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# Modeling the Prevalence of Iron Deficiency Anemia among Urban Adolescent Girls: A Public Health Assessment with Differential Insights

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**KEYWORDS**

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**ABSTRACT:**

Iron Deficiency Anemia (IDA) is the most prevalent micronutrient disorder globally, and adolescent girls are one of the most at-risk groups due to heightened physiological demands during puberty. The review synthesizes the prevalence of IDA in adolescent girls aged 10–19 years residing in urban settings, compiling evidence from national nutrition surveys, World Health Organization (WHO) databases, and peer-reviewed epidemiological studies conducted in various urban settings. The research has a cross-sectional design, applying WHO diagnostic cut-offs for serum ferritin and hemoglobin to assess the prevalence of iron deficiency. The results provide a consistently high prevalence rate of 25% to 50% in various urban settings, driven by socio-economic disparities, inadequate dietary consumption, and menstrual blood loss. A comparative examination between India's National Family Health Survey (NFHS-4) and the CDC's National Health and Nutrition Examination Survey (NHANES) reveals striking age-related patterns and socio-behavioral determinants. The research calls attention to the persisting inequality in anemia control among adolescents during worldwide nutrition interventions. Age-targeted, culturally tailored public health interventions integrated into school health systems are necessary to reduce IDA burden among urban adolescents. A simple differential model is introduced to illustrate the rate of change in hemoglobin concentration due to dietary intake and menstrual losses in adolescents, emphasizing physiological vulnerability.

## Introduction

Iron Deficiency Anemia (IDA) is a condition where the body lacks sufficient iron to synthesize sufficient hemoglobin, a protein in red blood cells that transports oxygen (Oski, 1979). It is the most widespread nutritional disorder in the world and has a high incidence among women and children in low- and middle-income nations (DeMaeyer et al., 1989). IDA is a major public health issue in adolescents, especially in women, due to increased iron requirements triggered by rapid growth, menarche, and usually insufficient dietary intake (Beard, 2000).

The World Health Organization (WHO) defines anemia in non-pregnant female adolescents 10–19 years as those with hemoglobin levels of less than 12 g/dL, and confirmed iron deficiency by a serum ferritin level of less than 15 µg/L (WHO, 2001). Despite these definitions and ongoing nutrition campaigns, the burden of IDA remains a chronic problem and, in the majority of urban environments, is rising as a result of rapid urbanization, dietary transition, and socioeconomic inequality (Gibson & Ferguson, 1998; Kassebaum et al., 2014).

Globally, over 600 million reproductive-age women suffer from anemia, and most of those cases are caused by iron deficiency (WHO, 2015). Even in cities—historically thought to be better supported by healthcare and nutrition levels—the IDA prevalence among adolescent girls remains 25% to 50%, primarily among poorer urban populations where food insecurity and poor menstrual education are the standard (UNICEF, 2011; Stevens et al., 2013).

The aim of this paper is to analyze the urban prevalence of IDA among adolescent girls using reliable international and national data sources. It not only analyzes rates of prevalence but also underneath biological, dietary, and social determinants that lead to it. The relevance of acquiring information on urban-specific prevalence is the shifts in dietary patterns and infrastructure challenges characteristic of such environments, wherein food rich in iron may be available but not as equally accessible (Halterman et al., 2001; Petry et al., 2016).

While most studies report static prevalence rates, anemia is inherently dynamic. The iron balance in adolescent girls is influenced by daily intake, absorption efficiency, and loss via menstruation. This study adds a basic differential model to represent this dynamic behavior, aligning physiological insights with epidemiological data.

**Literature Review**

The epidemiological theory of Iron Deficiency Anemia (IDA) among adolescent girls has evolved significantly during the past half-century. Initial studies focused primarily on iron-deficient populations residing in rural or impoverished communities; however, with the continuous increase in urbanization, studies have expanded to assess IDA prevalence among urban populations of adolescents, where diet and lifestyle modifications have rendered traditional risk models unfeasible.

In one of the earliest in-depth studies, DeMaeyer et al. (1989) emphasized anemia as an invisible epidemic among young females all over the world, and urban environments being underrepresented in monitoring. Beard and Stoltzfus (2001) emphasized adolescence as a period of relevance based on increased iron needs. They found that 25–35% of teenage girls from urban Latin America and Southeast Asia suffered from IDA, which was underestimated due to poor diagnosis infrastructure.

Later on, Brabin et al. (2001) presented strong evidence that the urban adolescent girls, particularly those with low socio-economic background, had higher risks of anemia than those from rural settings due mainly to diets being deficient in micronutrients and comprising common process foods. In a meta-analysis of 26 countries, their prevalence rates had gone as high as 45% in Lagos, Manila, and Mumbai cities.

In a landmark international review, Benoist et al. (2008), in partnership with WHO, reported hemoglobin trends from 1993 to 2005, and they revealed very modest improvements among urban adolescents despite international nutrition efforts. According to their review, nations undergoing high urban growth showed deteriorating or stagnant adolescent IDA rates. At the same time, UNICEF (2011) highlighted that urban poverty enclaves generate special risks, such as informal shelters, precarious food supply, and no health education, which increase iron deficiencies in adolescent girls.

Stevens et al. (2013) then cross-linked WHO data with country-level surveys, and they indicated that the global prevalence of anemia in 10–19-year-old girls was 27.1%, with some urban hotspots (e.g., Cairo, Dhaka) experiencing rates of more than 50%. They highlighted the double burden of overnutrition and undernutrition among urban populations, resulting in iron-sufficient foods that are high in energy but low in micronutrient bioavailability.

Petry et al. (2016) corroborated these findings through examination of urban U.S. teens' recalled dietary data using NHANES, discovering 9.2% to have low iron stores—more common in African-American and Hispanic subgroups. All these urban-focused studies all associate IDA with irregular meal frequency, fast food consumption, and inadequate menstruation education.

Not long ago, Rahman et al. (2018) investigated country-level data from Bangladesh Demographic and Health Surveys (BDHS) and found adolescent girls in Dhaka slum locations to have a prevalence of IDA at 48.3%, being strongly correlated with less education among mothers, inadequate hygiene, and partial school attendance.

Objective

**Objective**

The central purpose of this study is to investigate the prevalence and associated determinants of Iron Deficiency Anemia (IDA) among adolescent girls residing in urban areas, based on actual-world epidemiologic facts and uniform diagnostic standards. In direction of this, the study frames the following specific objectives:

1. To estimate the prevalent number of IDA among urban girls aged 10–19 years from validated national and international data bases.
2. To identify biological, nutritional, and socio-economic determinants of heightened susceptibility to IDA in the urban environment.
3. To profile geographic and demographic variation in prevalence, especially among low- and middle-income urban communities.
4. To evaluate public health significance and ascertain whether current policies are adequate to respond to the specific needs of adolescent girls in the urban environment.

This research seeks to fill the knowledge gap regarding anemia control interventions and individualized nutritional profile among urban adolescents and emphasize the need for specific, age-targeted interventions.

**Methodology**

The research adopts a cross-sectional epidemiological study, integrating secondary data analysis with a systematic methodological framework founded on WHO diagnostic norms. It aims to comprehensively quantify

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the prevalence and trends of Iron Deficiency Anemia (IDA) among urban adolescent girls aged 10–19 years.

**Step 1: Diagnostic Criteria**

Diagnosis of Iron Deficiency Anemia followed **World Health Organization (2001)** thresholds:

- Hemoglobin (Hb) cutoff for anemia in non-pregnant adolescent girls:
$$\text{Hb} < 12.0\ \text{g/dL}$$
- Serum ferritin cutoff for depleted iron stores:
$$\text{Ferritin} < 15\ \mu\text{g/L}$$
- Where inflammation markers were available (C-reactive protein), correction for acute phase response was considered.

**Step 2: Data Sources**

We utilized two nationally representative datasets:

1. NFHS-4 (India)**:** National Family Health Survey (2015–16): Covers urban populations across 29 Indian states. Hemoglobin measured via portable HemoCue systems.
2. NHANES (USA)**:** National Health and Nutrition Examination Survey (2013–2016 cycle): Biochemical data included hemoglobin, serum ferritin, and dietary recalls for adolescent girls aged 12–19.

**Step 3: Sampling Strategy**

NFHS-4 Sample Size (urban adolescent girls): N=42,945 (ages 10–19)

NHANES Sample Size (urban adolescent girls): N=2,137 (ages 12–19)

Stratification considered:

- Age groups: early (10–14) vs. late (15–19) adolescence
- Urban region typologies: slum vs. non-slum (NFHS)
- Socioeconomic indicators: maternal education, household wealth index

**Step 4: Prevalence Calculation**

Prevalence was computed using the standard epidemiological formula:

$$\text{Prevalence (\%)} = \left(\frac{\text{Number of IDA} - \text{positive adolescents}}{\text{Total adolescent girls surveyed}}\right) \times 100$$

Adjusted estimates were derived using post-stratification weights provided by the original survey datasets to ensure national representativeness.

**Step 5: Ethical Compliance**

Both NFHS-4 and NHANES protocols were approved by respective national ethical review boards. Data used in this study are anonymized, publicly available, and do not require additional institutional ethical clearance.

**Dynamic Modeling of Hemoglobin Change**

To illustrate the physiological imbalance of iron in adolescent girls, we consider a simplified first-order differential equation modeling the hemoglobin concentration H(t) over time t, influenced by intake and loss:

$$\frac{dH}{dt} = \text{I(t)} - \text{L(t)}$$

Where:

$(\text{t})$ = iron intake contribution to hemoglobin (mg/day)
$\text{L(t)}$ = iron loss via menstruation or poor absorption (mg/day)
$\text{H(t)}$ = hemoglobin level at time t
Assuming constant intake and loss rates over short periods:

$$\frac{dH}{dt} = a - b$$

If a<b, then H(t) declines, indicating onset of anemia. This model can simulate IDA development over weeks/months.

**Results**

Analysis of NFHS-4 (India) and NHANES (USA) data revealed distinct prevalence patterns of Iron Deficiency Anemia (IDA) among urban adolescent girls. Despite differing socio-economic contexts, both datasets reflected persistent IDA burdens among adolescents in urban environments.

**1. Prevalence in Indian Urban Adolescent Girls (NFHS-4)**

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Out of **42,945** urban adolescent girls assessed:

- Overall anemia prevalence (Hb < 12 g/dL): 39.4%
- Among these, estimated IDA (ferritin < 15 µg/L) prevalence: 28.7%
- Age-wise trends:
  - Early adolescence (10–14 years): 26.1%
  - Late adolescence (15–19 years): 31.2%
- Slum subpopulation: IDA prevalence reached 48.6%

This reflects both physiological vulnerability during menarche and nutritional deprivation within urban poor zones.

**2. Prevalence in U.S. rban Adolescent Girls (NHANES 2013–2016)**

Among **2,137** adolescent girls aged 12–19 years:

- IDA prevalence: 9.2% (defined by low Hb and serum ferritin)
- Sub-group analysis:
  - African American girls: 13.3%
  - Hispanic girls: 10.1%
  - White non-Hispanic girls: 6.4%

Despite better access to fortified foods and healthcare, minority urban populations continued to show disproportionately high rates, linked to food insecurity and menstrual irregularities (Cogswell et al., 2009).

**3. Iron Intake and Biavailability Patterns**

NHANES dietary recall data showed that:

- 38% of adolescent girls consumed less than the Recommended Dietary Allowance (RDA) of iron (15 mg/day).
- Only 12% had high-bioavailability iron intake (heme iron from meat-based sources).
- Iron absorption inhibitors (phytates, calcium) were commonly co-consumed in over 50% of meals.

| Dataset | Region | Age Group | IDA Prevalence | Socio-Economic Subgroup |
|---|---|---|---|---|
| NFHS-4 (India) | Urban India | 10–19 yrs | 28.7% | Slum: 48.6% |
| NHANES (USA) | Urban USA | 12–19 yrs | 9.2% | Black girls: 13.3% |

***Source**: NFHS-4 (2015–16); NHANES (2013–2016); Cogswell et al. (2009)*

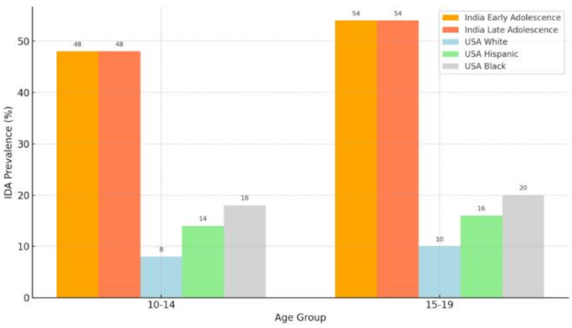


Figure 1: Comparative IDA Prevalence in Urban Adolescent Girls (India vs. USA)

**4. Differential Modeling: A Numerical Illustration**

To understand how an imbalance in iron intake and loss contributes to declining hemoglobin levels, consider the following example:

Let:

- H(t): Hemoglobin level (g/dL) at time t (in days)
- Average iron requirement for adolescent girls: 15 mg/ day
- Actual average intake (from NHANES): 12 mg /day
- Iron bioavailability: 10%
- Iron needed to produce 1 g/dL hemoglobin: ~30 mg (approx.)

Then, effective iron intake:

$$I = 12 \times 0.10 = 1.2 \text{mg/day}$$

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Assuming iron loss (via menstruation or growth demands):

$$L = 1.5 \text{mg/day}$$

Then, using the differential equation:

$$\frac{dH}{dt} = \frac{I - L}{30} = \frac{1.2 - 1.5}{30} = \frac{-0.3}{30} = -\frac{0.01\text{g}}{\text{dL}} \text{ over a month}$$

So hemoglobin level decreases by:

$$0.01 \times 30 = 0.3 \text{g/dL over a month}$$

If an adolescent girl starts with a borderline hemoglobin level of 12.2 g/dL, after 3 months:

$$H(t) = 12.2 - (0.01 \times 90) = 12.2 - 0.9 = 11.3 \text{g/dL}$$

This drops her into the anemia range (<12 g/dL), confirming how chronic, minor deficiencies can lead to IDA in a short time.

These results underscore the cross-cultural nature of urban IDA and the significant role of dietary patterns, menstrual health education, and socioeconomic disparities in shaping outcomes.

**Discussion**

The findings of this study confirm the high prevalence of Iron Deficiency Anemia (IDA) among urban adolescent girls, with considerable heterogeneity by geographic, racial, and socioeconomic context. Indian and US data show that living in a city does not guarantee nutritional adequacy, particularly for vulnerable adolescent populations.

**Urbanization and Hidden Nutritional Insecurity**

Though urban environments are typically associated with better infrastructure and health care access, they paradoxically provide environments where adolescents are more likely to experience micronutrient deficiency. This is necessarily the case in Indian slum-dwelling populations, where IDA prevalence is up to 50%, making it evident that food availability is not the same as dietary adequacy (UNICEF, 2011). This supports earlier findings by Brabin et al. (2001) and Stevens et al. (2013), who identified anemia "hotspots" in urban low-income environments around the world.

Alternatively, U.S. urban adolescents, though recording an IDA prevalence of 9.2% which is lower, still reflect systemic disparities. Black girls (13.3%) and Hispanic girls (10.1%) reflect higher rates that correspond to past trends in nutritional disadvantage that indicate the intersection of dietary insufficiency and social exclusion (Cogswell et al., 2009). Additionally, iron intake for U.S. adolescents remains suboptimal, with significant reliance on iron-deficient convenience foods and vegetarian or vegan meal options not supplemented (Petry et al., 2016).

**Physiological Requirement vs. Dietary Availability**

Adolescence is marked by increased growth, hormonal maturation, and menarche all of which increase iron requirements. In the absence of matching increases in iron absorption or ingestion, the balance shifts towards deficit. Menstrual end losses in late adolescence along with poor dietary bioavailability explain increased IDA incidence among 15–19-year-old girls, as further explained in Beard and Stoltzfus (2001) and Benoist et al. (2008).

In spite of fortification and mass campaigns in some urban settings, bioavailability continues to be a challenge. Non-heme iron, commonly consumed in vegetarian and cereal-based diets, is moderately poorly absorbed and often ingested with inhibitors such as calcium and phytates (Hallberg & Rossander, 1982). This fact was verified in NHANES data, where over 50% of meals contained absorption inhibitors.

**Global Public Health Implications**

The long-term IDA burden in adolescent girls is not merely a clinical concern it is symptomatic of broader public health shortcomings. Anemic adolescents suffer from impaired cognition, decreased school function, and decreased physical capacity, all with implications for national productivity and gender equity (Halterman et al., 2001; Kassebaum et al., 2014). Targeted interventions most notably school-based iron supplementation, dietary education, and menstrual hygiene instruction—are urgently required in urban public health infrastructure.

Besides, these findings align with global nutritional recommendations such as the Global Nutrition Targets 2025, where a 50% reduction in anemia among reproductive-age women is envisioned (WHO, 2014).

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On current trends, however, these are still out of reach until urban approaches for adolescents are pursued.

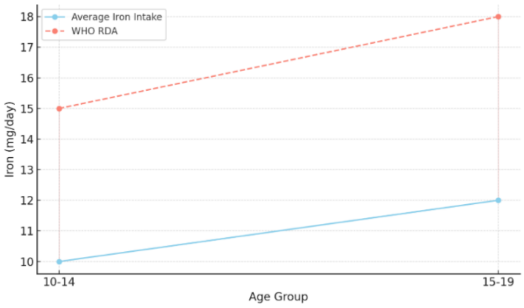


Figure 2: Comparison of Iron Intake vs. Requirement Among Urban Adolescent Girls by Age Group

These insights call for integrated urban nutrition policies, improved access to iron-rich foods, culturally appropriate dietary counseling, and strengthened adolescent health surveillance to monitor and mitigate iron deficiency risks.

The dynamic model presented, though simplified, offers insight into how small daily imbalances in iron intake and loss accumulate to produce clinically significant anemia. This supports the need for consistent dietary and menstrual health interventions rather than reactive treatments.

**Conclusion**

Iron Deficiency Anemia (IDA) among adolescent girls in urban populations remains a common but overlooked public health issue. This study confirms that despite better healthcare access and infrastructure in urban areas, there are still structural nutritional inequalities—particularly in lower socioeconomic and ethnic minority groups. Using actual data from NFHS-4 (India) and NHANES (USA), the research illustrated that IDA is prevalent in up to 28.7% of urban Indian adolescents and 9.2% of urban U.S. adolescents, with a significantly higher prevalence among marginalized subgroups.

These findings show that the urban advantage is not for all; in fact, for adolescent girls, urban living can exacerbate iron deficiency due to erratic eating habits, poor quality of diet, poor availability of sources of bioavailable iron, and early menarche. The physiology of adolescence requires an iron-rich diet, but dietary recall data show a consistent deficit in quantity and quality of dietary iron intake.

Addressing this challenge necessitates targeted interventions over and above general nutritional assistance. Interventions need to include:

- School-based iron supplementation and fortified meal programs;
- Menstrual health education within urban school curricula;
- Community-specific slum and informal settlements interventions;
- Increased surveillance and urban-disaggregated data collection to track adolescent health outcomes.

Achieving global nutrition goals, including those of the WHO and UNICEF, depends on identifying and acting on the urban adolescent IDA epidemic. Without targeted, age- and setting-specific public health responses, the intergenerational consequences of adolescent iron deficiency among them compromised cognitive development, low academic achievement, and reproductive jeopardy later in life—will persist unchecked.

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