Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Prevalence and Impact of Micronutrient (Iron–Folic Acid) Deficiencies on the Health of Adolescent Girls in Coastal Areas of Bangladesh

Md. Ripon Ali Sarkar
pg7222070502@pgs.pstu.ac.bd
Patuakhali Science and Technology University
Dilruba Easmin Jharna
Patuakhali Science and Technology University
Sultana Rabeya
Patuakhali Science and Technology University
Md. Golam Rabbani Akanda
Patuakhali Science and Technology University
Md. Fazlul Hoque
Patuakhali Science and Technology University
Khadija Akhter
Begum Rokeya University
Atif Abdullah Saem
Shaheed Suhrawardy Medical College
Samiya Sultana
Birmingham City University
Tashmiah Binte Shams
University of Dhaka

Research Article

Keywords: Adolescent girls, anemia, iron–folic acid supplementation, micronutrient deficiency, hemoglobin, coastal Bangladesh

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11354220/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Prevalence and Impact of Micronutrient (Iron–Folic Acid) Deficiencies on the Health of Adolescent Girls in Coastal Areas of Bangladesh

[Md. Ripon Ali Sarkar[1*], Dilruba Easmin Jharna[2], Sultana Rabeya[3], Md. Golam Rabbani Akanda[4], Md. Fazlul Hoque[5], Khadija Akhter[6], Atif Abdullah Saem[7], Samiya Sultana[8], Tashmiah Binte Shams[9]]

[1][Department of Biochemistry and Molecular Biology, Faculty of Nutrition and Food Science, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, pg7222070502@pgs.pstu.ac.bd, https://orcid.org/0000-0001-7988-1952]

[2][Department of Biochemistry and Molecular Biology, Faculty of Nutrition and Food Science, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, jharnabcm@pstu.ac.bd, https://orcid.org/0009-0006-5574-4623]

[3][Department of Biochemistry and Molecular Biology, Faculty of Nutrition and Food Science, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, src762001@yahoo.com, https://orcid.org/0009-0006-5574-4623]

[4][Department of Agricultural Extension and Rural Development, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, rabbani@pstu.ac.bd, https://orcid.org/0009-0000-4220-7024]

[5][Department of Soil Science, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, fhoque_pstu@yahoo.com, https://orcid.org/0009-0002-5751-2288]

[6][Department of History and Archaeology, Begum Rokeya University, Rangpur, Bangladesh, mkhadija.akhter@gmail.com, https://orcid.org/0009-0004-0287-5342]

[7][Shaheed Suhrawardy Medical College, Sher E Bangla Nagar, Dhaka, Bangladesh, satif2135@gmail.com, https://orcid.org/0009-0009-6115-4779]

[8][Faculty of Business, Law and Social Sciences, Birmingham City University, Birmingham B4 7XG, United Kingdom, samiyadu@gmail.com, https://orcid.org','0000-0002-9090-2969]

[9][Department of Geography and Environment, University of Dhaka, Dhaka-1000, Bangladesh, tashmiah@gmail.com, https://orcid.org/0009-0002-3065-3523]

Corresponding author:

[1*][Md. Ripon Ali Sarkar, Department of Biochemistry and Molecular Biology, Faculty of Nutrition and Food Science, Patuakhali Science and Technology University Dumki, Patuakhali- 8602, Bangladesh, pg7222070502@pgs.pstu.ac.bd , +8801710055195]

Short title: Iron–Folic Acid(IFA) Deficiency and Health Outcomes

Abstract

Background: Anemia and iron–folic acid (IFA) deficiencies are major nutritional concerns among adolescent girls in environmentally vulnerable coastal areas of Bangladesh. However, evidence on anemia prevalence and health outcomes relation to IFA supplement receipt remains limited.

Objectives: This study aimed to assess IFA deficiency-related health problems and the impact of IFA supplementation on hematological, nutritional, and overall health outcomes among adolescent girls in coastal Bangladesh

Methods: A randomized controlled trial study was conducted among 440 adolescent girls from Patuakhali, Bagerhat, Noakhali, and Cox's Bazar districts of Bangladesh. In each district, 60 participants were assigned to the IFA intervention group and 60 to the control group. The intervention group received IFA for three months, with assessments of hemoglobin, anemia, nutritional status, and health outcomes. And data were analyzed using IBM SPSS Statistics.

Results: The prevalence of anemia among participants in the placebo group ranged from 37.5% to 52.0% across the four study districts. After three months of IFA supplementation among intervention group, anemia prevalence decreased to 2.0% in Patuakhali, 2.2% in Bagerhat, 0% in Noakhali, and 4.7% in Cox's Bazar. The intervention group showed significantly higher hemoglobin concentration compared with the placebo group (12.20 ± 0.30 vs. 11.96 ± 1.18 g/dL; $p < 0.001$). Significant improvements were also observed in mid-upper arm circumference (24.20 ± 4.12 vs. 22.58 ± 2.88 cm; $p < 0.001$), platelet count ($p < 0.001$), and anemia-related symptoms, including dizziness ($p < 0.001$), infection symptoms ($p < 0.001$), and pale skin/gum symptoms ($p = 0.027$). Furthermore, IFA supplementation was associated with improved iron-rich food intake, nutrition knowledge, vitamin/mineral awareness, and iodized salt use.

Conclusion: Anemia remains prevalent among adolescent girls in coastal Bangladesh. IFA supplementation was strongly associated with a lower likelihood of anemia, highlighting the potential importance of strengthening adolescent supplementation, nutritional screening, and adherence-focused interventions in vulnerable coastal populations.

Keywords: Adolescent girls; anemia; iron–folic acid supplementation; micronutrient deficiency; hemoglobin; coastal Bangladesh.

Trial registration: ClinicalTrials.gov, NCT07903558. Date of registration: 21-10-2026.

1. Introduction

Adolescence is a critical period of rapid physical growth, increased nutritional requirements, and biological development. The proper amount of micronutrient intake during this stage is essential for maintaining optimal health, cognitive performance, reproductive maturity, and future maternal health. However, micronutrient deficiencies, particularly iron deficiency and iron deficiency anemia (IDA), remain among the most widespread nutritional problems affecting adolescent girls worldwide. Iron deficiency is recognized as the leading cause of anemia globally, disproportionately affecting populations in low- and middle-income countries where inadequate dietary intake, infections, and poor access to health services contribute to increased vulnerability(Mahar et al., 2024)

Anemia in adolescent girls has multi-faceted consequences where their life is hampered by inability to do physical work, academically poor performance due to insufficient cognitive skills, lack of energy and poor pregnancy outcome. Globally, anemia affects approximately 30% of women aged 15–49 years, with women and girls in the WHO African and South-East Asia Regions carrying a particularly high burden(WHO, 2025). Iron deficiency remains the most common cause of anemia worldwide and is particularly prevalent in populations living in low- and middle-income countries, which often face debilitating levels of dietary inadequacy, infections and poor access to health services that exacerbate their susceptibility(Kassebaum et al., 2014; Stevens et al., 2013).

Iron–folic acid (IFA) supplementation has been widely recommended as an effective public health strategy to prevent and control anemia among adolescent girls. Iron supplementation improves hemoglobin concentration and iron stores, while folic acid contributes to red blood cell formation and supports healthy growth and reproductive outcomes. The World Health Organization recommends intermittent or daily iron and folic acid supplementation for adolescent girls in populations where anemia prevalence is high(WHO, 2016). Several intervention studies have demonstrated that IFA supplementation can significantly reduce anemia prevalence and improve hematological outcomes among adolescent populations(Mistry et al., 2017; Stevens et al., 2013).

Bangladesh has made remarkable progress in improving maternal and child nutrition; however, the anemia among adolescent girls remains a persistent public health challenge. The study surveys

indicate that nutritional deficiencies, inadequate dietary diversity, and poor micronutrient intake continue to affect adolescent health outcomes in Bangladesh(NIPORT, 2019). Although national adolescent nutrition programs have introduced iron–folic acid supplementation initiatives, coverage, adherence, and effectiveness remain influenced by geographical, socioeconomic, and healthcare-access disparities(Mistry et al., 2017; WHO, 2016).

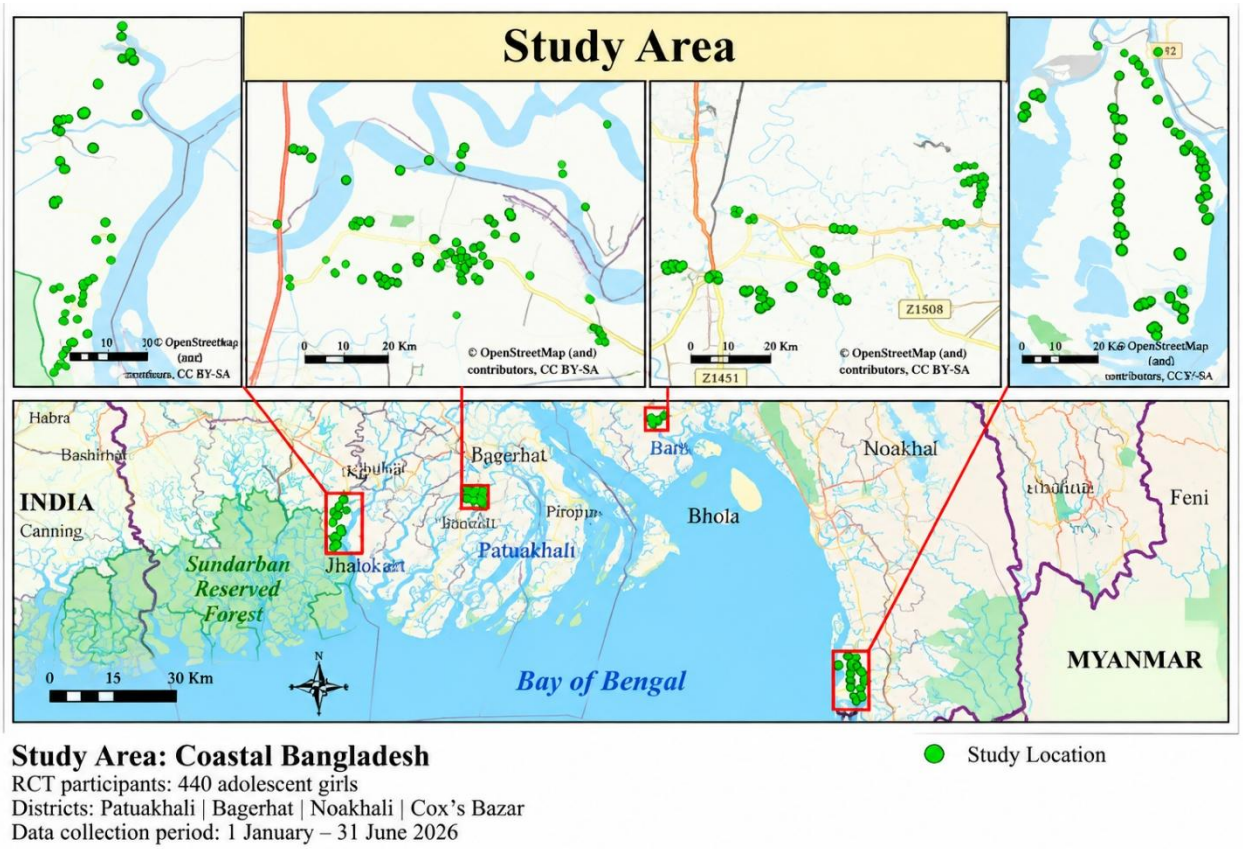
Coastal areas of Bangladesh represent particularly vulnerable environments due to recurrent climate-related hazards like cyclones, flooding, salinity intrusion, and livelihood insecurity. These factors negatively influence food availability, diversity of dietary, household income, and access to healthcare services, potentially increasing the risk of micronutrient deficiencies among adolescent girls(Ali et al., 2025; Khanom, 2016). Previous studies have mainly focused on national-level anemia prevalence or urban and non-coastal populations, while evidence from climate-vulnerable coastal regions remains limited. Adolescent girls living in coastal Bangladesh experience unique nutritional challenges, including food insecurity, limited dietary diversity, poverty, and restricted access to healthcare, which may increase their vulnerability to micronutrient deficiencies(Ali et al., 2025; *FAO*, 2023).

Indications from prior studies conducted in Bangladesh have mainly focused on cross-sectional assessments of anemia prevalence or nutritional status and as well as providing limited evidence regarding the impact of micronutrient supplementation interventions. Furthermore, very few studies have assessed the combined effect of demographic characteristics, dietary factors, menstrual health, and supplementation status on anemia risk using robust analytical approaches. This evidence from controlled intervention studies, particularly among geographically vulnerable coastal populations, is therefore needed to guide targeted adolescent nutrition policies and programs.

To address these knowledge gaps the study finds out prevalence of anemia and evaluated the association between iron–folic acid supplementation and hematological outcomes among adolescent girls living in coastal areas of Bangladesh. It included data from a controlled intervention study in four coastal districts with aims to provide evidence for the potential role of IFA supplementation for reducing anemia burden among a vulnerable population of adolescents.

2. Materials & Methods

2.1 Study Area: The study was conducted in Patuakhali, Bagerhat, Noakhali, and Cox's Bazar districts of Bangladesh. These districts were chosen because of their socioeconomic traits, coastline exposure, and geographic susceptibility. Under this randomly selected four coastal vulnerable upazila that namely Dumki, Morrelganj, Noakhali Sadar, and Moheshkhali under those districts.



Study Area: Coastal Bangladesh
RCT participants: 440 adolescent girls
Districts: Patuakhali | Bagerhat | Noakhali | Cox's Bazar
Data collection period: 1 January – 31 June 2026

Figure 1: Geographic distribution of study locations across coastal districts of Bangladesh

2.2 Study Design: Its was cluster randomized controlled trial (cRCT) design and which was effectively captured a comprehensive snapshot of demographic data, reproductive health & menstrual history, medical history & current health, dietary intake & habits, clinical assessments & anthropometry knowledge, attitudes, and practices (KAP).

2.3 Study Duration: Data was collected from 1st January 2026 to 31th June 2026.

2.4 Sampling Frame and Sample Size: For sampling, a cluster randomized controlled trial (cRCT) technique was used. Four Upazilas were chosen at random from each of the four districts that were purposively chosen. Unions were then randomly sampled in proportion to population size, followed by villages and mahallas.

To estimate proportions, the sample size (n) formula is(Ali Sarkar et al., 2026) :

$$n = Z^2. P (1-P)/E^2$$

Here, Z is the Z-score corresponding to the chosen confidence level (e.g., 1.96 for a 95% confidence level), n is the sample size, E is the margin of error (5% = 0.05), and P is the expected prevalence (unknown 0.5 is taken into consideration for maximum variability).

$$\text{So, } n = (1.96)^2*0.25/ (.05)^2 = 384.16 \approx 384$$

Adding 15% non-response rate the total sample size n = 384/0.85 ≈ 452. Considering logistical feasibility and equal distribution across study clusters final target sample size was set at 440 adolescent girls with approximately 110 participants from each district. After enrollment, participants were randomly allocated into two groups in a 1:1 ratio: the intervention group receiving daily iron–folic acid (IFA) supplementation and the control group following the standard practice without the intervention. A total of 440 eligible adolescent girls were enrolled in the trial. Out of them 377 participants completed the follow-up assessment, resulting in an overall retention rate of 86%. The final analysis was performed based on the available data from participants who completed the study assessments.

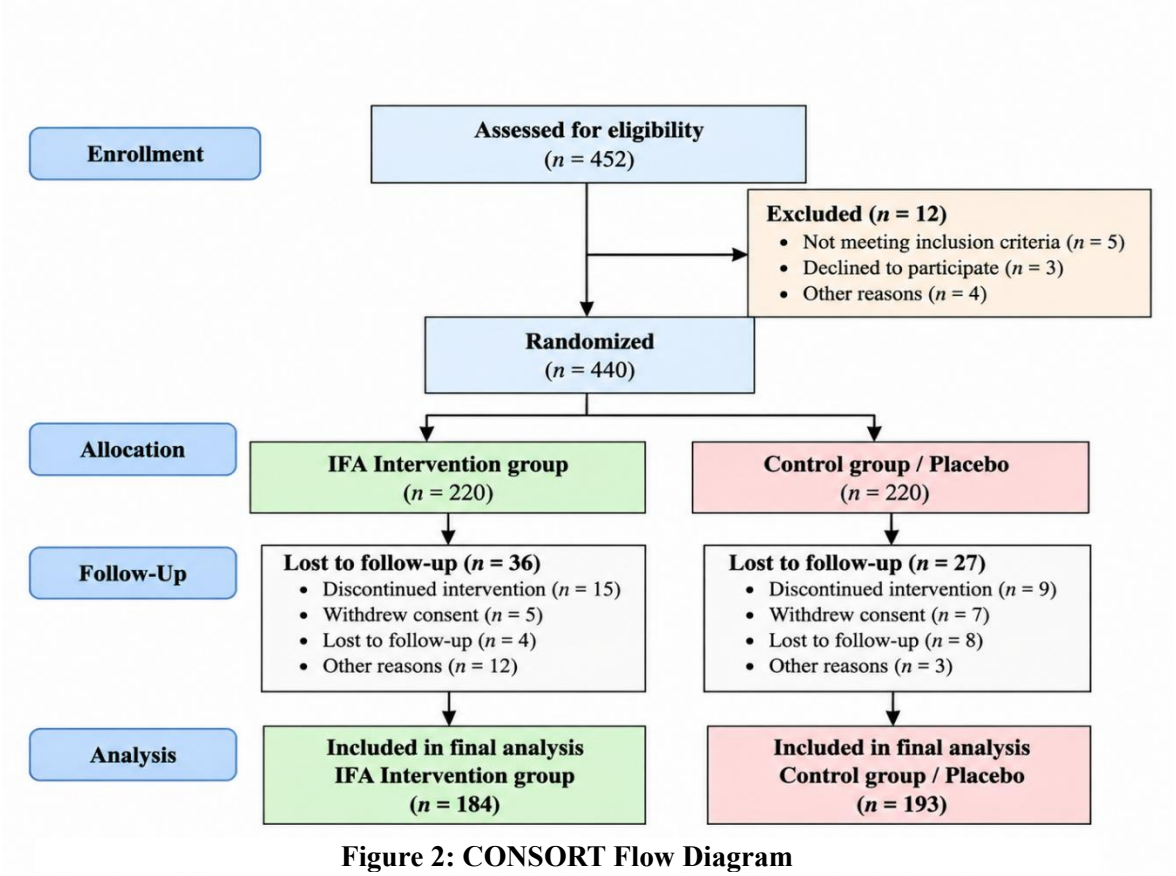


Figure 2: CONSORT Flow Diagram

2.5 Intervention: The intervention group received daily IFA supplementation capsules that contained 47 mg elemental iron, 500 µg folic acid, and 22.5 mg zinc for three months. And the supplement intake, adherence, or any reported side effects were recorded during follow-up visits school or HH visit. The placebo group received Vitamin C (500 mg) daily supplement for the same period and was not supplemented with IFA. Compliance and adverse events were monitored similarly in both groups.

2.6 Data collection method: The data were collected using a structured questionnaire through Kobo Toolbox and questionnaire comprised sections on socio-demographic characteristics, reproductive and menstrual history, medical history, dietary practices and knowledge attitude and practices (KAP) regarding nutrition and health. Anthropometric measurements, including height, weight, and mid-upper arm circumference (MUAC), were recorded using standardized procedure(Gibson, 2005).

The blood samples were collected by trained medical assistants from designated healthcare laboratories for hematological and biochemical assessments, including complete blood count (CBC), hemoglobin concentration, red blood cell indices (MCV, MCH, MCHC, RDW), serum ferritin, inflammatory markers (CRP and AGP), and micronutrient-related biomarkers etc. Hemoglobin levels were determined with a calibrated automated analyzer (Beckman Coulter life sciences, Brea, CA), and anemia classification was based on internationally accepted cutoff values.

2.7 Inclusion criteria: Only coastal teenage girls between the ages of 11 and 19 who had resided in the study area for at least a year before data collection were included. Participants who provided informed consent/assent by legal guardian and were willing to participate in the intervention and also complete the three-month follow-up assessment were included in the study.

2.8 Exclusion criteria: Participants were excluded if they had severe chronic illnesses or diagnosed medical conditions that could effect on hematological status, were currently receiving iron, folic acid, or other micronutrient-containing supplements/medications, or had incomplete baseline or follow-up data required for analysis.

2.9 Data Analysis: For quantitative data descriptive statistics, inferential statistics (t-tests, ANOVA), and regression analysis, IBM Statistical Package for the Social Sciences (SPSS) statistics version 27.0.1_IF026 was utilized. Anemia prevalence was reported with Wilson 95% CIs. Welch's t-test was used for continuous variables and Pearson's chi-square test for categorical variables to evaluate between-group differences. A multivariable logistic model estimated the

association between recorded receipt of supplementation and anemia, adjusting for age, district, household-income category and heavy menstrual flow. A heteroskedasticity-robust linear model assessed adjusted mean hemoglobin differences using the same covariates. Among other variables from univariate analysis with a p-value of less than 0.5, the adjusted model included sex, education, occupation, and wealth index. A 95% confidence interval was shown for each precision estimate.

3. Results

3.1 Socio-Demographic Characteristics of the Participants

In Table 1 shows that a total of 377 adolescent girls participated in the study and among the respondents 41.1% were early adolescent girls (11–14 years) from the placebo group, followed by 31.3% from the intervention group, while late adolescents (15–19 years) constituted 27.6%. Nearly all participants were studying at the secondary level (98.4%). In terms of maternal education, most mothers completed higher secondary education (37.4%) while 14.3% had no formal education. All participants were single (100%), and the majority came from medium-sized families (4–6 members) (89.1%).

Government/private sector employment (28.1%) and business activities (26.0%) accounted for most of the household (HH) income source. The monthly household income in 51.2% of the households was BDT 10,001–20,000 and (20.7%) in the range of 20,001–30,000. And also, participants were selected from four coastal districts of Bangladesh with the highest representation from Patuakhali (26.0%) and Noakhali (25.2%), Bagerhat (24.9%) and Cox's Bazar (23.9%).

Table 1: Socio-demographic characteristics of the study participants (N =377)

Variables	Category	n	%
Age (years)	Placebo early adolescent girls (11 – 14yr)	155	41.1
	Placebo late adolescent girls (15 – 19yr)	38	10.1
	Intervention early adolescent girls (11 – 14yr)	118	31.3
	Intervention late adolescent girls (15 – 19yr)	66	17.5
Respondent Education level	Secondary level	371	98.4
	Higher Secondary level	3	0.8
	Others (Maktoob, Religious institute etc.)	3	0.8
Mother's education level	No formal education	54	14.3
	Primary level	9	2.4
	Secondary level	67	17.8
	Higher Secondary level	141	37.4
	University/Degree level	30	8.0
	Others (Maktoob, Religious institute etc.)	76	20.2

Marital status	Married	0	0
	Unmarried	377	100
Respondent Family Size	Small (Family members up to 3)	25	6.6
	Medium (4-6 members in family)	336	89.1
	Large (7 or more members)	16	4.2
Family Income Source	Livestock and Agriculture	42	11.1
	Business and Commerce	98	26.0
	Day Labor /Informal Sector	37	9.8
	Private sector & Govt.	106	28.1
	Others (Please Specify)	94	24.9
HH income per month[a]	Below 5000(Ext Poor)	19	5.0
	5000-10000(Poor)	28	7.4
	10001-20000(Middle)	193	51.2
	20001-30000(Rich)	78	20.7
	Above 30000(Rich)	59	15.6
District-wise respondents	Patuakhali	98	26
	Bagerhat	94	24.9
	Noakhali	95	25.2
	Cox's Bazar	90	23.9

***Note**: [a]Bangladesh Bureau of Statistics (BBS), Household Income and Expenditure Survey (HIES), [2026].*

3.2 Prevalence and severity of anemia in placebo and intervention groups by study area

In figure-03, the study results showed that the prevalence of anemia in the placebo group was, 37.5%, 52.0%, 38.0%, and 51.1% respectively in Patuakhali, Bagerhat, Noakhali, and Cox's Bazar. Following the three-month IFA supplementation intervention, the prevalence of anemia in the intervention group decreased to 2.0%, 2.2%, 0%, and 4.7% respectively in Patuakhali, Bagerhat, Noakhali, and Cox's Bazar. The boxplot comparison also shown the distributional difference in the two group, participants from intervention group are substantially lower anemia prevalence than those of placebo.

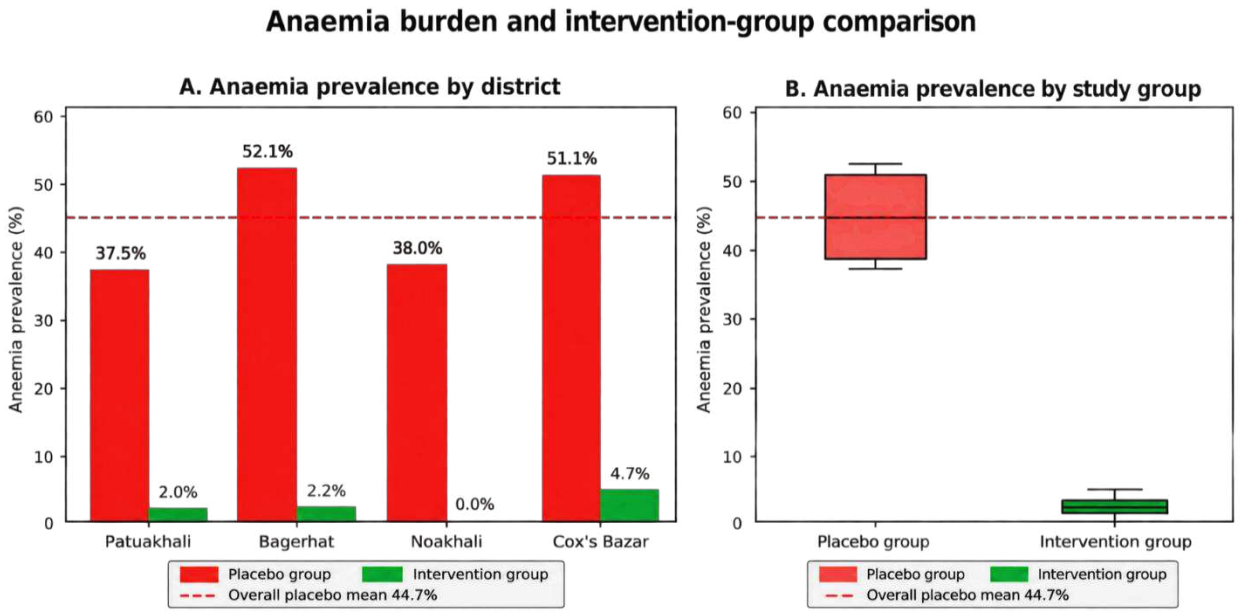


Figure 3: Area-wise prevalence of anemia comparison between placebo and IFA supplementation intervention groups among adolescent girls in coastal Bangladesh.

3.3 Comparison of Clinical, Nutritional, and Hematological Characteristics Between Placebo and Intervention group of IFA Supplementation

The independent sample t test was performed to analysis comparison of clinical, nutritional, and hematological characteristics between placebo and intervention group of IFA supplementation in Table *2*. Participants in the IFA intervention group exhibited significantly higher hemoglobin concentrations compared with the placebo group (12.20 ± 0.30 vs. 11.96 ± 1.18 g/dL; mean difference [MD] = −0.234, 95% CI: −0.406 to −0.062; $p < 0.001$). In addition, significant differences were observed in total WBC count ($p = 0.019$) and circulating eosinophil count ($p = 0.006$), with lower values among supplemented participants. Platelet count was markedly higher in the intervention group compared with the placebo group (345,965.12 ± 79,150.34 vs. 294,601.04 ± 80,122.70 cells/μL; $p < 0.001$). Furthermore, participants receiving IFA supplementation demonstrated significantly greater MUAC values, indicating improved nutritional status (24.20 ± 4.12 vs. 22.58 ± 2.88 cm; MD = 1.621, 95% CI: 0.903–2.338; $p < 0.001$).

The menstrual and clinical health indicators showed the differences between two groups. It's shown that participant who received IFA supplementation reported higher IFA-use scores than those who received a placebo (0.26 ± 0.44 vs. 0.16 ± 0.37; p = 0.016). The intervention group had lower scores for frequent dizziness (1.63 ± 0.77 vs. 1.94 ± 0.76; p < 0.001) and frequent infection

symptoms than the placebo group (1.10 ± 0.39 vs. 1.36 ± 0.63; $p < 0.001$). Pale skin/gum scores were also significantly lower among participants who received supplementation ($p = 0.027$). There was no significant difference in menstrual flow scores between the two groups ($p = 0.051$). In terms of dietary intake patterns significant differences were identified in selected dietary indicators. Milk/dairy intake scores were significantly higher among intervention participants compared with placebo participants (3.30 ± 1.33 vs. 3.03 ± 1.30; $p = 0.044$). Iron-rich food intake scores also differed significantly between groups ($p < 0.001$). However, no statistically significant differences were showed in green leafy vegetable intake ($p = 0.201$) or fruit intake ($p = 0.052$).

The study also showed nutrition knowledge and practices associated significantly between two groups. Food–health awareness, vitamin/mineral knowledge, and iron-rich food knowledge were significant (all $p < 0.001$). Iodized salt use was higher in the IFA group ($p = 0.002$), with a marginal difference in nutrition education scores ($p = 0.049$).

Table 2: Comparison of Clinical, Nutritional, and Hematological Characteristics Between Participants Receiving and Not Receiving Iron–Folic Acid Supplementation(N=377)

Variables	Placebo Group (Mean ± SD), n=193	Intervention Group (Mean ± SD), n=184	Mean Difference (95% CI)	P-value
Clinical and Anthropometry Parameter				
Hemoglobin (Hb, g/dL)	11.962 ± 1.177	12.196 ± 0.295	-0.234 (-0.406, -0.062)	**<0.001**
Total WBC count (cells/µL)	9557.36 ± 1978.421	9124.67 ± 1558.715	432.684 (70.850, 794.517)	**0.019**
Total circulating eosinophil count (cells/µL)	346.40 ± 292.750	283.35 ± 99.438	63.048 (18.324, 107.771)	**0.006**
Total RBC count (million cells/µL)	4.639 ± 0.362	4.510 ± 0.907	0.130 (-0.012, 0.271)	0.072
Total Platelet Count(cells/µL)	294601.04 ± 80122.701	345965.12 ± 79150.343	-51364.083 (-67500.947, -35227.220	**<0.001**
MUAC (cm)	22.58 ± 2.877	24.20 ± 4.123	1.621 (0.903, 2.338)	**<0.001**
Menstrual and Clinical Health Status				
Menstrual flow score	2.11 ± 0.54	2.22 ± 0.53	-0.110 (-0.221, 0.000)	0.051
Iron/folate use	0.16 ± 0.37	0.26 ± 0.44	-0.103 (-0.186, -0.019)	0.016
Frequent dizziness score	1.94 ± 0.76	1.63 ± 0.77	0.313 (0.158, 0.468)	**<0.001**
Frequent infection score	1.36 ± 0.63	1.10 ± 0.39	0.260 (0.154, 0.366)	**<0.001**
Pale skin/gum score	1.45 ± 0.62	1.31 ± 0.62	0.141 (0.016, 0.266)	0.027
Hair loss/brittle nail score	2.03 ± 0.94	2.24 ± 1.10	-0.213 (-0.421, -0.006)	0.044
Dietary Intake Pattern				

Green leafy vegetables intake score	4.00 ± 1.01	4.13 ± 0.97	-0.130 (-0.331, 0.070)	0.201
Milk/dairy intake score	3.03 ± 1.30	3.30 ± 1.33	-0.273 (-0.539, -0.007)	0.044
Fruits intake score	3.09 ± 1.07	3.29 ± 0.92	-0.200 (-0.402, 0.002)	0.052
Iron-rich food intake score	3.03 ± 0.84	2.27 ± 1.38	0.759 (0.526, 0.992)	**<0.001**
Nutrition Knowledge and Practice Indicators				
Food-health relationship awareness	0.98 ± 0.14	0.76 ± 0.43	0.224 (0.158, 0.290)	**<0.001**
Awareness of vitamins and minerals	0.69 ± 0.46	0.41 ± 0.49	0.281 (0.184, 0.378)	**<0.001**
Knowledge of iron-rich foods	0.53 ± 0.50	0.33 ± 0.47	0.208 (0.109, 0.306)	**<0.001**
Iodized salt use	0.90 ± 0.31	0.97 ± 0.16	-0.076 (-0.126, -0.027)	**0.002**
School-based nutrition education	0.99 ± 0.10	0.96 ± 0.20	0.033 (0.000, 0.066)	0.049

Note: The independent sample t test was performed for between two group comparisons and mean differences are given at 95% confidence intervals (CI). Homogeneity of variance assumptions were violated and consequently, Welch correction was applied. A p-value < .05 was considered statistically significant.

4. Discussion

4.1 Main findings and interpretation: Iron deficiency anemia remains a significant public health concern among adolescent girls, especially those in low- and middle-income countries (LMIC), where factors such as rapid growth, menstrual blood loss, inadequate dietary intake of iron-rich foods and lack of access to micronutrient-dense foods contribute to increased risk. The current study showed a significant decrease of anemia frequency among the adolescent girls after three months of iron–folic acid (IFA) supplementation in among adolescent girls living in coastal regions of Bangladesh. Across the four study areas, anemia prevalence decreased from 37.5–52.0% in the placebo group to 0–4.7% following IFA supplementation. These results provide strong evidence that routine IFA supplementation is an effective intervention to improve the hematological health status of adolescent girls in nutritionally vulnerable coastal populations. And also, the intervention group demonstrated significantly higher hemoglobin concentration, improved mid-upper arm circumference (MUAC), reduced anemia-related symptoms, improved selected dietary indicators, and better nutrition-related knowledge compared with the placebo group.

4.2 Burden of anemia among adolescent girls in coastal Bangladesh: The high burden of anemia among placebo participants suggests that micronutrient deficiency continues to be a serious problem for adolescent girls in Bangladesh. Anemia prevalence in excess of 20% among adolescents is classified as important public health issue necessitating population-wide response(WHO, 2011). The anemia prevalence in this study (37.5–52.0%) shown that adolescent girls in coastal Bangladesh represent a high-risk group requiring targeted nutritional strategies.

Anemia is a key issue for adolescent girls globally, with the highest burden in South Asia and sub-Saharan Africa. The Global Burden of Disease analysis found that anemia was one of the top causes of health loss in adolescent females and iron deficiency was a major contributor(McLean et al., 2009) Similarly, another study reported that anemia remains particularly prevalent in populations where dietary iron intake is inadequate and access to health and nutrition services is limited(Pasricha et al., 2013)

Multiple interacting factors may explain the high prevalence of anemia in coastal Bangladesh. At adolescent age needs iron for increase substantially due to rapid growth, expansion of blood volume, and menstrual iron losses(Pasricha et al., 2013). Moreover, in low-resource settings the dietary patterns often lack adequate amounts of bioavailable iron from animal sources(Beard,

2001). Although plant-based foods like vegetables and cereals contribute iron and their absorption may be limited due to the presence of phytates and other inhibitors. And also, socioeconomic situation, HH income, and maternal education influence already food choices, nutrition awareness, and healthcare-seeking behaviors(Hurrell & Egli, 2010).

The socio-demographic characteristics of the current study population also indicated multiple factors contributing to adolescent nutritional vulnerability. The majority of participants (98.4%) were students at these secondary-level schools, implying that school-based programs may offer a viable structure for implementing nutritional programs. However, if the mothers were uneducated,14·3% and ~50% of the households had monthly incomes that ranged between BDT 10 001 and 20 000 indicating a possible lower economic status that could underline diet quality limitations. Maternal education has previously been associated with improved adolescent nutrition outcomes because educated caregivers are more likely to have better knowledge regarding iron rich leave vegetable in coastal areas, balanced diets, micronutrient sources, and preventive healthcare practices(Jharna et al., 2026; Kang et al., 2021).

4.3 Effect of IFA supplementation on anemia prevalence: The most important result from this study is the substantial decline in anemia prevalence after three months of IFA supplementation. Anemia prevalence significantly decreased among intervention participants in all four study districts: from 37.5% to 2.0% in Patuakhali, 52.0% to 2.2% in Bagerhat, 38.0% to 0% in Noakhali and 51·1 %–4·7 %in Cox's Bazar. These findings are consistent with previously conducted intervention studies showing that iron supplementation plays a highly significant role in lowering the prevalence of anemia in adolescent girls. Another randomized controlled trial conducted among rural Bangladeshi adolescent girls with nutritional anemia reported significant improvements in hemoglobin and micronutrient status following long-term iron-containing supplementation and improving iron intake can substantially enhance hematological outcomes among adolescent girls(Ahmed et al., 2010)

These findings also support the implementation of school-based IFA supplementation programs in Bangladesh. The school platform offers tangible local advantages as the continuation of education is an opportunity for adolescent girls to be reached certainly, adherence to supplementation can be monitored easily, and nutrition education can be well integrated within existing educational frameworks. Similar evidence from elsewhere in low-resource settings shows that interventions

such as school based weekly IFA supplementation programs can be effective for anemia reduction among adolescent girls(Gosdin et al., 2021).

4.4 Improvement in hemoglobin and hematological parameters following IFA supplementation: This study showed a significant improvement in hemoglobin concentration among adolescent girls receiving IFA supplementation compared with the placebo group. The intervention group showed higher mean hemoglobin levels (12.20 ± 0.30 g/dL vs. 11.96 ± 1.18 g/dL; $p < 0.001$), confirming the effectiveness of iron–folic acid supplementation in improving hematological status among nutritionally vulnerable adolescents. This result is consistent with earlier studies, that have indicated the beneficial effects of iron on hemoglobin and anemia in adolescents' girls particularly in populations with lower baseline iron status(Ahmed et al., 2010). However, a meta-analysis already showed a large effect of iron supplementation on hemoglobin concentration in children and adolescents(Low et al., 2016).

4.5 Improvement in nutritional status and anthropometric indicators: In this study IFA supplementation significantly improved MUAC among adolescent girls, with higher values observed in the intervention group compared with placebo (24.20 ± 4.12 cm vs. 22.58 ± 2.88 cm; $p < 0.001$), indicating improved nutritional status. Although IFA primarily addresses micronutrient deficiencies, correction of anemia may enhance energy, appetite, and physical activity, contributing to better nutritional outcomes. A study shown that adolescent nutritional status can be improved with micronutrient supplementation along with nutrition education(Keats et al., 2021). This result is especially relevant for coastal Bangladesh, where food insecurity is high, dietary diversity low and integrated nutrition interventions are urgently needed.

4.6 IFA supplementation Effects on clinical symptoms and functional health indicators: The study showed that IFA supplementation significantly help to improves clinical outcomes in anemia as found by lower dizziness scores (1.63 ± 0.77 vs. 1.94 ± 0.76; $p < 0.001$). are in line with the life-sustaining biological impact of iron on oxygen carrying capacity, energy metabolism and immune function(Weiss et al., 2019). Although medians of menstrual flow scores were not significantly different ($p = 0.051$) between groups, the intervention markedly alleviated major clinical manifestations of anemia during the study timeframe. A longer follow-up period is necessary to evaluate its effects on menstrual and long-term iron status outcomes.

4.7 Dietary behavior and nutrition knowledge changes after intervention: This study showed IFA supplementation was associated with significant improvements in dietary behaviors and nutrition-related knowledge. The intervention group showed higher intake scores for milk/dairy and iron-rich foods, along with improved awareness of food–health relationships, micronutrients, and iron sources ($p < 0.001$). These results indicate that the possibility of improving dietary behavior and knowledge through supplementation programs together with nutrition education. The increased iodized salt usage among intervention participants were indicative of diverse improved nutritional nutrition with support from integrated programmatic micronutrient interventions. However, there are no significant changes observed in fruit and green leafy vegetable intake, possibly due to short intervention duration and persistent socioeconomic and food availability constraints. Food systems based on community-wide approaches to dietary diversity and food access are necessary for sustainable improvements in diet quality.

4.8 Public health implications for adolescent nutrition programs in Bangladesh: The current study findings emphasize that provision of IFA during adolescence may present a novel public health approach to target girls at risk for anemia, especially where iron status is likely compromised according to elevated blood values. Improvements in nutrition during adolescence may help improve educational, reproductive and long-term health outcomes. While there have been proven advantages with existing WIFA programs, they still face challenges related to adherence, supply chains, monitoring and regional coverage(Gosdin et al., 2021). In Bangladesh coastal communities are most likely to experience vulnerabilities related to their micronutrient status and, therefore interventions should be tailored accordingly with consideration for local socio-economic and environmental conditions. Of the dietary indicators which were assessed in a similar population, none showed significant changes after intervention indicating supplementation alone cannot ensure sustained improvements in nutritional status. Thus, integrated approaches as combined solutions involving IFA supplementation supported through nutrition education, food diversification, and community engagement. The school-based systems may be an effective delivery platform for supplementation, monitoring adherence, and as well as promotion of adolescent girls' health.

4.9 Study Strengths and Limitations:

Strengths:

- The study was intervention-based design allowed comprehensive assessment of IFA effects on hematological, anthropometric, clinical, dietary, and knowledge-related outcomes.
- The study included of adolescent girls from four coastal districts of Bangladesh that improved geographical indication of result and provided evidence from nutritionally vulnerable adolescent girls.
- The study was placebo-controlled comparison, standardized assessments, and evaluation of multiple health indicators that strengthened the reliability and interpretation of the study result.

Limitations:

- Although six months was utilized for overall study period but effect of IFA supplementation on long term sustainability could not be evaluated due to the three-month intervention. And also, biochemical markers of iron status and inflammation were not assessed, preventing confirmation of specific anemia causes.
- In this study dietary information was self-reported, which may lead to recall and reporting bias, while a few dietary indicators showed improvement, additional evidence from objective dietary assessment methods.
- The study participant loss during follow-up and use of self-reported dietary information may have been subject to bias. Future research should include larger samples, longer follow-up, and laboratory confirmation.

Conclusion:

The study result indicates that three-month IFA supplementation has beneficial effects on anemia status, hemoglobin concentration, indices of nutrition and clinical symptoms of anemia as well anemia related knowledge among adolescents in coastal areas of Bangladesh. The decreased of anemia prevalence across all intervention districts indicates that IFA supplements through school-based initiatives can be a useful strategy for addressing micronutrient deficiency among vulnerable adolescents in Bangladesh. These results also provide support for the further strengthening of school- and community-based adolescent nutrition promotion in Bangladesh, especially in coastal settings where nutritional vulnerabilities may be exacerbated by inherent socio-economic and environmental challenges. However, sustainable improvement requires to integration of supplementation with nutrition education, dietary diversification strategies, and long-term monitoring of adolescent nutritional status.

Acknowledgements: First and foremost, I would want to thank Allah Ta'ala for his mercies and grace, which have enabled me to go this far. My sincere gratitude goes out to my supervisor, Prof. Dr. Dilruba Easmin Jharna, for her understanding, discernment, and support. This research would not have been completed without her technical, untiring, and intellectual efforts. I also want to sincerely thank all of the staff at Patuakhali Science and Technology's Faculty of Nutrition and Food Science at Dumki, Patuakhali, for their encouragement and assistance during the study period. I also want to express my sincere appreciation to my coworkers, the local government, and the students at the Faculty of Nutrition and Food Science for all of their assistance. Finally, I want to express my gratitude to my family and friends for their consistent moral support and inspiration.

Funding Support: I also would like to express my gratitude and cordial thanks to the Research and Training Center (RTC) of Patuakhali Science and Technology University, Dumki, Patuakhali-8602, Bangladesh (Ref. No. PSTU/RTC-B/01/15/25/19) for their financial assistance during the study period, which enabled me to conduct my research efficiently but to a limited extent.

Competing interests: None

Author's contributions:

MRAS conceived and designed the study, developed the methodology, conducted data analysis and visualization, and drafted the manuscript. **DEJ** supervised the study, reviewed the manuscript, and contributed to statistical interpretation. **SR** contributed to field data collection and laboratory assessments. **MGRA** supported study implementation and critically reviewed the manuscript. **MFH** contributed to study implementation and manuscript review. **KA** contributed to field data collection and quality monitoring. **AAS** contributed to clinical data collection and interpretation. **SS** contributed to data management and manuscript review. **TBS** contributed to field data collection and data-quality monitoring. All authors read and approved the final manuscript.

Declarations

- **Ethical Approval:** All methods involving research study participants were authorized by the Institutional Ethical Committee of Patuakhali Science and Technology University, Dumki, Patuakhali-8602, Bangladesh, and this study was conducted in compliance with the Declaration of Helsinki (Ref. No. PSTU/IEC/2024/03). Every subject or patient

provided written informed consent. Additionally, parents or legal guardians provided written informed consent for participants under the age of sixteen.

- **Clinical trial number:** ClinicalTrials.gov, NCT07903558. Date of registration: 21-10-2026
- **Consent to participate:** Written informed consent was given by each subject. In addition, written informed consent was supplied by parents or legal guardians of people under sixteen.
- **Consent for publication:** Not Applicable (N/A).
- **Availability of data and materials:** On reasonable request, the corresponding author will provide the data and materials produced and/or analyzed during the current work.

REFFERENCES

Ahmed, F., Khan, M. R., Akhtaruzzaman, M., Karim, R., Williams, G., Torlesse, H., Darnton-Hill, I., Dalmiya, N., Banu, C. P., & Nahar, B. (2010). Long-Term Intermittent Multiple Micronutrient Supplementation Enhances Hemoglobin and Micronutrient Status More Than Iron + Folic Acid Supplementation in Bangladeshi Rural Adolescent Girls with Nutritional Anemia. *The Journal of Nutrition*, *140*(10), 1879–1886. https://doi.org/10.3945/jn.109.119123

Ali, K. M. B., Ferdos, J., & Molla, M. H. (2025). Climate Change and Public Health in Bangladesh: Perceptions, Vulnerabilities, and Empirical Evidence from Coastal Communities. *Journal of Sustainability and Environmental Management*, *4*(2), 130–143. https://doi.org/10.3126/josem.v4i2.91549

Ali Sarkar, Md. R., Easmin Jharna, D., Rabbani Akanda, Md. G., Hoque, Md. F., & Rabeya, S. (2026). Dietary habits and nutritional status of adolescent girls in environmentally vulnerable coastal areas of Bangladesh. *Journal of Health, Population and Nutrition*, *45*(1), 145. https://doi.org/10.1186/s41043-026-01285-y

Beard, J. L. (2001). Iron Biology in Immune Function, Muscle Metabolism and Neuronal Functioning. *The Journal of Nutrition*, *131*(2), 568S-580S. https://doi.org/10.1093/jn/131.2.568S

FAO. (2023). Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), UNICEF, World Food Programme (WFP), World Health Organization (WHO).

Gibson, R. S. (2005). *Principles of nutritional assessment*. Oxford university press. https://books.google.com.bd/books?hl=en&lr=&id=lBlu7UKI3aQC&oi=fnd&pg=PR11&dq=Gibson,+R.+S.+(2024).+Principles+of+Nutritional+Assessment+(3rd+ed.).+Oxford+University+Press&ots=RYTCXPatoy&sig=4HWRe3J4DZKDf4a2bd96SQ4WS_E&redir_esc=y#v=onepage&q&f=false

Gosdin, L., Sharma, A. J., Tripp, K., Amoaful, E. F., Mahama, A. B., Selenje, L., Jefferds, M. E., Martorell, R., Ramakrishnan, U., & Addo, O. Y. (2021). A School-Based Weekly Iron and Folic Acid Supplementation Program Effectively Reduces Anemia in a Prospective Cohort of Ghanaian Adolescent Girls. *The Journal of Nutrition*, *151*(6), 1646–1655. https://doi.org/10.1093/jn/nxab024

Hurrell, R., & Egli, I. (2010). Iron bioavailability and dietary reference values. *The American Journal of Clinical Nutrition*, *91*(5), 1461S-1467S. https://doi.org/10.3945/ajcn.2010.28674F

Jharna, D. E., Rabbi, F., Sarkar, Md. R. A., & Islam, Md. S. (2026). Nutritional Quality and Heavy Metal Contamination of Selected LeafyVegetables in the Coastal District of Patuakhali, Bangladesh. *Journal of Emerging Global Health*, *13*(1), 41–59. https://doi.org/10.36481/w20f7d96

Kang, M., Joo, M., Hong, H., & Kang, H. (2021). Eating Speed, Physical Activity, and Cardiorespiratory Fitness Are Independent Predictors of Metabolic Syndrome in Korean University Students. *Nutrients*, *13*(7), 2420. https://doi.org/10.3390/nu13072420

Kassebaum, N. J., Jasrasaria, R., Naghavi, M., Wulf, S. K., Johns, N., Lozano, R., Regan, M., Weatherall, D., Chou, D. P., Eisele, T. P., Flaxman, S. R., Pullan, R. L., Brooker, S. J., & Murray, C. J. L. (2014). A systematic analysis of global anemia burden from 1990 to 2010. *Blood*, *123*(5), 615–624. https://doi.org/10.1182/blood-2013-06-508325

Keats, E. C., Das, J. K., Salam, R. A., Lassi, Z. S., Imdad, A., Black, R. E., & Bhutta, Z. A. (2021). Effective interventions to address maternal and child malnutrition: An update of the evidence. *The Lancet Child & Adolescent Health*, *5*(5), 367–384. https://doi.org/10.1016/S2352-4642(20)30274-1

Khanom, T. (2016). Effect of salinity on food security in the context of interior coast of Bangladesh. *Ocean & Coastal Management*, *130*, 205–212. https://doi.org/10.1016/j.ocecoaman.2016.06.013

Low, M. S. Y., Speedy, J., Styles, C. E., De-Regil, L. M., & Pasricha, S.-R. (2016). Daily iron supplementation for improving anaemia, iron status and health in menstruating women. *Cochrane Database of Systematic Reviews*, *2016*(4). https://doi.org/10.1002/14651858.CD009747.pub2

Mahar, B., Shah, T., Shaikh, K., Shaikh, S. N., Uqaili, A. A., Memon, K. N., Warsi, J., Mangi, R., Aliyu, S., Abbas, Q., & Shaikh, F. (2024). Uncovering the hidden health burden: A systematic review and meta-analysis of iron deficiency anemia among adolescents, and pregnant women in Pakistan. *Journal of Health, Population and Nutrition*, *43*(1), 149. https://doi.org/10.1186/s41043-024-00643-y

McLean, E., Cogswell, M., Egli, I., Wojdyla, D., & De Benoist, B. (2009). Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993–2005. *Public Health Nutrition*, *12*(4), 444–454. https://doi.org/10.1017/S1368980008002401

Mistry, S. K., Jhohura, F. T., Khanam, F., Akter, F., Khan, S., Yunus, F. M., Hossain, M. B., Afsana, K., Haque, M. R., & Rahman, M. (2017). An outline of anemia among adolescent girls in Bangladesh: Findings from a cross-sectional study. *BMC Hematology*, *17*(1), 13. https://doi.org/10.1186/s12878-017-0084-x

NIPORT. (2019). [The Bangladesh National Nutrition Survey 2018–2019]. National Institute of Population Research and Training (NIPORT). https://www.bracjpgsph.org/assets/pdf/research/research-reports/State%20of%20Food%20Security%20and%20Nutrition%20in%20Bangladesh%202018-19.pdf

Pasricha, S.-R., Hayes, E., Kalumba, K., & Biggs, B.-A. (2013). Effect of daily iron supplementation on health in children aged 4–23 months: A systematic review and meta-analysis of randomised controlled trials. *The Lancet Global Health*, *1*(2), e77–e86. https://doi.org/10.1016/S2214-109X(13)70046-9

Stevens, G. A., Finucane, M. M., De-Regil, L. M., Paciorek, C. J., Flaxman, S. R., Branca, F., Peña-Rosas, J. P., Bhutta, Z. A., & Ezzati, M. (2013). Global, regional, and national trends in haemoglobin concentration and prevalence of total and severe anaemia in children and

pregnant and non-pregnant women for 1995–2011: A systematic analysis of population-representative data. *The Lancet Global Health*, *1*(1), e16–e25. https://doi.org/10.1016/S2214-109X(13)70001-9

Weiss, G., Ganz, T., & Goodnough, L. T. (2019). Anemia of inflammation. *Blood*, *133*(1), 40–50. https://doi.org/10.1182/blood-2018-06-856500

WHO. (2011). World Health Organization. Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Geneva.

WHO. (2016). World Health Organization (WHO). (2016). Guideline: Daily iron supplementation in adult women and adolescent girls.

WHO. (2025). World Health Organization (WHO) global anemia estimates. https://www.who.int/data/gho/data/themes/topics/anaemia_in_women_and_children

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORT2025editablechecklist.docx