

Research



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Received: 13 Sep 2025 - **Accepted:** 17 Jan 2026 - **Published:** 25 Jan 2026

Keywords: Anemia, iron deficiency, Yemen, conflict, epidemiology, rural health, risk factors

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Cite this article: Mamoona Al-Namer et al. Prevalence, severity, and predictors of anemia in a conflict-affected clinical population: a retrospective cross-sectional study from Ibb, Yemen. PAMJ-One Health. 2026;19(4). 10.11604/pamj-oh.2026.19.4.49368

Available online at: <https://www.one-health.panafrican-med-journal.com/content/article/19/4/full>

Prevalence, severity, and predictors of anemia in a conflict-affected clinical population: a retrospective cross-sectional study from Ibb, Yemen

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Abstract

Introduction: anemia is a critical public health burden in Yemen, exacerbated by protracted conflict. Detailed data on its morphological patterns, severity, and specific risk factors within clinical settings are scarce. This study aimed to determine the prevalence, morphological subtypes, severity, and independent predictors of anemia among patients in Ibb Governorate, Yemen.

Methods: this was a retrospective cross-sectional study analyzing hematological data from patients attending a private tertiary laboratory clinic in Ibb City between March and October 2021. A final cohort of 320 anemic patients was derived from 7,928 records. Anemia and its severity were classified using World Health Organization (WHO) criteria. Nutritional deficiencies were defined using a two-step process: initial hematological screening followed by biochemical confirmation (serum ferritin, B12, folate) where available. Multivariable logistic regression identified independent predictors of severe/life-threatening anemia (hemoglobin <8.0 g/dL). **Results:** the mean age was 29.4 ± 20.1 years; 59.7% were female. Moderate anemia was most prevalent (49.4%), while severe and life-threatening anemia collectively affected 29.7% of patients. Microcytic anemia was the dominant morphological subtype (56.9%). Confirmed iron deficiency was the leading nutritional deficiency (35.0%). In the adjusted model, female sex (adjusted Odds Ratio [aOR] 1.87; 95% CI 1.22-2.87), rural residence (aOR 2.05; 95% CI 1.28-3.28), confirmed iron deficiency (aOR 3.52; 95% CI 2.01-6.15), and age >50 years (aOR 1.75; 95% CI 1.04-2.94) were independent predictors of severe anemia. **Conclusion:** this study reveals a high burden of moderate-to-severe anemia in a Yemeni clinical population, primarily linked to iron deficiency. The significant associations with female sex, rural residence, and older age highlight profound health disparities. These findings underscore the urgent need for targeted nutritional interventions, strengthened rural healthcare access, and context-specific public

health strategies to mitigate anemia in conflict-affected Yemen.

Introduction

Anemia is a significant global public health concern, affecting over 1.6 billion people and disproportionately impacting low- and middle-income countries [1]. It is characterized by insufficient hemoglobin levels or red blood cell counts, which impair oxygen delivery to tissues and result in increased morbidity, particularly among women of reproductive age, young children, and the elderly [2,3]. While nutritional deficiencies—primarily of iron, vitamin B12, and folate—are the leading etiologies, iron deficiency alone accounts for nearly half of all anemia cases worldwide [2,3].

Complete Blood Count (CBC) parameters play a pivotal role in the diagnosis and morphological classification of anemia. Indices such as hemoglobin concentration, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and red cell distribution width (RDW) enable detection of anemia and provide valuable clues to its underlying causes [4-6]. Recent studies, including diagnostic accuracy analyses using Receiver Operating Characteristic (ROC) curves, have supported the utility of CBC parameters in distinguishing iron deficiency anemia, especially in resource-limited settings where biochemical assays are often unavailable [4]. Despite this, limitations exist in specificity, particularly in differentiating iron deficiency from other conditions like thalassemia or the anemia of chronic inflammation, which is highly prevalent in conflict settings.

Yemen's protracted conflict has intensified anemia's burden through a synergistic degradation of social determinants of health: exacerbating food insecurity, disrupting healthcare infrastructure, and increasing vulnerability to infections. Prior research in Yemen largely targets specific populations such as pregnant women and

adolescents, leaving important gaps in understanding the broader epidemiology of anemia, including its morphological subtypes, severity patterns, and risk factors across age and sex groups in diverse clinical populations [7,8]. This lack of comprehensive data hinders effective public health planning and intervention in the country's conflict-affected regions. This study addresses these critical knowledge gaps by examining the prevalence, severity, and morphological characteristics of anemia in a diverse clinical cohort from Ibb Governorate, Yemen. It further identifies independent demographic and nutritional predictors of severe anemia, using a diagnostic approach that emphasizes hematological morphology while acknowledging the constraints of the setting. The findings provide evidence crucial for tailoring effective public health measures in this vulnerable, resource-constrained humanitarian context.

Methods

Study design and setting: this retrospective cross-sectional study was conducted at the Al-Rafa Healthcare Institute, a private tertiary laboratory clinic in Ibb City, Yemen. In the context of Yemen's protracted humanitarian crisis, where systematic public health surveillance is disrupted, such clinical facilities serve as critical sources of health data [9]. We analyzed de-identified hematological data from patients who underwent Complete Blood Count (CBC) testing between March 1 and October 30, 2021. The study was approved by the Institutional Review Board of Ibb University (approval no. IBBUNI.AC.YEM.2024.10.102). In alignment with ethical standards for retrospective research on anonymized records, the requirement for individual informed consent was waived. The study adhered to the principles of the Declaration of Helsinki.

Study population and sample size: the initial dataset comprised 7,928 electronic medical records. To construct a focused cohort for

investigating anemia determinants, we applied the following criteria:

Inclusion: patients diagnosed with anemia based on World Health Organization (WHO) age- and sex-specific hemoglobin thresholds.

Exclusion: pregnant women; individuals taking mineral/vitamin supplements; and records with missing critical demographic or laboratory data. After applying these filters, 320 anemic patients formed the final analytic cohort. We acknowledge that the use of a private laboratory database may limit the generalizability of our findings to populations relying on public healthcare services and may introduce selection bias (Figure 1). This diagram illustrates the screening and enrollment process. From an initial screening of 7,928 records, 5,598 participants were excluded based on clinical criteria and data incompleteness, resulting in a final analytic cohort of 320.

Sample size calculation: a post-hoc sample size calculation was performed to contextualize the analytic power of our study. As our primary outcome was the prevalence of anemia and its subtypes, we used the standard formula for estimating a single population proportion. The calculation was performed using G*Power 3.1 software. Based on an anticipated iron deficiency anemia prevalence of 30.4% from prior research in a similar Yemeni population by Al-Alimi *et al.* [8], a 95% confidence level, and a 5% margin of error, the minimum required sample size was 323 participants. Our final analytic cohort of 320 patients, therefore, provides comparable precision (margin of error = 5.1%).

Data extraction: de-identified data were extracted from the laboratory information system, encompassing:

Demographic variables: age (categorized as <2, 2-4, 5-15, 16-50, >50 years), sex, and residence (urban/rural).

Hematological parameters: hemoglobin (Hb, g/dL), mean corpuscular volume (MCV, fL), mean corpuscular hemoglobin (MCH, pg), and red cell distribution width (RDW, %).

Biochemical parameters (for confirmatory testing): for cases with suggestive CBC indices, available serum ferritin, vitamin B12, and folate levels were reviewed.

Operational definitions: anemia was defined and classified according to World Health Organization (WHO) criteria [10], with severity categorized as mild, moderate, or severe (encompassing the life-threatening category) based on established hemoglobin thresholds [11]. Morphological classification was based on Mean Corpuscular Volume (MCV) as microcytic (<80 fL), normocytic (80-97 fL), or macrocytic (>97 fL) [12].

Defining nutritional deficiencies: a two-step diagnostic process: to improve diagnostic specificity, we employed a sequential two-step approach: 1) hematological screening: cases were flagged as suggestive of: (i) iron deficiency: MCV <80 fL, MCH <26 pg, and RDW >14.5%; (ii) B12/folate deficiency: macrocytic anemia (MCV >97 fL) with normal RDW (11.5-14.5%). 2) Biochemical confirmation: for screen-positive cases, the diagnosis was confirmed using available biochemical assays: serum ferritin <30 µg/L for iron deficiency; serum B12 <200 pg/mL or folate <4 ng/mL for respective deficiencies [13,14]. For cases where initial biochemical results were unavailable, a supplementary verification process (consultation with a senior hematologist and review of additional medical history) was undertaken. Cases without definitive biochemical confirmation after this process were not classified as having a confirmed nutritional deficiency in the primary analysis.

Statistical analysis: data were analyzed using SPSS version 26 (IBM Corp.). Descriptive statistics summarized the prevalence, severity, and morphological patterns of anemia. All analyses were conducted as complete-case analyses.

Categorical variables were reported as frequencies (%) and continuous variables as mean ± standard deviation. To identify independent predictors of severe anemia (Hb <8.0 g/dL), we first performed univariate analyses (Chi-square tests). Variables with $p < 0.10$ were included in a multivariable logistic regression model, adjusted for age, sex, residence, and confirmed nutritional deficiencies. Results are presented as adjusted odds ratios (aOR) with 95% confidence intervals (CI). Statistical significance was set at $p < 0.05$. Sensitivity analyses were conducted to assess robustness, including re-running models on the subset with complete biochemical data.

Results

Study population derivation and characteristics: the analytic cohort was derived from 7,928 consecutive electronic medical records of patients who underwent CBC testing. After applying the eligibility criteria, 320 patients with confirmed anemia were included in the final analysis (Figure 1). The mean age of the cohort was 29.4 ± 20.1 years. Females comprised a significant majority (191, 59.7%) compared to males (129, 40.3%; $p < 0.001$). Most participants resided in rural areas (197, 61.6%), with the largest age group being 16-50 years (195, 60.9%) (Table 1).

Prevalence and severity of anemia: the mean hemoglobin concentration for the cohort was 8.6 ± 1.7 g/dL (range: 5.7-11.1 g/dL). Moderate anemia (8.0-9.9 g/dL) was the most prevalent severity category, affecting nearly half of all patients (158, 49.4%). Severe (6.5-7.9 g/dL) and life-threatening anemia (<6.5 g/dL) were present in 63 (19.7%) and 32 (10.0%) patients, respectively, indicating that approximately one-third of the clinical cohort (29.7%) had hemoglobin levels below 8.0 g/dL (Table 2).

Morphological characteristics and confirmed nutritional deficiencies: microcytic anemia (MCV < 80 fL) was the predominant morphological subtype, identified in 182 patients (56.9%).

Normocytic and macrocytic anemia were present in 107 (33.4%) and 31 (9.7%) patients, respectively. The distribution of erythrocyte hemoglobinization (by MCH) across these volumetric subtypes (MCV) is shown in Figure 2. This figure illustrates the predominance of hypochromic cells within the microcytic category, supporting presumptive iron deficiency as the leading morphological subtype. Following the two-step diagnostic process, confirmed iron deficiency (serum ferritin $<30 \mu\text{g/L}$) was the leading nutritional deficiency, identified in 112 patients (35.0%). Confirmed vitamin B12 or folate deficiencies were less common, documented in 44 patients (13.8%). The age-stratified patterns of morphology, confirmed deficiencies, and anemia severity are presented in Table 3.

Predictors of severe anemia (Hb $< 8.0 \text{ g/dL}$): in univariate analysis, female sex, rural residence, iron deficiency, and age >50 years were significantly associated with severe/life-threatening anemia (Hb $< 8.0 \text{ g/dL}$). The multivariable logistic regression model, adjusted for age, sex, residence, and confirmed nutritional deficiencies, identified four independent predictors: female sex (adjusted Odds Ratio [aOR] 1.87; 95% Confidence Interval [CI], 1.22-2.87; $p = 0.004$), rural residence (aOR 2.05; 95% CI, 1.28-3.28; $p = 0.003$), confirmed iron deficiency (aOR 3.52; 95% CI, 2.01-6.15; $p < 0.001$), and age above 50 years (aOR 1.75; 95% CI, 1.04-2.94; $p = 0.04$). Conversely, children under 2 years old had significantly lower odds of severe anemia compared to the reference group aged 16-50 years (aOR 0.22; 95% CI, 0.05-0.93; $p = 0.04$). Neither confirmed B12 nor folate deficiency was a significant predictor in the adjusted model (Table 4). A sensitivity analysis restricted to the 156 cases with complete biochemical data yielded consistent results, confirming the robustness of the primary model.

Discussion

While anemia is widely acknowledged as a critical public health issue in conflict-torn Yemen, detailed evidence on its specific characteristics, such as morphological patterns, severity, and predictors within clinical populations, remains scarce. Conducted under the severe constraints of the ongoing humanitarian crisis, this study addresses this gap by analyzing the prevalence, subtypes, and determinants of anemia among patients at a single center in Ibb Governorate. Our findings reveal that anemia poses a profound burden, with 79.1% of patients affected by moderate, severe, or life-threatening disease. The high proportion of microcytic anemia (56.9%) and the confirmation of iron deficiency as the most frequent nutritional deficiency (35.0%) strongly suggest that inadequate iron intake is the primary driver. Importantly, we identified distinct vulnerability profiles: female sex, rural residence, age over 50 years, and confirmed iron deficiency each independently increased the odds of severe anemia. These results highlight how the ongoing crisis intensifies pre-existing health disparities, placing the most vulnerable populations at greatest risk.

The 49.4% prevalence of moderate anemia and the finding that 29.7% of patients had severe or life-threatening anemia underscore a critical level of morbidity in this clinical population. This is consistent with previous research documenting similarly high anemia rates among vulnerable Yemeni populations, including adolescents and pregnant women. For example, studies in Yemeni adolescents, particularly from the war-affected region of Hodeida, have reported anemia prevalence around 38% to 49% [7]. Likewise, anemia prevalence among pregnant women in Yemen ranges from approximately 25% to over 40%, depending on the region and study population [15,16]. This persistent burden highlights the ongoing impact of chronic food insecurity, limited healthcare access, and disruptions to nutritional support programs due to

humanitarian challenges amid the protracted conflict [16,17]. The mean hemoglobin concentration of 8.6 g/dL in our cohort reflects clinically significant anemia, likely contributing to substantial functional impairment and adverse health outcomes [16,18].

Morphologically, microcytic anemia predominated in our cohort (56.9%), consistent with both global and regional data identifying iron deficiency as a predominant cause of anemia worldwide [2,7,15]. A key methodological strength of this study was the use of a sequential diagnostic approach. We employed a composite hematological index as an initial screen, followed by biochemical confirmation where available. This pragmatic method is suitable for resource-constrained settings, yet our final diagnosis of confirmed iron deficiency in 35.0% of patients (aOR for severe anemia = 3.52; 95% CI: 2.01-6.15) provides a more specific estimate of its role, mitigating potential misclassification from anemia of chronic disease which may also present with microcytosis [19]. Comparatively, regional studies reveal similar patterns. For example, studies from Ethiopia and Mozambique reported anemia prevalences of 35.3% and nearly 50%, respectively, with multifactorial etiologies including malaria, food insecurity, and limited healthcare access [20,21]. These data contextualize our findings within a broader epidemiological framework, underscoring the persistent burden of nutritional anemia in vulnerable populations and highlighting the urgent need for targeted interventions addressing nutrition, infection control, and healthcare access [18].

The observed female predominance in anemia cases concurs with existing global and regional epidemiological evidence, which identifies menstruation, increased iron requirements during pregnancy, and sociocultural determinants as key contributors to heightened vulnerability among females [22]. The statistically significant independent association between female sex and severe anemia (aOR = 1.87) supports findings from Middle Eastern and South Asian regions, where

gender disparities in anemia prevalence and severity are consistently documented, often exacerbated by restricted access to nutritional supplementation and healthcare services [2,22,23]. Moreover, rural residence emerged as a significant independent predictor of severe anemia (aOR = 2.05), reflecting patterns observed in low-income settings worldwide [24, 25]. In the specific context of Yemen's conflict, this association is powerfully amplified. These areas frequently encounter compounded risk factors, including acute food insecurity, limited availability of diagnostic and therapeutic care, and elevated burdens of parasitic infections [26]. The protracted conflict has deliberately deteriorated infrastructure and fragmented the healthcare system, intensifying rural-urban health inequities and plausibly accounting for the markedly increased susceptibility noted among rural populations in our study [27].

Age-stratified analysis shows a complex risk profile. The elevated severe anemia prevalence in young children (2-4 years) likely reflects increased metabolic demands and dietary transitions post-breastfeeding, whereas in older adults, multifactorial causes including nutritional deficits, chronic inflammation, and comorbid illnesses prevail [20,21]. The significant independent association of age >50 years with severe anemia (aOR = 1.75) highlights the vulnerability of the elderly in this crisis. The comparatively lower anemia severity in infants under two years suggests protective effects of maternal iron stores and breastfeeding, consistent with global findings [1,28]. While confirmed deficiencies in vitamin B12 and folate were observed, their lack of association with severe anemia, combined with the established primacy of iron deficiency in such settings [18,29] indicates that iron supplementation should be the primary intervention focus. Nevertheless, the complexity of micronutrient interactions underscores the need for further biochemical investigations to inform comprehensive nutritional strategies [2].

In this study, as in many resource-limited settings, CBC parameters including hemoglobin concentration, hematocrit, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and red cell distribution width (RDW), served as the foundational diagnostic tool for anemia diagnosis due to their accessibility, cost-effectiveness, and rapid turnaround [30-32]. Multiple studies have demonstrated that indices such as low MCV and elevated RDW effectively differentiate iron deficiency anemia from other etiologies, providing valuable diagnostic clues, especially in resource-limited settings [5,6]. However, CBC parameters have limitations as they may not reliably distinguish between iron deficiency anemia and anemia of chronic disease, and can be influenced by hydration status and comorbid conditions, potentially causing misclassification [4]. Clinically, while CBC offers a pragmatic initial screening tool, it often requires complementary biochemical assays for definitive diagnosis and tailored treatment planning. Therefore, despite the inherent limitations, CBC remains a cornerstone in anemia evaluation, particularly where advanced diagnostics are unavailable.

Study limitations and strengths: interpretation of our findings must consider several limitations. The retrospective design and the setting within a single private laboratory may affect generalizability, potentially underestimating the anemia burden in Yemen's broader, often more impoverished, populations who rely on under-resourced public clinics. While we implemented a two-step diagnostic process, the retrospective and pragmatic nature of the study meant that biochemical confirmation was not available for all cases, which could introduce some residual misclassification bias. Moreover, unmeasured confounding from helminth infections, inflammatory disorders, and hemoglobinopathies could influence the observed associations. Despite these limitations, the study provides vital, timely epidemiological data from a region where such evidence is scarce. Key strengths include the use

of a rigorous two-step process to define nutritional deficiencies, a post-hoc sample size calculation confirming the adequacy of our cohort, and the employment of multivariable analysis to identify independent predictors. These analyses provide crucial insights to inform targeted public health strategies in a severely resource-constrained, conflict-affected context.

Conclusion

This study underscores a significant public health burden of anemia in central Yemen, predominantly attributable to iron deficiency and disproportionately impacting women, rural populations, and older adults. These findings reveal critical health disparities exacerbated by the ongoing humanitarian crisis. Addressing this challenge requires a multifaceted approach, including scaling up targeted iron supplementation and food fortification programs, integrating anemia screening and management into primary healthcare—especially in underserved rural areas—and implementing community-based nutritional education. Ultimately, sustainable reduction of anemia-related morbidity in Yemen depends on strengthening food security and rebuilding the health system. This study provides timely and critical evidence to inform policymakers and health agencies in designing effective, context-specific interventions to mitigate this pressing health issue.

What is known about this topic

- *Anemia is a major public health challenge in conflict-affected, resource-limited settings like Yemen, disproportionately impacting women, children, and the elderly;*
- *Iron deficiency is the leading global cause of anemia, a situation exacerbated in humanitarian crises by food insecurity, poor healthcare access, and infection;*

- Significant disparities exist, with rural populations consistently showing a higher prevalence and severity of anemia due to compounded socioeconomic and healthcare access barriers.

What this study adds

- This study provides contemporary, laboratory-confirmed epidemiological data on the prevalence, severity spectrum, and morphological subtypes of anemia within a diverse clinical cohort in conflict-affected Yemen;
- It identifies female sex, rural residence, confirmed iron deficiency, and older age (>50 years) as key independent predictors of severe anemia, quantifying the associated risks;
- The findings underscore the urgent need for targeted, iron-focused interventions and the strengthening of rural healthcare systems as essential components of public health strategy in Yemen's ongoing humanitarian crisis.

Competing interests

The authors declare no competing interests.

Authors' contributions

Mamoona Al-Namer, Safwana Al-Tahesh, and Basheera Abdo: conceptualization, investigation, data curation, writing - original Draft. Khaled Alzanen and Fadhla Alselmi: formal analysis, methodology, writing - review and editing. Nabile Albadani and Nasr Alhajeeli: validation, data Interpretation, writing - review and editing. Faisal Ahmed: supervision, project administration, writing - review and editing. All the authors have read and agreed to the final manuscript.

Tables and figures

Table 1: demographic characteristics of the analytic cohort (N=320)

Table 2: anemia severity, morphological subtypes, and confirmed nutritional deficiencies (N=320)

Table 3: age-stratified patterns of morphology, confirmed deficiencies, and anemia severity

Table 4: unadjusted and adjusted analysis of factors associated with severe or life-threatening anemia (Hb <8.0 g/dL)

Figure 1: strobe flowchart of participant selection and analysis; Hb: hemoglobin; MCH: mean corpuscular hemoglobin; MCV: mean corpuscular volume; RDW: red cell distribution width; WHO: World Health Organization

Figure 2: distribution of erythrocyte hemoglobinization (by MCH) across volumetric subtypes (by MCV) in the study cohort (N=320)

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Table 1: demographic characteristics of the analytic cohort (N=320)

Characteristic	Category	n (%)	p-value
Age group (years)	< 2	30 (9.4)	0.003
	2-4	15 (4.7)	
	5-15	39 (12.2)	
	16-50	195 (60.9)	
	> 50	41 (12.8)	
Sex	Male	129 (40.3)	<0.001
	Female	191 (59.7)	
Residence	Urban	123 (38.4)	<0.001
	Rural	197 (61.6)	

SD, Standard Deviation Note: p-values are derived from Pearson's χ^2 test against a uniform distribution hypothesis

Table 2: anemia severity, morphological subtypes, and confirmed nutritional deficiencies (N=320)

Parameter	Value
Hemoglobin, mean \pm SD (g/dL)	8.6 \pm 1.7
Anemia severity, n (%) [*]	
Mild	67 (20.9)
Moderate	158 (49.4)
Severe	63 (19.7)
Life-threatening	32 (10.0)
Morphological subtype, n (%)	
Microcytic (MCV <80 fL)	182 (56.9)
Normocytic (MCV 80-97 fL)	107 (33.4)
Macrocytic (MCV >97 fL)	31 (9.7)
Confirmed nutritional deficiency, n (%) [†]	
Iron deficiency	112 (35.0)
B12 / Folate deficiency	44 (13.8)

MCV: mean corpuscular volume; SD: standard deviation * Severity defined by WHO criteria as detailed in the methods. †Deficiencies confirmed via a two-step process of hematological screening and biochemical assay (serum ferritin, B12, folate) where available, as detailed in the methods

Table 3: age-stratified patterns of morphology, confirmed deficiencies, and anemia severity

Characteristic	<2 Years (n=30)	2-4 years (n=15)	5-15 years (n=39)	16-50 years (n=195)	>50 years (n=41)	p-value
Morphology, n (%)						0.15
Microcytic	14 (46.7)	9 (60.0)	18 (46.2)	115 (59.0)	26 (63.4)	
Normocytic	13 (43.3)	5 (33.3)	16 (41.0)	62 (31.8)	11 (26.8)	
Macrocytic	3 (10.0)	1 (6.7)	5 (12.8)	18 (9.2)	4 (9.8)	
Confirmed iron deficiency, n (%)	10 (33.3)	7 (46.7)	13 (33.3)	68 (34.9)	14 (34.1)	0.88
Confirmed B12/folate deficiency, n (%)	1 (3.3)	3 (20.0)	6 (15.4)	30 (15.4)	4 (9.8)	0.21
Anemia severity, n (%)						0.002
Mild	15 (50.0)	5 (33.3)	7 (17.9)	36 (18.5)	4 (9.8)	
Moderate	13 (43.3)	5 (33.3)	18 (46.2)	101 (51.8)	21 (51.2)	
Severe	1 (3.3)	4 (26.7)	8 (20.5)	36 (18.5)	14 (34.1)	
Life-threatening	1 (3.3)	1 (6.7)	6 (15.4)	22 (11.3)	2 (4.9)	

P-values derived from Pearson's χ^2 test for differences across age groups

Table 4: unadjusted and adjusted analysis of factors associated with severe or life-threatening anemia (Hb <8.0 g/dL)

Predictor	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI) *	p-value
Age group				
< 2 Years	0.18 (0.04-0.76)	0.02	0.22 (0.05-0.93)	0.04
2-4 Years	1.58 (0.70-3.57)	0.27	1.62 (0.70-3.77)	0.26
5-15 Years	1.31 (0.75-2.30)	0.34	1.29 (0.72-2.30)	0.39
16-50 Years	1 [Reference]	—	1 [Reference]	—
> 50 Years	1.82 (1.10-3.01)	0.02	1.75 (1.04-2.94)	0.04
Female sex	1.65 (1.15-2.36)	0.006	1.87 (1.22-2.87)	0.004
Rural residence	2.21 (1.50-3.26)	<0.001	2.05 (1.28-3.28)	0.003
Confirmed iron deficiency	3.10 (1.95-4.92)	<0.001	3.52 (2.01-6.15)	<0.001
Confirmed B12/folate deficiency	1.15 (0.78-1.71)	0.48	1.24 (0.81-1.89)	0.32

CI: confidence Interval; OR: odds ratio * Adjusted for all other variables listed in the table (multivariable logistic regression model)

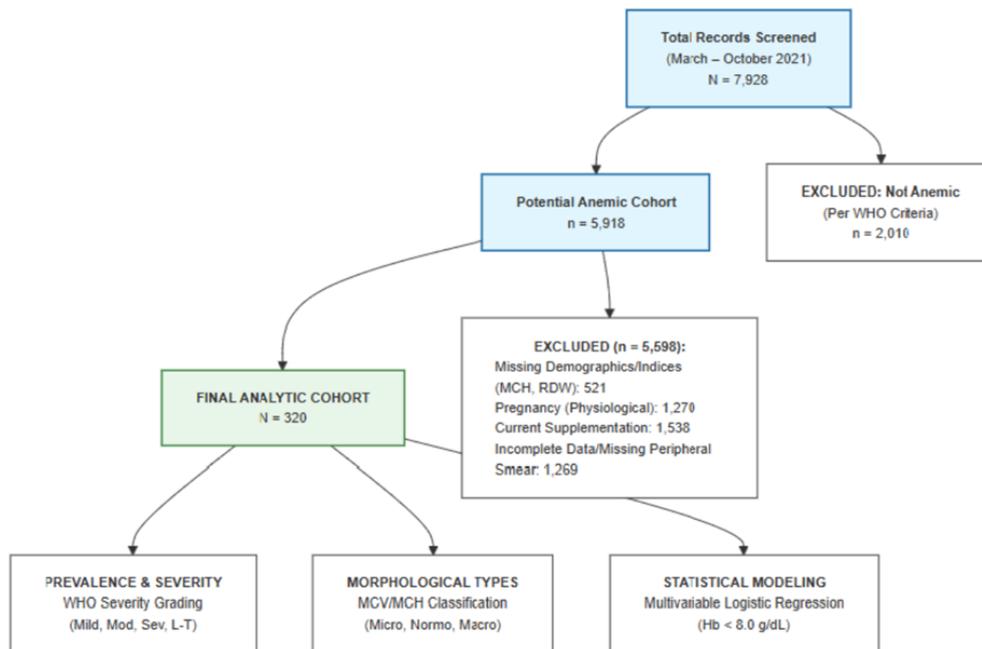


Figure 1: strobe flowchart of participant selection and analysis; Hb: hemoglobin; MCH: mean corpuscular hemoglobin; MCV: mean corpuscular volume; RDW: red cell distribution width; WHO: World Health Organization

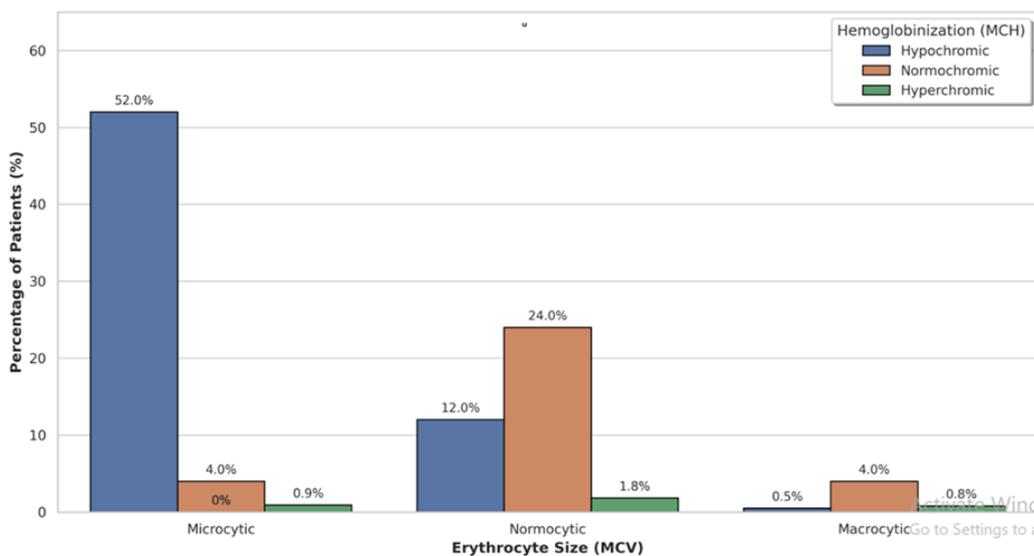


Figure 2: distribution of erythrocyte hemoglobinization (by MCH) across volumetric subtypes (by MCV) in the study cohort (N=320)