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A Comprehensive Review Of Iron Intake Among Young And Pregnant Women In The Uttarakhand Region

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Abstract: Background: *Iron is a critical micronutrient for oxygen transport, metabolism, and immune function. Women, especially during adolescence and pregnancy, have increased iron needs. Despite national health programs, NFHS and CNNS data reveal persistently high anemia prevalence. In Uttarakhand, low-iron diets, vegetarian practices, cultural food habits, poor healthcare access, and socio-economic constraints intensify the problem.*

Aim: *This review synthesizes evidence on iron intake, absorption, and life stage–specific requirements, focusing on adolescent and pregnant women in Uttarakhand. It also examines the health and socio-economic consequences of deficiency and evaluates government interventions.*

Methodology: *A narrative review approach was employed, drawing on peer-reviewed studies, national surveys, and regional reports. Special emphasis was placed on dietary practices, cultural influences, and public health initiatives such as Anemia Mukt Bharat, ICDS, Janani Suraksha Yojana, and Weekly Iron and Folic Acid Supplementation.*

Results: *Findings show persistently high anemia prevalence in women despite ongoing programs. Consequences include impaired maternal and fetal health, adolescent growth deficits, cognitive decline, and reduced productivity, with risks of intergenerational transmission. Region-specific barriers limit the effectiveness of national interventions when applied uniformly.*

Conclusion: *Iron deficiency among women in Uttarakhand remains a major public health challenge. Tailored, culturally sensitive strategies—combining dietary diversification, nutrition education, supplementation, and stronger healthcare delivery—are urgently required to improve maternal-child health and break the cycle of anemia.*

Keywords: *Anaemia, Bioavailability, Dietary Intake, Iron Deficiency, Maternal Health, Uttarakhand*

1. INTRODUCTION

1.1. Iron as a vital Micronutrient

Iron is the second most prevalent metal on Earth, constituting around 5% of the Earth's crust. Its importance to humans is crucial, as it is an essential vitamin for human survival. As a d-block transition metal, it oscillates between multiple oxidation states, enabling it to engage in electron transfer and bind to numerous biological ligands [1]. The two predominant oxidation states of iron are divalent ferrous (Fe^{2+}) and trivalent ferric (Fe^{3+}). Iron is essential as a cofactor for numerous hemoproteins and non-heme iron-containing proteins in the human body. Haemoproteins encompass haemoglobin and myoglobin, which facilitate oxygen binding and transport; catalase and peroxidase enzymes, which participate in oxygen metabolism; and cytochromes, which are integral to electron transport and mitochondrial respiration. Proteins containing non-haem iron play essential roles in DNA synthesis, cell proliferation and differentiation, gene control, drug metabolism, and steroid synthesis [2].

In a 70 kg adult male, the total body iron content is approximately 3500–4000 mg, averaging 50–60 mg/kg of body weight. Around 65% (≈2300 mg) is contained within hemoglobin in erythrocytes. Approximately 350 mg is allocated in myoglobin in and iron-dependent enzyme throughout diverse organs. Iron reserves comprise 500 mg in macrophage of the reticuloendothelial system, also known as (RES), 200–1000 mg in hepatic as ferritin, and around 150 mg in the bone marrow [3,4].

The duodenum is crucial for the absorption of dietary iron. The ingested iron can be retained in the the enterocytes or reach the bloodstream, where it is distributed throughout the body coupled to the liver-derived blood protein transferrin (Tf). Subsequently, it is absorbed by tissues and used for several purposes, including erythrocyte in the bone marrow, myoglobin production in muscles, and the breakdown of oxygen in all respiring cells [5]. Macrophages in the spleen, liver, and bone marrow, essential to the reticuloendothelial system, enable the recycling of iron from aged erythrocytes. The liver is essential for regulation and storage. By producing the hormone hepcidin, it controls the amount of iron that enterocytes and macrophages release into the bloodstream. This makes it possible to precisely control and preserve plasma iron levels within physiological bounds. The main tissues involved in iron metabolism are depicted in Figure 1 [6].

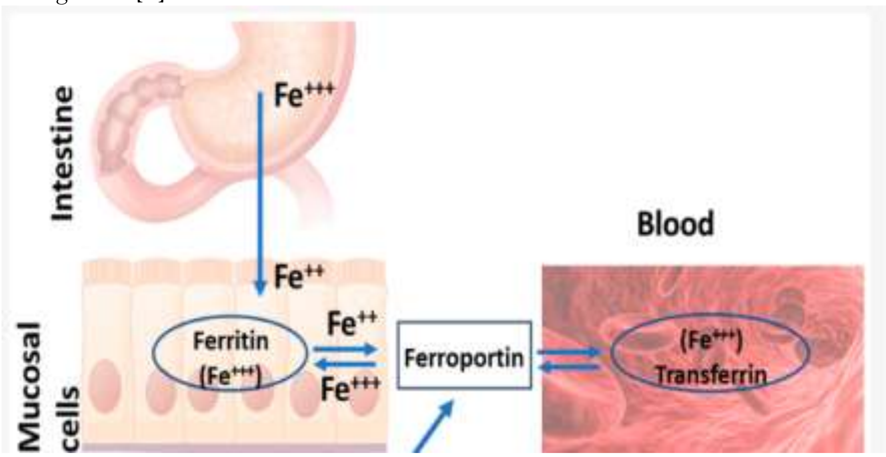

Figure 1: The principal tissues involved in the regulation of systemic iron metabolism [6]

The body loses about 1-2 mg of iron every day as a result of hemorrhages, parasite infections, and enterocyte and skin desquamation. There is no effective system in place to remove iron [7-9]. Thus, to maintain iron homeostasis, 1-2 mg of intestinal iron absorption must be consumed daily. During physiological events including development, pregnancy, and menstruation, this need increases [10,11]. As aging erythrocytes undergo phagocytosis, the reticuloendothelial system, or RE, recycles about 25 mg of iron every day. This implies that iron recycling plays a major role in maintaining human iron homeostasis. Iron balance depends on strict control of its breakdown [12,13].

1.2. Global and National prevalence of Iron deficiency

"The World Health Organization (WHO)" estimates that more than two billion individuals globally experience iron deficiency, with women and children in low- and middle-income nations bearing a disproportionate burden. Iron deficiency anemia (IDA) constitutes a significant public health issue in India. "The National Family Health Survey-5 (NFHS-5)" indicates that over fifty percent of Indian women aged 15 to 49 are anemic. Anemia in women, especially during pregnancy, heightens the risk of maternal death, adverse pregnancy outcomes, and developmental delays in newborns. Despite the introduction of many national initiatives such as the Anemia Mukt Bharat project and iron-folic acid supplementation schemes, their effectiveness has varied significantly across different states and socio-economic categories [17]. Figure 2 depicts the worldwide prevalence of iron deficiency anemia (IDA), indicating that 16% of the global population—approximately 1.2 billion individuals in 2016—were impacted, with children (41.7%), pregnant women (40.1%), and non-pregnant women (32.5%) identified as the most susceptible demographics [18].

Figure 2: "The prevalence of Iron deficiency Anemic (IDA) and Non-Iron Deficiency Anemic (Non-IDA)" [18]

In this context, Uttarakhand presents a unique case due to its diverse topography, predominantly rural population, and scattered healthcare infrastructure [19]. The hill districts face challenges such as food

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insecurity, limited access to healthcare facilities, and poor dietary diversity. These factors collectively contribute to the risk of iron deficiency among vulnerable groups [20]. Furthermore, cultural food practices, lack of awareness, and insufficient intake of iron-rich foods exacerbate the problem [21]. Many women in remote areas remain unaware of the importance of iron during pregnancy and adolescence, leading to poor compliance with supplementation programs.

Young and pregnant women are the focus because of their higher physiological needs and susceptibility to iron deficiency [22]. While pregnant women need a higher iron intake to support fetal development, increase maternal red blood cells, and placenta formation, adolescents need iron to support their growth and make up for menstrual losses [23]. Low birth weight, early delivery, and perinatal mortality are just a few of the severe outcomes that can arise from an iron deficit during pregnancy. It is crucial to address iron consumption in these communities for the sake of future generations' health as well as the health of the women themselves [24].

This review aims to provide a comprehensive analysis of iron intake and deficiency among young and pregnant women in the Uttarakhand region. It synthesizes available literature to explore dietary habits, nutritional awareness, socio-economic determinants, government interventions, and healthcare access related to iron nutrition. By identifying region-specific gaps and challenges, the review aims to inform effective strategies and policy recommendations that can enhance iron status and improve overall maternal health outcomes in Uttarakhand.

2. Physiological and Life Stage-Specific Iron Requirements in Women

Iron is an indispensable micronutrient for women due to its critical role in oxygen transport, energy metabolism, cognitive function, immune defense, and hormonal regulation. Throughout a woman's life, especially during adolescence, menstruation, pregnancy, and lactation, iron requirements vary considerably. These physiological phases are often marked by increased demands that, if unmet, lead to iron deficiency or anemia. This section explores the biological basis of iron needs, absorption mechanisms, influencing factors, and the consequences of deficiency for both the mother and child.

2.1. Increased Iron Demands During Adolescence and Gestation

Iron, a vital element, is crucial for sustaining good health in women, especially during key life stages such as menstruation, pregnancy, postpartum, and the various periods of menopause [25]. Optimal iron levels in the body are crucial for several physiological tasks, including oxygen transport, energy metabolism, and immune system enhancement. Iron is critically required during menstruation and pregnancy, rendering women susceptible to shortage if food intake is insufficient [26]. Inadequate iron levels can result in anaemia and various health issues, underscoring the necessity for proactive measures to guarantee proper iron intake and absorption.

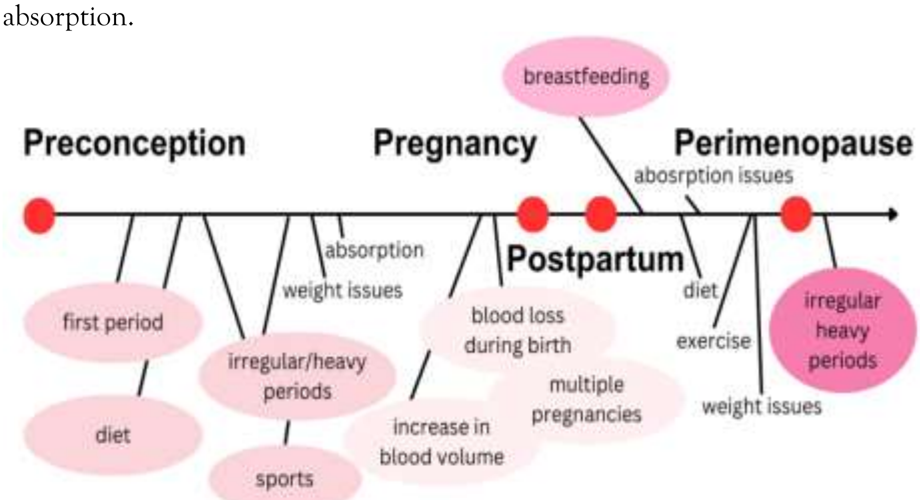

Figure 3: Iron Requirements Across Women's Life Stages [27].

Iron insufficiency is among the most widespread dietary deficiencies globally, significantly impacting several women, especially throughout critical life periods characterized by heightened physiological requirements

[28]. Iron deficiency is the primary cause of anemia worldwide, affecting almost one billion people. Iron deficiency anemia (IDA) substantially adds to morbidity and disease burden, being associated with chronic kidney disease, chronic heart failure, cancer, and inflammatory bowel disease (IBD), among other disorders. It is a key factor in chronic health deterioration in women [29].

The documented incidence of iron deficiency in women worldwide ranges from 15 to 18 %. Anemia is predicted to affect 29.9% of non-pregnant women and 38 percent of pregnant women worldwide. among 2021, the World Health Organization (WHO) reported that the global average incidence of iron deficiency anemia (IDA) among pregnant women was 37%. Women are prone to iron shortage owing to menstruation and inadequate intake of iron-rich foods to offset the loss [31]. A recent comprehensive survey revealed that 42 % of Irish women may be prone to iron deficiency [32].

2.2. Iron Bioavailability and Mechanisms of Absorption

Iron is a key component of haemoglobin in red blood cells and myoglobin in muscles, together accounting for about 60% of total body iron [33]. It supports vital cellular functions such as respiration, enzymatic activity, DNA synthesis, and mitochondrial energy production. The adult human body contains approximately 3–5 grams of iron, with daily needs of 20–25 mg to support red blood cell production and metabolism [34]. Although only 1–2 mg of iron is absorbed from the diet daily, the body maintains balance through efficient recycling, storage, and regulated absorption, compensating for equivalent daily losses via menstruation, sweating, skin shedding, and urination.

In active women, particularly endurance athletes, iron loss may increase due to sweating and foot strike haemolysis—the breakdown of red blood cells from repetitive ground impact [35].

Dietary iron exists in two forms: haem iron (from meat, fish, and poultry) which is more efficiently absorbed, and non-haem iron (from plant sources like cereals, leafy greens, and nuts) which has lower bioavailability [36]. Absorption of non-haem iron is enhanced by vitamin C and inhibited by phytates and polyphenols present in some plant-based foods and beverages

“Table 1: Examples of haem and non-haem iron [36]

Haem iron	**Non-haem iron**
Red meat	Beans
Poultry	Lentils
Fish	Tofu
Shellfish	Green leafy veg, eg, spinach
Eggs	Nuts and seeds, Fortified cereals”

2.3. Factors increasing iron demand among females

Several physiological, lifestyle, and socio-demographic factors contribute to the elevated iron needs in women, making them particularly vulnerable to iron deficiency and Iron Deficiency Anaemia (IDA) throughout their life stages [37]:

Figure 4: Factors that contribute to increasing the susceptibility to iron deficiency Among Women [37]

❖ **Menstruation:**

Monthly blood loss, especially in cases of heavy menstrual bleeding (HMB), significantly increases iron loss. HMB affects up to one-third of menstruating women and is a leading cause of IDA, particularly in developed nations [38]. Underlying gynecological conditions such as uterine fibroids, endometriosis, and polycystic ovary syndrome (PCOS) can further intensify menstrual blood loss, depleting iron reserves more rapidly if not compensated through diet or supplementation.

❖ **Frequent Pregnancies and Short Intervals:**

Women with closely spaced pregnancies or multiple childbirths face cumulative iron losses. Pregnancy already demands 1000–1200 mg of iron, and without sufficient recovery time between pregnancies, the body may not replenish its iron stores adequately [39]. This chronic depletion increases the risk of maternal anaemia and can affect fetal development and maternal postpartum recovery.

❖ **Dietary Limitations:**

Vegetarian and vegan diets, while healthful in many ways, often lack adequate amounts of haem iron, which is more bioavailable than non-haem iron [40]. Women following restrictive or unbalanced diets, including those with eating disorders or chronic gastrointestinal conditions like inflammatory bowel disease (IBD) or coeliac disease, may have reduced iron absorption or increased losses, compounding their risk of deficiency.

❖ **Athletic Activity:**

Women participating in high-intensity endurance sports, including long-distance running, triathlons, or competitive cycling, experience heightened iron depletion through perspiration, gastrointestinal hemorrhage, and a condition termed foot-strike hemolysis, which involves the destruction of red blood cells resulting from repeated impact with rigid surfaces. These factors, coupled with high energy demands and sometimes restricted diets, make female athletes a high-risk group for iron deficiency [41].

❖ **Socioeconomic and Cultural Factors:**

In many regions, especially rural or underprivileged communities, women have limited access to nutritionally diverse foods, healthcare services, and iron supplementation programs. Food insecurity, low literacy, and cultural dietary taboos—such as avoiding certain iron-rich foods during menstruation or pregnancy—can significantly hinder adequate iron intake. Additionally, women often prioritize their family's nutrition over their own, unintentionally compromising their micronutrient intake [42].

2.4. Importance of Iron in Maternal Well-being and Fetal Development

Iron is vital for the well-being and physiological functioning of pregnant women and is needed for the appropriate development and growth of the fetus. Pregnancy imposes heightened demands on the mother's iron reserves due to the rise in maternal blood volume, the formation of the placenta, and the escalating requirements of the fetus. The World Health Organization (WHO) estimates that the overall extra iron demand during pregnancy is around 1000–1200 mg, allocated as follows: enhanced maternal red cell mass (~450 mg), placental development (~90 mg), fetal requirements (~270 mg), and blood loss after birth (~250 mg) [44].

❖ **Maternal Health Outcomes**

Adequate iron levels are vital for synthesizing hemoglobin, the oxygen-carrying component of red blood cells. “During pregnancy, maternal blood volume increases by nearly 50%, requiring higher hemoglobin production. If iron needs are not met, the mother is at increased risk of Iron Deficiency Anemia (IDA), which can lead to fatigue, impaired immune function, poor physical work capacity, dizziness, and in severe cases, cardiac stress and heart failure. IDA during pregnancy is associated with a higher risk of preeclampsia”, placental abruption, postpartum hemorrhage, and increased maternal mortality, especially in resource-constrained settings. Iron also plays a non-hematological role in energy metabolism, enzymatic function, and immune regulation, making it critical for maternal well-being beyond oxygen transport [45].

❖ **Fetal Developmental Outcomes**

For the developing fetus, iron is indispensable for brain development, particularly in the processes of myelination, neurotransmitter synthesis, and neuronal differentiation. The fetus depends entirely on maternal iron stores, especially in the third trimester when iron transfer from mother to fetus is at its peak. Iron deficiency during this crucial window can impair fetal iron stores and affect cognitive, behavioural, and motor development in infancy and early childhood [46].

Low maternal iron levels have been associated with:

- Intrauterine Growth Restriction (IUGR)
- Preterm birth

- Low birth weight
- Stillbirths and perinatal mortality
- Delayed psychomotor development in children

These developmental consequences may persist long after birth, potentially affecting school performance and productivity in later life, making maternal iron status a long-term public health concern.

3. Epidemiology of Iron Deficiency in India and Uttarakhand

"Iron deficiency remains one of the most pressing public health concerns in India, particularly among vulnerable populations such as adolescent girls and pregnant women [47]. National-level surveys, including the National Family Health Surveys (NFHS-4: 2015–16 and NFHS-5: 2019–21), highlight a concerning upward trend in the prevalence of anaemia—often a proxy for iron deficiency—among women aged 15–49 years, increasing from 53% in NFHS-4 to 57% in NFHS-5. This rising trend underscores the limited progress made in combating iron deficiency, despite several national programs aimed at nutritional improvement" [48].

Data from the Comprehensive National Nutrition Survey (CNNS, 2016–18) provides a more detailed picture of the burden among adolescents. It reports that 31.3% of adolescent girls aged 10–19 years were iron deficient, with a higher prevalence observed in older adolescents (15–19 years), indicating increased vulnerability during late adolescence due to menstrual blood loss and growth spurts [49].

At the state level, Uttarakhand faces distinct challenges due to its predominantly rural and mountainous geography, which affects access to nutrition, health services, and education. A field study in the rural block of Udham Singh Nagar found that 46% of adolescent pregnant mothers were anaemic, reflecting the persistent nutritional deficits in low-resource settings. Furthermore, while iodine status was found to be adequate in adolescent girls across the districts of Udham Singh Nagar, Nainital, and Pauri, anaemia prevalence remained high, suggesting the coexistence of multiple micronutrient imbalances [50].

Socio-economic and demographic factors play a substantial role in determining iron status. Analysis of national datasets reveals that girls from low-income households, with lower education levels and poor dietary diversity, are disproportionately affected. The rural–urban divide is especially stark: rural adolescent girls consistently exhibit higher anemia rates compared to their urban peers, primarily due to limited access to iron-rich foods and inadequate healthcare infrastructure [51].

Despite the introduction of national schemes such as the Weekly Iron and Folic Acid Supplementation (WIFS) program and mid-day meal initiatives, their implementation and reach remain suboptimal. Factors such as irregular supply chains, lack of awareness, and non-compliance continue to hinder the impact of these interventions.

Iron deficiency in India—and particularly in states like Uttarakhand—represents a complex, multifactorial public health issue. It is influenced by age, gender, geography, socio-economic status, and systemic health service gaps.

4. Dietary Sources and Patterns of Iron Intake

4.1. Typical Diets of Women in Uttarakhand

Women in the Uttarakhand region typically consume cereal-based meals with limited diversity, largely depending on wheat, rice, and maize as staple foods [52]. These are supplemented with pulses, seasonal vegetables, and dairy products. Meat and fish consumption remain low, particularly due to cultural vegetarianism and economic constraints [53]. As a result, the daily diets of both young and pregnant women are often calorie-sufficient but micronutrient-deficient, particularly with respect to iron intake.

4.2. Vegetarian Dietary Practices and Low Iron Density

A significant proportion of women in Uttarakhand follow vegetarian diets, which increases reliance on non-heme iron sources [54]. Non-heme iron has low absorption efficiency compared to heme iron found in animal foods. Since animal-source foods are consumed sparingly, the iron density of the diet remains low, often falling short of meeting the higher physiological requirements during pregnancy and adolescence [55]. This dietary gap is one of the key contributors to the persistent high prevalence of anemia among women in the state.

4.3. Iron-Rich Local Foods

Despite these challenges, the region possesses a range of traditional iron-rich foods that, if promoted effectively, can help improve dietary iron intake [56]. Table 2 presents some common local food sources, their approximate iron content, and their relative bioavailability.

Table 2: Common Local Foods in Uttarakhand and Their Iron Contribution [57]

Food Source	Type	Iron Content (mg/100 g)	Bioavailability	Remarks
Mandua (Finger millet)	Millet (Plant)	3.9 – 4.2	Low (non-heme)	Traditional staple, eaten as roti
Jhangora (Barnyard millet)	Millet (Plant)	2.5 – 3.0	Low	Seasonal food grain
Rajma (Kidney beans)	Legume (Plant)	5.0 – 6.0	Low	Popular pulse, but high phytates
Horse gram (Kulthi)	Legume (Plant)	6.8 – 7.6	Low	Common among rural households
Bathua leaves	Leafy vegetable (Plant)	2.1 – 2.5	Moderate	Seasonal green, contains vitamin C
Amaranthus (Chaulai leaves)	Leafy vegetable (Plant)	3.0 – 3.5	Moderate	Consumed as saag
Nettle (Bichhu ghas)	Leafy vegetable (Plant)	4.0 – 5.0	Moderate	Used in traditional cooking
Jaggery	Plant-based sweetener	4.0 – 5.0	Low	Contributes modestly to iron intake

4.4. Issues of Bioavailability

Even when women consume iron-rich foods, the absorption is strongly influenced by inhibitors and enhancers present in the diet [58]. Phytates in cereals and pulses, tannins from tea, and polyphenols in vegetables reduce absorption of non-heme iron. The common cultural habit of drinking tea immediately after meals further compounds this problem [59]. Conversely, vitamin C from amla, guava, citrus fruits, and tomatoes can significantly enhance absorption, but these foods are not consistently consumed. Table 3 summarizes the major factors affecting iron absorption in the Uttarakhand diet.

Table 3: Factors Influencing Iron Absorption in Uttarakhand Diets [60]

Category	Examples in Local Diet	Effect on Iron Absorption
Inhibitors	Phytates (cereals, pulses), tannins (tea), polyphenols (spices, vegetables)	Decrease absorption of non-heme iron
Enhancers	Vitamin C (amla, guava, citrus fruits, tomatoes), animal proteins (meat, fish, dairy)	Increase non-heme iron absorption
Cultural habits	Drinking tea with meals, low fruit intake	Net negative effect

5. Public Health Initiatives and Supplementation Programs

5.1. Government Programs Addressing Iron Deficiency and Anemia

- **Anemia Mukt Bharat (AMB)**

Figure 5: Anemia Mukt Bharat (AMB)

"Introduced in 2018 under the National Health Mission, Anemia Mukt Bharat (AMB) represents a comprehensive lifecycle initiative aimed at reducing the prevalence of anemia among vulnerable groups in India. The program focuses on six key beneficiary groups: children aged 6–59 months, children 5–9 years, adolescents 10–19 years, women of reproductive age (15–49 years), pregnant women, and lactating mothers [61]. Its implementation is guided by the well-known 6×6×6 strategy, which encompasses six core interventions: prophylactic iron–folic acid (IFA) supplementation tailored to physiological needs, biannual deworming through National Deworming Day, intensified behaviour change communication activities, digital anemia screening and point-of-care management, mandatory provision of IFA-fortified foods, and addressing non-nutritional causes such as malaria, hemoglobinopathies, and fluorosis [62]. Considered one of the most ambitious frameworks to address iron deficiency anemia, AMB has also been extended to Uttarakhand, where it is implemented through state health facilities, Anganwadi centres, and schools to improve maternal and child nutritional outcomes.

- **Integrated Child Development Services (ICDS)**

Figure 6: The Integrated Child Development Services (ICDS) scheme

Launched in 1975, the Integrated Child Development Services (ICDS) scheme continues to be India's flagship program for advancing maternal and child nutrition [63]. The scheme primarily targets children below six years of age, along with pregnant women, lactating mothers, and adolescent girls. Delivered through an extensive network of Anganwadi centres, ICDS provides six core services: supplementary nutrition, non-formal preschool education, nutrition and health education, immunization, routine health check-ups, and referral support [64]. In the context of anemia prevention, supplementary rations frequently include fortified cereals and pulses, while educational activities focus on promoting dietary diversity and iron-rich foods. Within Uttarakhand, ICDS centres serve as a vital channel for reaching rural and remote populations;

however, irregular supply chains, difficult terrain, and limited resources often restrict the consistency and effectiveness of service delivery.

❖ **Janani Suraksha Yojana (JSY)**

Figure 7: The Janani Suraksha Yojana (JSY)

Introduced in 2005 under the National Health Mission, the Janani Suraksha Yojana (JSY) is a conditional cash transfer scheme designed to promote institutional deliveries and thereby improve maternal and neonatal health outcomes [65]. Although its primary objective is to encourage safe childbirth, the program also serves as an important platform for antenatal interventions, including anemia screening, iron–folic acid (IFA) supplementation, and nutrition counselling during pregnancy. Beneficiaries enrolled under JSY are supported by Accredited Social Health Activists (ASHAs) and linked with healthcare facilities to ensure access to hemoglobin testing and timely distribution of IFA tablets [66]. In Uttarakhand, particularly across remote and hilly districts, JSY has played a critical role in increasing institutional delivery rates while simultaneously facilitating the integration of maternal anemia management within routine antenatal care services.

❖ **Weekly Iron and Folic Acid Supplementation (WIFS)**

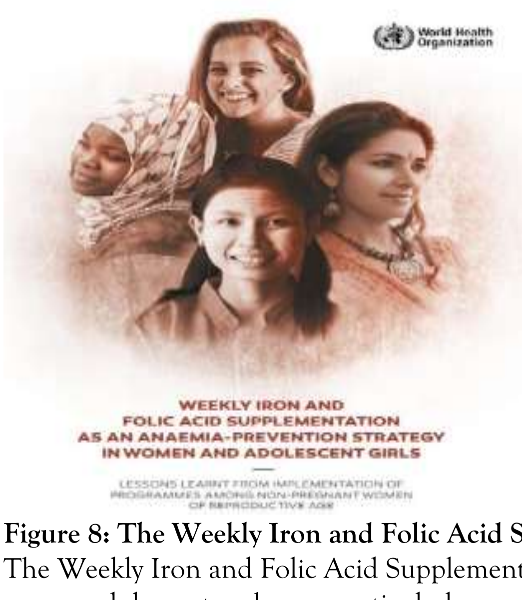

Figure 8: The Weekly Iron and Folic Acid Supplementation (WIFS) program

The Weekly Iron and Folic Acid Supplementation (WIFS) program was introduced to tackle iron deficiency among adolescents, who are particularly susceptible to anemia due to rapid growth and, in girls, the onset of menstruation [67]. Under this initiative, adolescents aged 10–19 years receive a weekly iron–folic acid (IFA) tablet, typically blue in colour, along with biannual deworming support. The program is implemented through schools for enrolled students and Anganwadi centres for out-of-school adolescents, thereby ensuring broad population coverage. In Uttarakhand, WIFS serves as a critical intervention for both boys and girls; however, challenges such as irregular distribution, limited awareness, and minor side-effects continue to affect compliance [68]. Strengthening delivery mechanisms at schools and enhancing peer-led awareness strategies are considered key measures to improve adherence and maximize the program's effectiveness".

5.2. IFA Supplementation: Coverage, Compliance, and Challenges

Iron and folic acid supplementation is the cornerstone of anemia prevention and control in India [69]. Pregnant women are entitled to 100 mg elemental iron + 500 µg folic acid daily for at least 180 days during pregnancy and 180 days postpartum, while adolescents are provided with weekly IFA supplementation under the Weekly Iron and Folic Acid Supplementation (WIFS) program. However, the coverage and compliance remain suboptimal in Uttarakhand due to several barriers. Commonly reported challenges include gastrointestinal side effects, misconceptions about IFA tablets, irregular supply chains, and inadequate follow-up by frontline workers. A significant proportion of women either discontinue midway or do not consume the tablets regularly, undermining program effectiveness [70].

5.3. Community-Level Implementation in Uttarakhand

In Uttarakhand, the success of these programs depends heavily on Accredited Social Health Activists (ASHAs), Anganwadi Workers (AWWs), and Auxiliary Nurse Midwives (ANMs) who are responsible for last-mile delivery [71]. Community outreach includes household visits, village health and nutrition days, and maternal counseling sessions. While the presence of Anganwadi centers across rural areas provides a platform for supplement distribution, challenges such as difficult terrain, dispersed populations, and seasonal migration limit regular access. Studies from hilly districts like Pauri Garhwal and Almora suggest that despite awareness, many women face interruptions in supply and limited monitoring, highlighting a need for more context-specific interventions in remote areas [72].

6. Consequences of Iron Deficiency

❖ Maternal Health Risks

Iron deficiency in pregnancy significantly increases maternal vulnerability to fatigue, reduced work capacity, and frequent infections [73]. Severe anemia is a major contributor to maternal mortality worldwide, as it heightens the risk of obstetric complications such as postpartum hemorrhage, sepsis, and cardiac failure. In settings like Uttarakhand, where health facilities are geographically scattered, untreated anemia can critically worsen maternal outcomes during delivery and the postpartum period [74].

❖ Fetal and Neonatal Outcomes

Iron deficiency during pregnancy is strongly associated with adverse fetal outcomes. Infants of anemic mothers are more likely to be born with low birth weight, suffer from preterm delivery, and face higher rates of perinatal mortality [75]. Furthermore, inadequate iron supply to the fetus impairs neurodevelopment, increasing the risk of long-term developmental delays and reduced learning capacity in later childhood.

❖ Impact on Adolescent Growth and Development

Adolescents, particularly girls, experience rapid growth and increased iron requirements during puberty. Iron deficiency at this stage leads to stunted growth, reduced physical fitness, and lower resistance to infections. In addition, menstrual blood loss in adolescent girls' compounds iron deficiency, making them highly vulnerable to chronic anemia that can persist into adulthood if not addressed early [76].

❖ Cognitive and Educational Impairment

Iron plays a vital role in brain development and neurotransmitter functioning [77]. Deficiency has been linked with impaired memory, reduced attention span, and poor concentration. In adolescents, this manifests as lower academic performance, decreased school attendance, and poor learning outcomes. For young women in rural areas like Uttarakhand, where education is already challenged by socio-economic barriers, iron deficiency further reduces their opportunities for educational advancement and empowerment.

❖ Socio-Economic Burden

Beyond health and education, iron deficiency imposes a significant economic cost on individuals, families, and society. Reduced physical capacity and chronic fatigue lower productivity, particularly in women engaged in agricultural and household labor. At the community level, widespread iron deficiency leads to a less efficient workforce and perpetuates poverty. The intergenerational cycle of malnutrition—where anemic mothers give birth to undernourished children—further entrenches socio-economic disadvantages [78].

7. CONCLUSIONS

Iron deficiency remains a critical public health challenge in Uttarakhand, particularly for young and pregnant women who face increased physiological demands but limited access to bioavailable dietary sources and supplementation. Despite the existence of national programs such as Anemia Mukt Bharat, ICDS, JSY, and WIFS, barriers including poor compliance, cultural practices, and geographic constraints continue to undermine progress. The consequences of iron deficiency extend beyond maternal morbidity and adverse pregnancy outcomes to long-term effects on child growth, cognition, and intergenerational health, while also imposing a significant socio-economic burden. Addressing this issue requires not only strengthening supplementation and public health delivery systems but also promoting dietary diversification, locally available iron-rich foods, and community-level awareness initiatives tailored to the unique socio-cultural and geographic context of Uttarakhand.

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