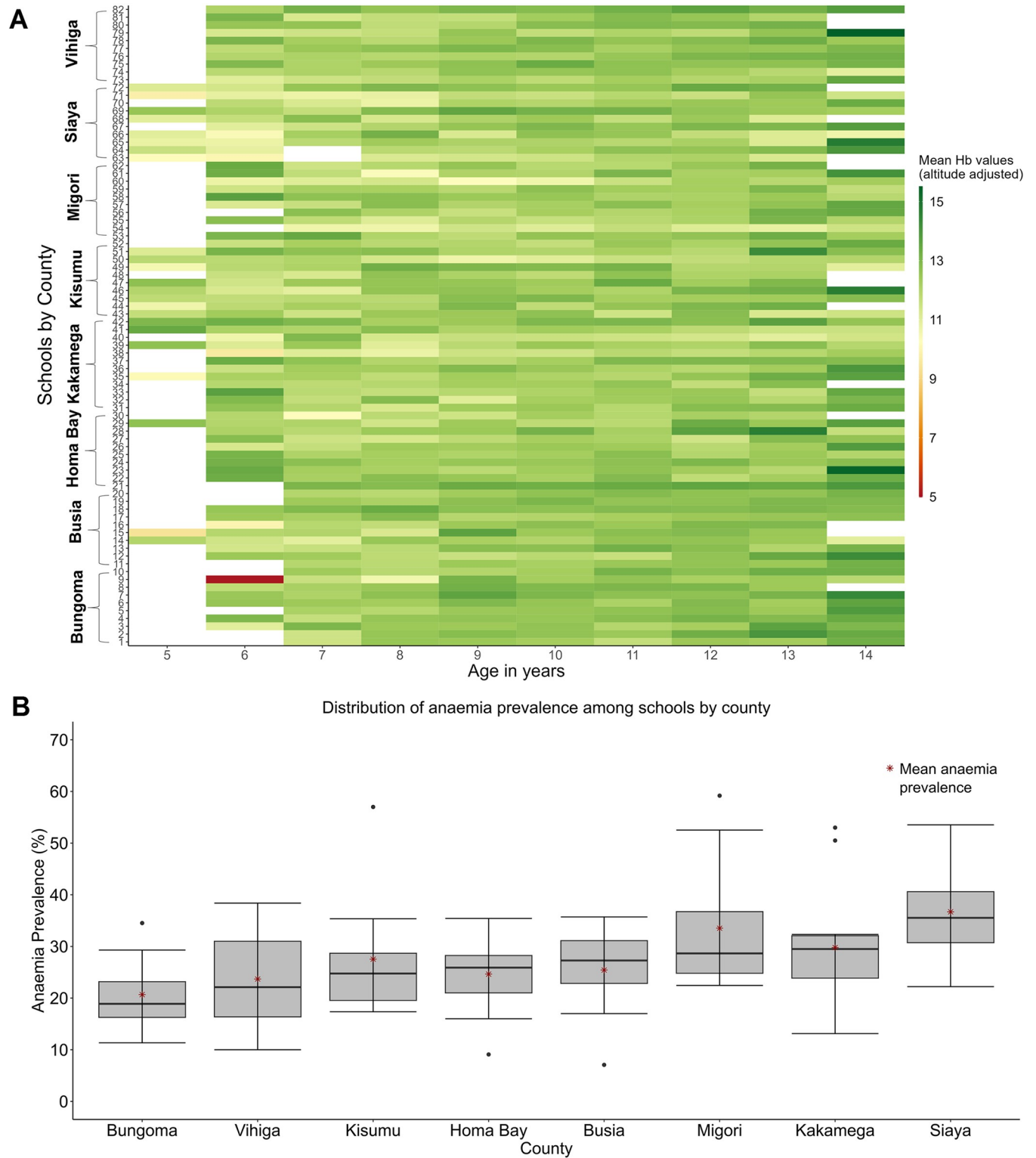
Fig 3. (A) Variation of mean Hb (adjusted for altitude) for each age (5–14 yrs) across the 82 schools. The blanks in white indicate missing samples for that age group. (B) Boxplots showing the distribution of anaemia prevalence among schools by county.

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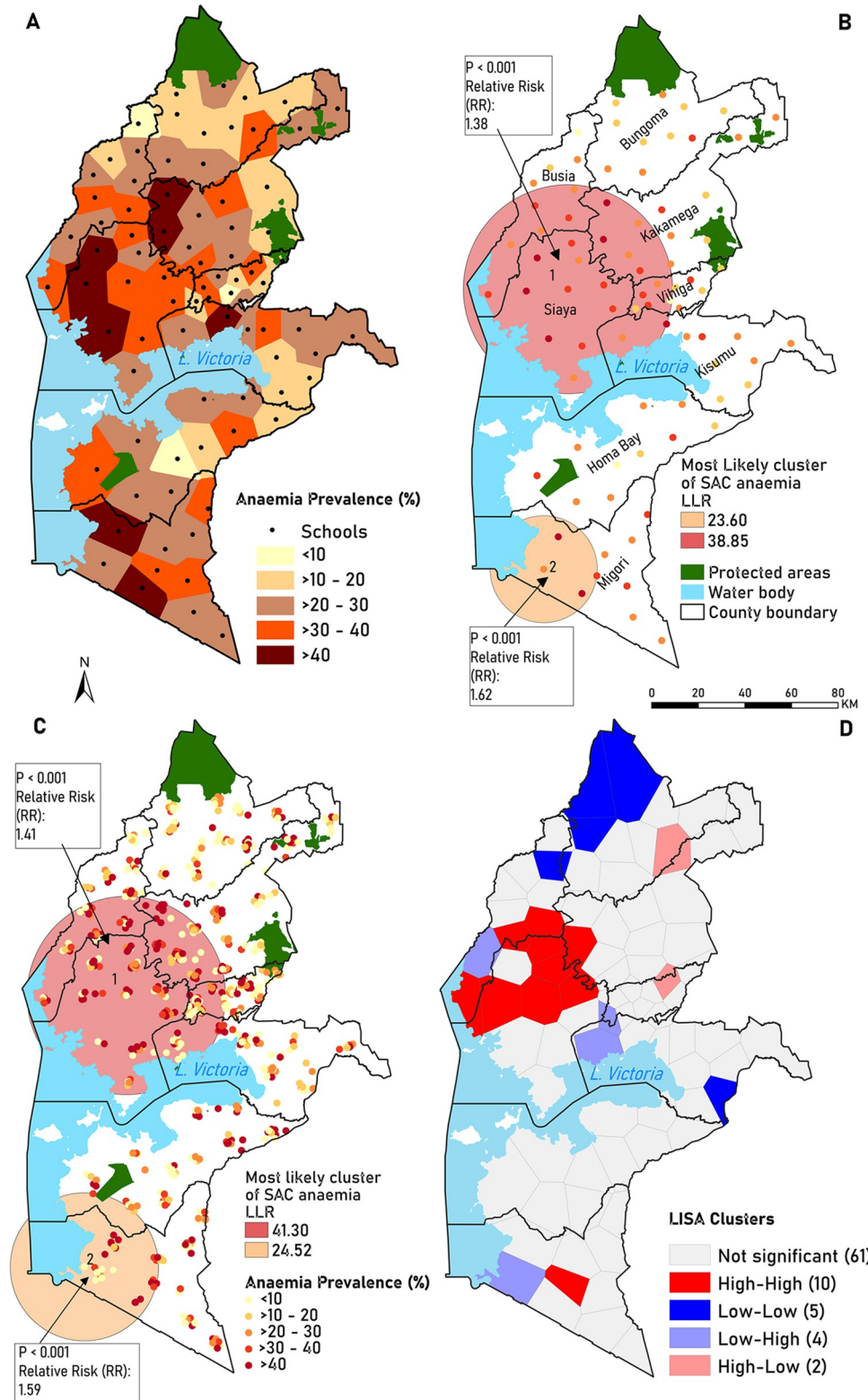
Fig 4. (A) Anaemia prevalence for each school catchment (computed from empirical Hb measurements), (B) Spatial scan statistics results of anaemia clusters for schools, (C) Spatial scan statistics results of anaemia clusters for villages and (D) LISA cluster map showing anaemia hotspots (red) and cold spots (blue). The corresponding LISA significance map in shown in S2 Fig. The Western Kenya county level shapefile was based on County Integrated Development Plans 2021 [22].

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Spatial autocorrelation and clustering

The Global Moran's I value of 0.2 (p <0.002) indicated significant clustering of anaemia within the study area. Spatial SatScan statistics identified two significant cluster spatial windows: primary cluster 1 (939 out of 769 expected cases) traversing Siaya County and parts of Busia, Kakamega, Vihiga, and Kisumu counties bordering Siaya County, and secondary cluster 2 (171 out of 109 expected cases) located in the southern part of the study area, covering a section of Migori County (Fig 4B). Cluster 1 had the highest Log-Likelihood ratio (LLR) of 38.9 with a relative risk (RR) of 1.4 implying that children within this cluster are at 40% more risk than those residing outside. In contrast, cluster 2 had an LLR of 23.6 with an RR of 1.6 and a 60% increased risk of anaemia. A total of 28 schools were within Cluster 1, and the majority (36%) were in Siaya County. Only four schools comprised cluster 2. Cluster analysis at the village level (location of residence) highlighted spatial patterns similar to those at schools (LLR = 41.3, RR = 1.4) for Cluster 1 and (LLR = 24.5, RR = 1.6) for Cluster 2 (Fig 4C).

The sensitivity analysis of the LISA results of the areal level clustering (at school catchments) are shown in (Fig 4D). A total of 10 catchments constituted the hotspots (high-high) shown in red, implying that catchments with high anaemia prevalence are surrounded by neighbouring catchments with high anaemia prevalence. In contrast, five cold spots (low-low) in blue indicate the opposite: a region of low anaemia prevalence. Six of the clusters indicated discordance with either low prevalence surrounded by high prevalence (low-high clusters), or high prevalence surrounded by low prevalence (high-low clusters). The ten hotspots (clusters with high anaemia prevalence) were located in the western part, north of Lake Victoria, and a section in the southern part of the study area. These clusters correspond spatially to those identified by the spatial scan statistical analysis (Fig 4B), and catchments were estimated to have a high prevalence of anaemia (Fig 4A).

Fig 5A illustrates the distribution of anaemia prevalence across schools and villages by SatScan clusters. In cluster 1, the median anaemia prevalence in schools is 32.0% (27.8–38.6) and is 33.3% (0–50) in villages. However, the observed variation between schools and villages was not statistically significant (chi = 0.2904, p = 0.590). Similarly, in cluster 2, the median prevalence was 45.5% (35.0–54.2) in schools and 36.8% (22.7–58.6) in villages, with no statistically significant variation found (chi = 0.1257, p = 0.723).

Across the four LISA clusters, the high clusters (High-High and High-Low) clusters had the highest median anaemia prevalence, with values of 32.0% (30.3–35.7) and 33.3% (32.6–33.9) respectively. In contrast, the Low clusters (Low-High and Low-Low) had lower median anaemia prevalence: 24.2% (19.7–25.8) for the Low-High cluster and 18.2% (17.4–23.2) for the Low-Low cluster (Fig 5B). The variation between the high and low clusters was statistically significant (chi = 13.235, p < 0.05).

Discussion

The government of Kenya recognizes that improving the health of learners is a critical driver for achieving Kenya Vision 2030 [32]. Unfortunately, little is known about the prevalence of anaemia among SAC, although this condition contributes to poor intellectual and physical development among this population [13,17]. In this study, we employed global and local spatial autocorrelation techniques to assess the geographical distribution of anaemia prevalence in SAC in Western Kenya. Over 25% of the SAC were anaemic, ranging from 20.6% in Bungoma to 36.7% in Siaya. Our findings underline the spatial heterogeneity of anaemia prevalence in this area of Kenya.

Overall, the prevalence of SAC anaemia in Western Kenya was 27.8%. Other similar studies conducted in Kenya reported the prevalence of SAC anaemia to be 35% (5–16 yrs) [33] and
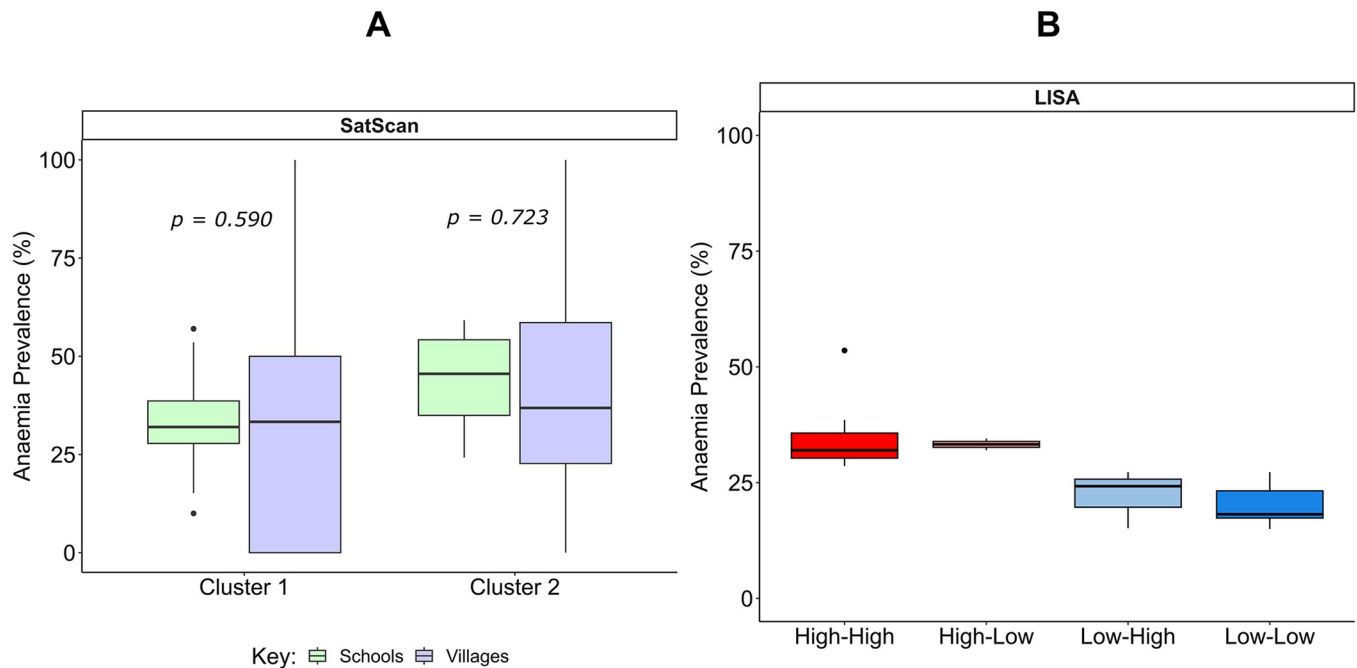
Fig 5. Box plot of the prevalence rates across clusters identified by SatScan and LISA cluster analysis. (A) shows distribution of anaemia prevalence across schools and villages in cluster 1 and cluster 2 identified from SatScan analysis; (B) shows distribution of anaemia prevalence across High-High, High-Low, Low-High and Low-Low LISA clusters.

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28.8% (6 months -14 yrs) [34] in 2013 and 2014, respectively. In our study, the average Hb concentration increased with age, but anaemia prevalence decreased progressively with age within each age group (5-11yrs & 12-14yrs) (Fig 2), which is comparable to a previous study [34]. Across studies, there are disparities in the variation in Hb concentration and prevalence of anaemia by sex [35]. Other studies in Kenya suggest that male SAC are at a higher risk of anaemia than female SAC [17,34]. The difference in this study was not statistically significant, which is consistent with earlier studies conducted in Ethiopia [16,36]. However, we have limited knowledge of what constitutes a biological framework for anaemia in SAC.

Spatial autocorrelation analysis revealed a non-random distribution of SAC anaemia. Although the spatial scan statistics identified more geographical locations (32) as high-risk anaemia areas compared to LISA (10), there was spatial consistency in the locations of these hotspots [37]. Generally, children residing in the western part of the study area, north of Lake Victoria, and southern parts of Migori County are at an elevated risk of anaemia compared to children residing in other regions of the study area. Based on spatial scan statistics, no significant differences in median anaemia prevalence were observed at the village and schools within cluster 1 and cluster 2. This finding suggests that the prevalence of anaemia in schools in Western Kenya represent where the children live and reflects the contextual residential characteristics [38]. However, there was a significant difference in median anaemia prevalence between high and low clusters from LISA analysis, further highlighting the spatial disparity of anaemia prevalence across school catchments. These results from the cluster analysis are useful for informing a targeted approach and prioritising resources as has been used in targeting malaria interventions [39]. Further, these findings form a basis for conducting further studies to understand the underlying factors of anaemia better. Specifically, SatScan provides a general overview of where clusters (Fig 4B and 4C) are, whereas LISA provides insights into which school catchments should be prioritised (Fig 4D).

In addition to hot spot areas, LISA identified outlier areas (areas with high anaemia prevalence close to areas with low anaemia prevalence and where areas with high prevalence surround high prevalence areas) (Fig 4D) [40]. These results provide additional insights for developing tailored strategies and policies considering spatial dependencies and relationships between neighbouring regions [41].

A complex configuration of causes such as socioeconomic status, environmental factors, food security, and differences in the prevalence of parasitic infections, such as soil-transmitted helminth infection, hookworms, and malaria, may contribute to anaemia risk [42–45]. Food insecurity for example, can cause nutritional deficiencies which are linked with anaemia [46]. However, in Western Kenya, where over 80% of the population is food secure according to the FEWS NET Integrated Phase Classification [47], food security is unlikely to be a significant driver of anaemia; instead, the region's high malaria transmission rates may be a key contributing risk factor for anaemia [48], as are variation in access to clean water.

The prevalence of anaemia can be reduced through a variety of interventions. In Kenya, some of the indirect interventions to manage parasitic infection for example, deworming to reduce the burden of intestinal parasites, promoting good hygiene, and promoting malaria intervention [49–52] have been implemented through National School-Based Deworming Programme (NSBDP) and the National Malaria Control Programme (NMCP) [51,52]. Other direct interventions include those related to nutrition (e.g., promoting healthy diets, food fortification and supplementing diets such as iron, and folic acid) [53–55]. Cluster analysis results such as those presented here can assist in efficiently targeting these interventions and in better allocating limited resources complemented by further research to better understand the role of different factors on anaemia prevalence.

This study had several limitations. First, we assumed that the school sample represented a community. However, the subset of children who go to school may be different from those who do not, but there is no information to assess this. Second, more than 50% of schools lacked samples of 5 years old children (Fig 3A), which could potentially underestimate anaemia prevalence at these schools because younger children are more vulnerable to anaemia. Third, the choice of the cluster window size is subjective. However, this study used a recommended window size of 50% of the study population to detect both small and large clusters [30]. Fourth, though the use of circular scan windows may hinder the detection of irregular clusters, they are rotationally invariant and provide clear signals of disease hotspots for public health decision-makers and stakeholders [56–60]. Lastly, it is important to highlight that our study specifically focused on the clustering of anaemia and did not include an analysis of associated risk factors. Although extensive research has been conducted on these factors in various contexts, including Kenya, providing a valuable resource for future investigations [8,34,38,44], the results from this study are useful for directing where further research should be conducted to better understand the factors driving anaemia within specific geographic locations since variation within school catchments can occur.

Conclusion

The prevalence of anaemia among SAC in Western Kenya is a moderate public health concern, as determined by WHO thresholds, with a prevalence of 27.8% [4,7]. Our findings indicate a need to expand control measures to address anaemia in this population, and that further research is needed to better assess the underlying causes. In light of geographical differences in anaemia prevalence, it is crucial to allocate resources to hotspot areas to effectively reduce the burden of anaemia among SAC in Western Kenya. Effective interventions such as providing iron and folic acid supplements, promoting healthy diets and food fortification, deworming to

reduce the burden of intestinal parasites, promoting good hygiene, and promoting malaria intervention should be prioritized to improve SAC health outcomes [51–54,60]. These interventions can be implemented through school feeding programs and other community- and school-based health intervention approaches [49–51].

Supporting information

S1 Fig. Thiessen polygons representing 82 school catchment areas. The Western Kenya shapefile was based on the County Integrated Development Plans 2021 [22].
(TIF)

S2 Fig. LISA significance map. The Western Kenya county level shapefile was based on the County Integrated Development Plans 2021 [22].
(TIF)

S1 File.
(DOCX)

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