Dissertation

At

IPE Global ltd

(1st March to 15th June 2023)

A Project Report On

Exposure to air pollution as a risk factor for anemia around the world: a scoping review

IIHMR Delhi

By **Dr Yasmin Khan**

PG/21/131

Under the guidance of

Dr. Rupsa Banerjee

PGDM (Hospital & Health Management)

2021-2023

International Institute of Health Management Research

New Delhi

Internship training

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New Delhi

Completion of Dissertation from respective organization

This certificate is awarded to.

NAME: Dr. Yasmin Khan

In recognition of having successfully completed his/her internship and has successfully completed his/her project on

TITLE OF PROJECT: Exposure to air pollution as a risk factor for anemia around the world: a scoping review

DATE: 1st March to 15th June 2023

ORGANIZATION

IPE Global ltd, New Delhi

She comes across as a committed, sincere & diligent person who has a strong drive

and Zeal for learning.

We wish her all the best for future endeavors.

Mentor
Deepika Joshi,
Senior Manager, HNWash,
IPE Global ltd, New Delhi.

TO WHOMESOEVER IT MAY CONCERN

This is to certify that **Dr Yasmin Khan** student of PGDHM (Hospital and Healthcare Management) from International Institute of Health Management and Research- Delhi has undergone internship training under **IPE Global Ltd, New Delhi** from **1st March to 15th June 2023**.

The candidate has successfully carried out the internship tenure and completed the projects assigned to her during her training. She has been sincere, scientific, and analytical in her approach to her study.

The internship is in fulfilment of the course requirement.

I wish her success in all the future endeavors.

Dr. Sumesh Kumar
Associate Dean
(Academic and student affairs)
IIHMR, New Delhi

Mentor,
Dr. Rupsa Banerjee
Assistant Professor,
IIHMR, Delhi

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Certificate of Approval

The following dissertation titled **"SCOPING REVIEW ON: EXPOSURE TO AIR POLLUTION AS A RISK FACTOR FOR ANAEMIA AROUND THE WORLD."** is hereby approved as a certified study in management carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite for the award of **PGDM (Hospital & Health Management)** for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the dissertation only for the purpose it is submitted.

Dissertation Examination Committee for evaluation of the dissertation.

Name	Signature
NAVEEN VASHIST	17/06/23
Dr Rohini Rahil	Rohini 17/06/23
MUKESH RAVI RAUSHAN	Raushan 17/06/23.

Certificate from Dissertation Advisory Committee

This is to certify that Dr. Yasmin Khan, a post-graduate student of the PGDM (Hospital & Health Management) at IIHMR- Delhi has worked under our guidance and supervision. She is submitting this dissertation titled **"Exposure to air pollution as a risk factor for anemia around the world: a scoping review"** in partial fulfillment of the requirements for the award of the PGDM (Hospital & Health Management).

This dissertation has the requisite standard and to the best of our knowledge no part of it has been reproduced from any other dissertation, monograph, report, or book.

Mentor,
Dr. Rupsa Banerjee
Assistant Professor,
IIHMR, Delhi

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CERTIFICATE BY SCHOLAR

This is to certify that the dissertation titled "**Exposure to air pollution as a risk factor for anemia around the world: a scoping review"** and submitted by Dr Yasmin Khan, Enrolment No. PG/21/131 under the supervision of Dr. Rupsa Banerjee. for award of PGDM (Hospital & Health Management) of the Institute carried out during the period from **1st March to 15th June 2023**, embodies my original work and has not formed the basis for the award of any degree, diploma associate ship, fellowship, titles in this or any other Institute or other similar institution of higher learning.

Signature

Dr. Yasmin Khan.

FEEDBACK FORM

Name of the student: Dr. Yasmin Khan

Name of the organization in which dissertation has been completed: IPE Global ltd, New Delhi

Area of dissertation: Climate and Health

Attendance: 100%

Objectives achieved: Ensured proper programmatic management of the solution and its government outreach.

Deliverables

1. **Involved in proposal writing**
2. **Reactive and proactive bidding**
3. **Monthly report writing to USAID**

Strengths:

1. **Good knowledge of public health**
2. **Passionate about her work**
3. **Showcased good communication skills**

Suggestions for improvement: -

Suggestions for institute (course curriculum, industry interactions, placement, alumni): -

Signature of the office-in- charge/organization mentor(dissertation)

Date: 28 / 07 /2023

Place: Delhi

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CERTIFICATE ON PLAGIARISM CHECK

Name of Student (in block letter)	Dr/Mr./Ms.: Dr Yasmin Khan		
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Course Specialization (Choose one)	Hospital Management	✓Health Management	Healthcare IT
Name of Guide/Supervisor	Dr/ Prof.: Dr. Rupsa Banerjee		
Title of the Dissertation/Summer Assignment	**Exposure to air pollution as a risk factor for anemia around the world: a scoping review**		
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Dr Yasmin Khan.

Date- 28 June 2023

ABOUT THE ORGANIZATION

The International Institute of Health Management Research (IIHMR), New Delhi is allied to the 'Society for Indian Institute of Health Management Research' which was established in October 1984 under the Societies Registration Act-1958.

IIHMR-Delhi was setup in 2008 in response to the growing needs of sustainable management and administration solutions critical to the optimal function of healthcare sector both in India and in the Asia-Pacific region.

IIHMR Delhi are a leading institute of higher learning that promotes and conducts research in health and hospital management; lends technical expertise to policy analysis and formulation; develops effective strategies and facilitates efficient implementation; enhances human and institutional capacity to build a competent and responsive healthcare sector. There multi-dimensional approach to capacity building is not limited to academic programs but offers management development programs, knowledge and skills-based training courses, seminars/webinars, workshops, and research studies.

There four core activities are…

- Academic courses at masters and doctoral level in health and hospital management to meet the growing need of skilled healthcare professionals.
- Research that has high relevance to health policies and programs at national and global level.
- Continued education through management development programs and executive programs for working professionals to help them upgrade their knowledge and skills in response to the emerging needs of the industry.
- Technical consultation to the national and state-level flagship programs to address the gaps in planning as well as implementation.

Mission

IIHMR Delhi is an institution dedicated to the improvement in standards of health through better management of health care and related programs. It seeks to accomplish this through management research, training, consultation and institutional networking in a national and global perspective.

Vision

IIHMR is a premier institute in health management education, training, research, program management and consulting in the health care sector globally. The Institute is known as a learning organization with its core values as quality, accountability, trust, transparency, sharing knowledge and information. The Institute aims to contribute to social equity and development through its commitment to support programs aiming at poor and the deprived population.

Understanding Barriers and Different Approaches to Intervene Quality of Home-Based Neonatal Care: A Rapid Review

BACKGROUND:

Exposure to air pollution as a risk factor for anemia around the world: a scoping review

Key words: Anemia, air pollution, Pm2.5, Iron deficiency, Global Burden, Health programs.

Background:

Anemia, simply put, refers to a condition where the level of hemoglobin in the blood falls below the average range, resulting in a decreased supply of oxygen to the body's tissues.[1] This serious global public health problem predominantly affects young children and pregnant women. According to the World Health Organization (WHO), approximately 42% of children under 5 years of age and 40% of pregnant women worldwide suffer from anemia, with developing countries shouldering more than 89% of this burden.[2]

The global age-standardized point prevalence and YLD rates for the year 2019 for anemia were 23,176.2 (22,943.5–23,418.6) and 672.4 (447.2–981.5) per 100,000 population, respectively with the highest number of cases found in Zambia, Mali and Burkina Faso.[3] Globally and in most populations, iron deficiency anemia (IDA) causes more than 60% of anemia, although other factors also contribute significantly to its occurrence.4

In most of the countries, the nutritional deficiency is always emphasized as the main cause of anemia, as evident by the number of health programs implemented at the national level that aim to improve

nutritional status and reduce anemia cases.5,6 Despite the efforts, the 2022 Global Nutrition Report showed most of the countries' progress was slow or went worse in terms of anemia prevalence when compared to previous years.7,8 This suggests the possibility of overlooking of other possible risk factors associated with anemia. For instance, reduced iron absorption can occur due to inflammation caused by infections and inflammatory disorders, which elevate circulating hepcidin levels, degrade ferroportin, and impede the transfer of iron from intestinal cells to the plasma.9

Ambient particulate matter (PM 2.5) for its detrimental health effects has been linked to cause of many health issues.10 Studies have also suggested a potential link between long-term PM2.5 exposure and an increased risk of developing anaemia.11 The mechanisms by which PM2.5 may contribute to anemia are not fully understood, but it is thought that the particles may directly damage red blood cells and interfere with their ability to transport oxygen. PM2.5 may also cause inflammation and oxidative stress, which can lead to the destruction of red blood cells.12,13 To better comprehend and address the global burden of anemia, it is imperative to conduct a comprehensive scoping review of studies exploring the association between anemia and ambient air pollutants on a global scale. Such a study will provide valuable insights into the interplay between anemia and ambient air pollution, contributing to the development of targeted interventions and strategies aimed at reducing the prevalence of anemia worldwide.

This scoping review aims to identify and evaluate studies that shows association of anemia with ambient air pollutant on a global context.

Need of this study:

Global anemia status has not been up to mark even after years of attempt to improve it. Hence this study emphasises on the need to look at factors other than nutrient deficiency as a cause of anemia so that wider and holistic approaches could be taken to reduce it.

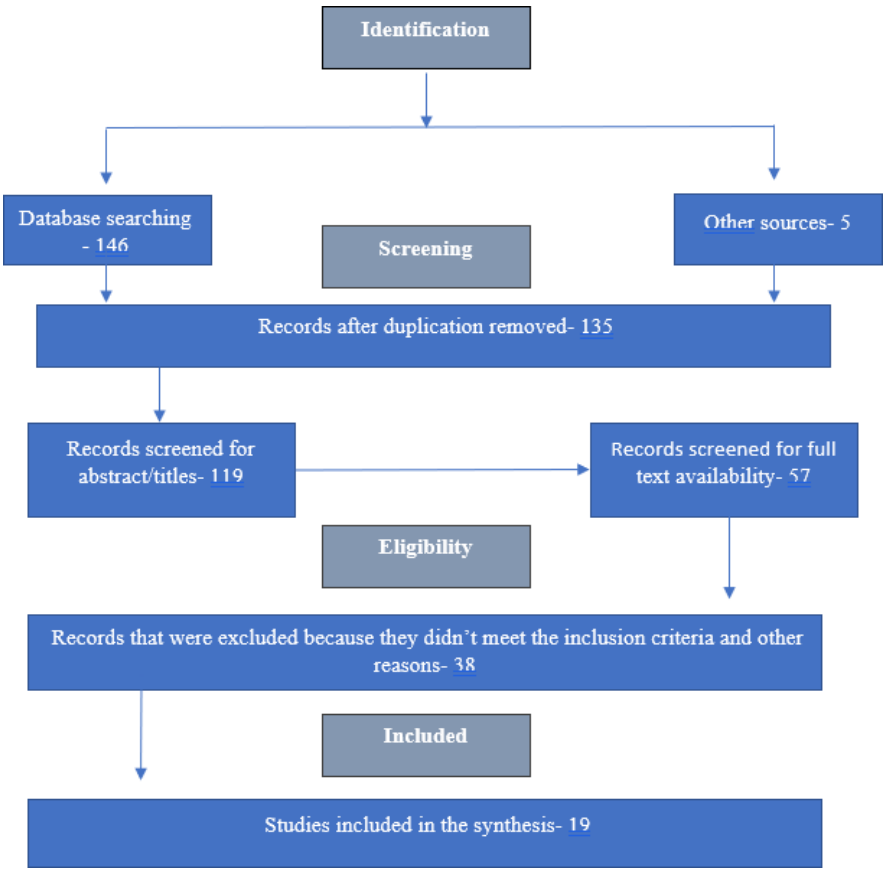
Aim and Objectives:

This review targets at finding articles that have analysed relationship between air pollution and anemia around the world.

Methodology:

Study type: Scoping Review.

Selection criteria: The scoping review have adopted the 4 steps by PRISMA statement described below:



Inclusion criteria: Studies done globally, that shows an association of air pollution with anemia and performed regression analysis to confirm the relationship.

Study population: Studies based on all the countries, which addressed association of air pollution with anemia.

Information sources: The literature screening process relied on keywords and subject headings to select relevant materials. Several databases and sources were utilized, including PUBMED, ProQuest, OPAC, Google Scholar, CORE, and Research Gate, using the specified search terms. Additionally, we examined the reference lists of the identified documents to uncover potential relevant papers. To maintain consistency, only articles written in English and published between 1st January 1990 and 1st January 2023 were considered for inclusion.

Search Strategy: Appropriate MESH terms were used. The search terms which were applied are as follows: Anemia, Hematologic Disease, Iron Deficiency, Sickle Cell, Air Pollutions, Air Quality, Particulate Matter, Global Burdens of Disease, Adult, Women, Pregnant Women, Preschool Child. These are the various terms that were searched using appropriate Boolean connectors (AND/OR) for example Anemia AND Air Pollution. We applied year of publication filter to 1 Jan 1990 till 1 Jan 2023.

Selection process: We first screened all the selected literatures title and abstract according to the eligibility criteria. A full text report screening was conducted and checked for cross references.

Data Management: To conduct this review, the reviewer extracted data from the selected studies into a Microsoft Excel spreadsheet to get further insights (Annexure 1)

Result:

The Study Profiles:

A total of 151 studies (publications) were extracted from the electronic databases (Pubmed = 134, Research Gate = 4 and ProQuest = 7) and another 5 studies from other resources and relevant studies

were added from checking the references of the included studies (using adjusted search terms to accommodate the length required for search terms). Ater removal of studies due to various factors explained above in the flow chart, 19 studies were finally included for this study. Exclusion reason were as follows:

1. Studies did not align with the research's objective.
2. Studies that included occupational exposure as one of the key factor leading to Anemia
3. Full text not available.

Full-text scrutiny was done for the selected 19 articles to answer the scoping review question.

Classification of the Risk Factors and outcome:

Indoor Pollutant: Out of the 19 relevant studies were included for analysis, 8 specifically investigated the relationship between indoor pollutants and anemia status. The focus of these studies centered around the impact of biomass fuel versus clean fuel usage, effect of passive smoking and particulate matter (PM 2.5 and PM 10) on anemia status. Biomass fuel sources such as wood, straw, animal dung, crop residue (High exposure group), kerosene, coal (medium exposure group) and electricity, liquid petroleum gas, biogas (low exposure group/cleaner fuels) were considered in the analysis.

Outcome: Among the eight studies reviewed, seven demonstrated a positive association between indoor air pollutants and anemia or a decrease in haemoglobin status. Only one study reported no significant effect. [14, 15, 16, 17, 18, 19, 20, 21] The calculated odds ratios for all the studies were greater than 1, indicating a positive correlation between indoor air pollutant exposure and adverse haematological outcomes. The majority of the studies investigated the impact of biomass fuel exposure on haemoglobin status and

indicated that the high and medium exposure groups experienced significantly greater effects compared to those using cleaner fuels.

Outdoor Pollutant: Outdoor air pollutant: 10 of the studies were on the effect of outdoor air pollutant on status of anemia. The matter of interest were PM1, PM2.5, PM10, NO2, SO2 and CO. The main component of interest was PM2.5 and its component (BC, NH4+, NO3−, OM, SO42−, and Dust). [, 23, 24, 25, 26, 27, 28, 29, 30, 31]

Outcome: All the included studies consistently demonstrated a positive relationship between outdoor air pollutants, particularly PM2.5, and the status of anemia. Based on the findings, for every 10µg/m3 rise in PM2.5 concentration, the observed range of decrease in haemoglobin levels was between 0.07 and 2.07 gm/dl. Furthermore, the studies indicated that among the various species of PM2.5, sulfate and black carbon showed stronger associations with anemia compared to organics and dust.

Indoor vs Outdoor pollutant: Due to variations in the methods of analysis and outcome measures employed in each study, a direct comparison between the effects of indoor and outdoor pollutants is challenging. However, it is worth noting that one study included in the analysis did provide a direct comparison between the impacts of indoor and outdoor pollutants. The study included a comparative analysis of Outdoor (PM 2.5) and indoor (Carbon monoxide) effect on anemia. The findings indicated that in children during in-utero and post-utero stage, a rise of **10 µg/m3** overall PM 2.5 exposures (Outdoor exposure) corresponded to a 4% to 5% rise whereas a 10 ppbv increase in cumulative carbon monoxide (Indoor exposure) exposures was associated with a 1% rise in anemia prevalence respectively. These results suggest that outdoor pollutants have a more pronounced impact on the occurrence of anemia. (1 ppb = **1.15 µg/m^3).**[32]

Classification of participants and outcome:

Women: Among the studies encompassed in the analysis, a total of nine specifically concentrated on the female population.[14, 15, 16, 18, 19, 24, 26, 28, 31] These studies explored the influence of both outdoor and indoor pollutants as potential exposure factors. The age range of the participants varied between 15 and 50 years, incorporating expecting mothers, non-pregnant women, and those of reproductive age. Nearly all of the studies revealed a positive correlation between the exposure factors under investigation and the prevalence of anemia, with the exception of one study where no significant effect was observed.[19] The investigations encompassed both indoor and outdoor exposure factors, with a predominant focus on expecting mothers and women of reproductive age. Notably, the third trimester of pregnancy emerged as a significant risk factor in the analysed studies.

Children: Seven studies specifically targeted children aged five years and younger. These studies examined the impact of both outdoor and indoor pollutants, including the influence of parental passive smoking. The findings consistently indicated a positive correlation between these factors and the occurrence of anemia among children. Notably, passive smoking in parents exhibited a particularly strong association with anemia in young children, with an odds ratio of 2.99 and a p-value of less than 0.01.[17, 20, 21, 25, 29, 30, 32]

Older Adults: Two studies specifically examined the correlation between outdoor pollutants and the occurance of anemia in individuals aged 50 years and above. Both studies demonstrated a positive relationship between outdoor pollutant exposure and anemia status in this population. However, no study were found to analyse association between indoor pollutants and anemia among older adults. [22, 23]

Men: A single study was identified in the available literature. The study focused on men ranging in age from 21 to 81 years. Specifically, the study examined the impact of outdoor pollutant- PRβ radioactive

beta particle associated with PM2.5 on anemia status. The findings of this study revealed a positive association between PRβ and the variable under investigation. [27]

Discussion:

The present study aimed to explore the existing literature on the association between exposure to air pollution and the risk of anemia worldwide. Through a comprehensive search and screening process, a total of 19 studies were included in the review, providing valuable insights into this important research area.

As mentioned above, In most of the countries, the nutritional deficiency is always emphasized as the main cause of anemia, as evident by the number of health programs implemented at the national level that aim to improve nutritional status and reduce anemia cases.[5,6] Despite the efforts, the 2022 Global Nutrition Report showed most of the countries' progress was slow or went worse in terms of anemia prevalence when compared to previous years.[7,8] This suggests the possibility of overlooking of other possible risk factors associated with anemia. For instance, reduced iron absorption can occur due to inflammation caused by infections and inflammatory disorders, which elevate circulating hepcidin levels, degrade ferroportin, and impede the transfer of iron from intestinal cells to the plasma.[9]

The findings of this scoping review indicate that there is a growing body of evidence suggesting a potential link between air pollution and anemia. Several studies have suggested associations between exposure to particulate matter (PM) and alterations in hemoglobin levels, as well as an increased risk of anemia. These associations were observed in various populations, including pregnant women, children, and adults. Such evidence supports the hypothesis that air pollution may act as a possible factor for the development or exacerbation of anemia. Apart from the studies that were included, Numerous reports have documented the association between occupational exposure to air pollutants, specifically benzene, and the development of anemia, particularly aplastic anemia.

However, it is crucial to interpret these findings in light of the limitations identified within the included studies. The limitations outlined in this review highlight important areas for future research and considerations when interpreting the results. For instance, one common limitation is the challenge of establishing a temporal relationship between exposure to air pollution and the development of anemia. Many studies relied on cross-sectional designs, limiting the ability to determine causality or establish the direction of the association. Future prospective studies or interventions that can better elucidate the temporal sequence of exposure and outcome are needed.

Exposure misclassification emerged as another significant limitation. Limited information on individuals' activity patterns and specific components of PM that contribute to the observed results may lead to exposure misclassification and potentially impact the accuracy of the findings. This emphasizes the need for more detailed and accurate exposure assessments, including variations in fuel types, duration of exposure, and indoor air pollution factors such as cooking habits and household devices.

The role of confounding factors and unmeasured characteristics should also be considered. Some studies attempted to address this by controlling for certain factors such as genetic background, cultural dietary differences, or socioeconomic status. However, the presence of residual confounding cannot be completely ruled out, and the effects of other unmeasured confounders may still influence the observed associations. Future studies should strive to incorporate a comprehensive set of confounders and potential effect modifiers to obtain a more accurate estimation of the air pollution-anemia relationship.

The spatial and temporal resolution of the data used in the included studies was another limitation. The use of large geographic regions and country-specific data from different years may not adequately capture regional variations in anemia prevalence or reflect the current burden of anemia in some countries. It is essential to improve the spatial resolution of environmental data and ensure the inclusion of up-to-date, representative information to enhance the generalizability of the findings.

The scoping review also identified gaps in the existing literature. For instance, there is a requirement for studies that explore the dose-response relationship between air pollution and anemia. Most of the included studies focused on the presence or absence of an association, but the precise dose or threshold at which air pollution becomes a significant risk factor remains unclear. Future research should aim to elucidate the exposure-response relationship, which can provide more precise estimates of the magnitude of the association.

Furthermore, the mechanisms underlying the association between air pollution and anemia require further investigation. The reviewed studies often relied on hemoglobin levels as a primary outcome measure, but the specific types of anemia were not consistently distinguished. Future studies should consider differentiating between types of anemia and explore potential mechanistic pathways through which air pollution may affect hematologic physiology.

Conclusion:

Despite the limitations and gaps identified, this scoping review highlights the importance of recognizing air pollution as a vulnerable factor for occurrence of anemia. The evidence gathered from various populations and settings suggests a consistent association, albeit with some variations in study design, exposure assessment, and confounder adjustment. These findings emphasize the imperative for focused interventions and policy measures designed to mitigate air pollution, which, in addition to its association with other significant health issues, can also contribute to the development of anemia.

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Annexure 1:

Sl No	References	Study design	Location	Period of study	Population	Age	Exposure measured	Results	Exposure - Effect	Limitations	Categories
	Ambient Air Pollution Exposure Association with Anaemia Prevalence and Haemoglobin Levels in Chinese Older Adults	Cross-sectional	China	2007 to 2010	Older Adults	50 Years and above	Outdoor Air Pollutant (PM1, PM2.5, PM10 and NO 2)	Positive	Each PM10, PM2.5, PM1 and NO2 IQR increase corresponded to −0.53 (95% CI: −0.67, −0.38), 0.52 (95% CI: −0.67, −0.38), 0.55 (95% CI: −0.69, −0.41) and 1.71 (95% CI: −1.95, −1.57) mg/dL decrements in haemoglobin levels, respectively.	The study faced challenges in establishing a temporal relationship between exposure and outcomes. Exposure misclassification was likely due to limited information on respondents' activity patterns. The study couldn't separate specific components of PM that might contribute to the results. Important risk factors like genetic background and cultural dietary differences were not considered, but the study attempted to address this by controlling for the community in multilevel models.	Older Adults, 50 Years and above, Outdoor Air Pollutant (PM1, PM2.5, PM10 and NO 2),
	The link between indoor air pollution from cooking fuels and anemia status among non-pregnant women of reproductive age in Ethiopia	Cross Sectional on secondary data	Ethiopia	2016	Non Pregnant Women	Not Specified	Indoor Air Pollutant- biomass fuels (wood, straw, animal dung, and crop residues) and clean fuels (electricity, LPG, and natural gas) and clean fuel	Positive	Non-pregnant women of reproductive age living in households that utilize biomass fuel for cooking were found to have a Blood hemoglobin level of 5.8 g/dL lower than those women who reside in households with clean fuels such as electricity.	The analysis did not consider variations in fuel type, duration of exposure to indoor air pollution, and feeding habits. Factors such as the use of improved biomass cook stoves and presence of chimneys in households can influence pollution exposure and affect the results. However, due to the absence of this information in the datasets, their effects were not assessed, which the researchers identify as a major limitation of the study. Therefore, caution is advised when interpreting the results.	Non Pregnant Women, Indoor Air Pollutant- Biomass fuels (wood, straw, animal dung, and crop residues) and clean fuels (electricity, LPG, and natural gas) and clean fuel
	Risk of anaemia among women engaged in Biomass-based fish smoking as their primary livelihood in the central region of Ghana: a comparative cross-sectional study	Comparative cross-sectional study	Ghana	Not Specified	Women	18-49 Years old	Indoor Pollution (fish smoking involving the Burning Biomass fuel or Other livelihoods)	Positive	After covariates adjustment, the FSL (fish smoking) women had statistically higher anaemia prevalence (36.4% vs. 20.9%; p = 0.032) and 80% greater risk of being anemic (RR: 1.8, 95% CI: 1.1, 3.0) than the OL (other livelihoods) women	Smoke exposure was not directly measured and so we cannot be truly certain whether the association observed was due to smoke exposure per se or other unmeasured characteristics that the women had.	Women, 18-49 Years old, Indoor Pollution (Fish smoking involving the Burning Biomass fuel or Other livelihoods)
	Anemia prevalence and hemoglobin levels are associated with long-term exposure to air pollution in an older population	Longitudinal study	America	2005-2011	Older Population	58-84 Years	Outdoor (PM2.5) and nitrogen dioxide (NO 2)	Positive	An inter-quartile range (IQR: 39 μg/m3) increase in the one-year moving average PM2.5 was positively associated with anemia prevalence (prevalence ratio, or PR: 1.33, 95% CI: 1.23, 1.45) and decreases in average hemoglobin of 0.81 g/dL ($p < 0.001$). Similarly, an IQR (9.6 ppb) increase in NO2 was associated with anemia prevalence (PR: 1.43, 95% CI: 1.25, 1.65) and a decrease in average hemoglobin of 0.84 g/dL ($p < 0.001$).	The study lacked data to distinguish between types of anemia, limiting analysis. The translation of short-term changes in hemoglobin or red blood cell counts to long-term effects is unclear. Short-term and long-term pollutant exposures may impact hematologic physiology differently, especially in different age groups. Older adults might experience different effects compared to younger individuals.	Older Population, 58-84 Years, Outdoor (PM2.5) and nitrogen dioxide (NO 2)
	Is Indoor Air Pollution From Different Fuel Types Associated With the Anemia Status of Pregnant Women in Ethiopia?	Cross Sectional	Ethiopia	2016	Pregnant Women	15-49 Years	Indoor- high pollution fuels (wood, straw, animal dung, and crop residues), medium polluting fuel types (kerosene and charcoal), and low pollution fuels (electricity, liquid petroleum gas, and natural gas)	Positive	The proportion of anemia in the low, medium, and high polluting fuel type users was 13.8%, 46%, 40.9% respectively. In the multivariable logistic regression analysis, the use of either kerosene or charcoal fuel types (AOR 4.6; 95% CI: 1.41–18.16) and being in the third trimester (AOR 1.72; 95% CI: 1.12–2.64) were significant factors associated with the anemia status of the pregnant women in Ethiopia	The data regarding the pregnant women's exposure to a single or multiple pollutants, continuous or one time, the presence of other additional exposure other than the polluting fuel such as presence or absence of atmospheric pollution are not included in this study. The use of improved cookstove and the ventilation status of the cooking environment are other factors that are not included but have the potential to alter the outcome of the study variable at hand.	Pregnant Women, 15-49 Years, Indoor- high pollution fuels (wood, straw, animal dung, and crop residues), medium polluting fuel types (kerosene and charcoal), and low pollution fuels (electricity, liquid petroleum gas, and natural gas)
	Effects of PM2.5 and its constituents on hemoglobin during the third trimester in pregnant women	Retrospective cohort study	China	2015-2018	Pregnant Women	20-45 Years	Outdoor (PM2.5), BC, NH4+, NO3−, OM, SO42−, and Dust	Positive	Per IQR increase (μg/m3) of PM2.5, BC, NO3−, and OM linked to − 0.75 (− 1.50, − 0.01), − 0.95 (− 1.45, − 0.04), − 0.79 (− 1.56, − 0.03), and − 0.73 (− 1.44, − 0.03) g/L decrease of Hb during the third trimester in multiparous pregnant women, but not for NH4+, SO42−, Dust, and primiparous pregnant women	The retrospective cohort study had limitations in capturing indoor pollution factors like household energy, cooking habits, and devices. While adjusting for regional-level GDP and population density accounted for socioeconomic status to some extent, the influence of family income remained relevant. Despite including gestational weight gain as a measure of nutritional state, dietary patterns and nutrient supplements were crucial confounders in assessing the associations between PM2.5, its constituents, and Hb levels and anemia.	Pregnant Women, 20-45 Years, Outdoor (PM2.5), BC, NH4+, NO3−, OM, SO42−, and Dust
	The Association Between Ambient PM2.5 Exposure and Anemia Outcome Among Children Under Five Years of Age in India	Cross Sectional study	India	Not Specified	Children	6 - 59 months	Outdoor (PM2.5)	Positive	For every 10 μg m-3 increase in ambient PM2.5 exposure, average anemia prevalence increased by 1.90% (95% CI = 1.43, 2.36) and average hemoglobin decreased by 0.07 g/dL (95% CI = 0.09, 0.05). At the individual level, for every 10 μg m-3 increase in ambient PM2.5 exposure, average hemoglobin decreased by 0.14 g/dL (95% CI = 0.12, 0.16.	In this study, assumptions were made about children staying in their district of birth for exposure assignment. Missing information on daily talk in the dataset was assumed to have minimal bias on the results. The cross-sectional design limited causal inferences and the study couldn't account for in-utero PM2.5 exposure, which may affect fetal growth and hematological development.	Children, 6 - 59 months, Outdoor (PM2.5)
	Prenatal Exposure to Air Pollution and Pre-Labor Rupture of Membranes in a Prospective Cohort Study: The Role of Maternal Hemoglobin and Iron Supplementation	Prospective Cohort Study	China	2015-2021	Pregnant Women	Not Specified	Outdoor (PM2.5, PM 10, SO 2 and CO)	Positive	Every 10-μg/m3 increase in PM2.5 and PM10, 5-μg/m3 increase in SO2, and 0.1-mg/m3 increase in CO was associated with low maternal hemoglobin levels [−0.96 g/L (95% confidence interval (CI): −1.15, −0.73), −1.31 g/L (95% CI −1.55, −1.07), −2.86 g/L (95% CI −3.22, −2.61), and −1.12 g/L (95% CI −1.31, −0.92), respectively] in the third trimester.	The study had limitations: it did not consider indoor air pollution factors, the study design was observational rather than a randomized controlled trial, and confounding factors and uncontrolled risks could introduce bias. It may have overestimated the impact of air pollution due to cumulative effects before conception, and biased exposure estimates could arise from limited address change information and reliance on nearest air quality monitors.	Pregnant Women, Not Specified, Outdoor (PM2.5, PM 10, SO 2 and CO)
	Early-life environmental exposures and anaemia among children under age five in Sub-Saharan Africa: An insight from the Demographic & Health Survey	Cross sectional	Sub Saharan Africa	Not Specified	Children	6 - 59 months	Outdoor (PM 2.5) and Indoor (Carbon monoxide)	Positive	A 10 μg/m−3 increase in in-utero, post-utero and cumulative PM 2.5 exposure was associated with 4% to 5% increase in the prevalence of anaemia among children. A 10ppbv increase in in-utero, post-utero and cumulative carbon monoxide exposure was associated with 1% increase in the prevalence of anaemia among children.	The study has limitations regarding the scale of analysis and spatial resolution. The use of large geographic regions may not capture regional variations in anaemia prevalence. The environmental data used has a limited spatial resolution. Additionally, the country-specific data used in the study come from different years, potentially not reflecting the current burden of anaemia in some countries. These limitations affect the accuracy and representativeness of the findings.	Children, 6 - 59 months, Outdoor (PM 2.5) and Indoor (Carbon monoxide)
1.	Does biofuel smoke contribute to anaemia and stunting in early childhood?	Cross Sectional	India	Not Specified	Children	6 - 35 months	Indoor- (high exposure group (only biofuels: wood, crop residues, or dung cakes), low exposure group (only cleaner fuels: electricity, liquid petroleum gas, biogas, or kerosene), and medium exposure group (a mix of biofuels and cleaner fuels or coal/coke/lignite/charcoal).	Positive	The unadjusted relative risk of moderate-to-severe anaemia (relative to no anaemia) is much greater among children in households using only biofuels than among children in households using only cleaner fuels (RRR 5.18; 95% CI: 3.90, 7.52). The unadjusted relative risk of moderate-to-severe anaemia is also significantly greater among children in households using a mix of biofuels and cleaner fuels than among children in households using only cleaner fuels (RRR 5.15; 95% CI: 3.31, 8.58)	The study's estimated effects on anaemia and stunting from biofuel smoke are likely underestimated due to cumulative effects and the shift to cleaner fuels. The survey lacked information on past fuel use and related illnesses, limiting the assessment of these factors.	Children, 6 - 35 months, Indoor- (high exposure group (only biofuels: wood, crop residues, or dung cakes), low exposure group (only cleaner fuels: electricity, liquid petroleum gas, biogas, or kerosene), and medium exposure group (a mix of biofuels and cleaner fuels or coal/coke/lignite/charcoal).
1.	Relationship between Exposure to air pollution and occurance of anemia in pregnancy	Cohort	Serbia	1998-2003	Pregnant Women	Not Specified	Outdoor air pollutants (sulphur dioxide, soot and lead in sediment matters)	Positive	After statistic application of a chi-square test, it was confirmed that there was a significant difference in anemia incidence in pregnant women exposed to higher concentrations of air pollution (12.68% women), when compared to those pregnant women who were exposed to lower concentrations of air pollution (5.88% women)	None	Pregnant Women, Not Specified, Outdoor air pollutants (sulphur dioxide, soot and lead in sediment matters)
1.	Direct and indirect Effects of Indoor Particulate Matter on Blood Indicators Related to Anemia	Cohort Study	Korea	2018–2020	Women (House wives)	20-50 Years	Indoor (PM 10 and PM 2.5)	Positive	The increase in the level of indoor PM2.5 was associated with a decrease in Hb (B: −0.024; SE: 0.011), hematocrit (B: −0.059, SE: 0.033), and MCV (B: −0.081, SE: 0.037) and MCH (B: −0.037, SE: 0.012) in sensor measurements (PM2.5 Lag10).	The sample size was very small and statistical power was limited. This was due to difficulties in recruiting participants, and accurately measuring exposure and outcome variables. The exposure data estimated by the modeling method had a relatively high percentage of missing data because of limitations in the loT sensors. Development of precision PM sensor technology and the continuity of communication connections remain important challenges.	Women (House wives), 20-50 Years, Indoor (PM 10 and PM 2.5)
1.	Is biomass fuel smoke exposure associated with anemia in non-pregnant reproductive-aged women?	Descriptive cross-sectional study	Sri Lanka	2020-2021	non-pregnant, reproductive-aged women	15-49 Years	Indoor pollutants (solid fuel)	No Effect	The study results suggest no impact of solid fuel smoke exposure on anemia among non-pregnant, reproductive-aged women	Firstly, the cross-sectional study design formely at fault for investigating the connection between predictors and outcome variable, not a causal relationship. Secondly, the results were not adjusted for the nutritional status of participants. Additionally, using Drabkin's cyanomethemoglobin method to determine blood hemoglobin concentrations may result in incorrect hemoglobin values, as abnormal plasma proteins and high leukocyte count can cause turbidity in diluted blood.	non-pregnant, reproductive-aged women, 15-49 Years, Indoor pollutants (solid fuel)
1.	A cross-sectional analysis of ambient fine particulate matter (PM2.5) exposure and haemoglobin levels in children aged under 5 years living in 36 countries	Cross sectional	Multi Country	Not Specified	Children	>5 years (6 - 59 months)	Outdoor pollutant (PM 2.5)	Positive	The adjusted model showed that a 10 μg/m3 increase in annual PM2.5 concentration was associated with greater odds of anaemia (OR= 1.098 (95% CI: 1.087, 1.109). The same increase in PM2.5 was associated with a decrease in average Hb levels of 0.075 g/dL (95% CI: 0.081, 0.068)	The study's effect estimate may be attenuated due to measurement errors and the absence of important predictors. The cross-sectional design hindered establishing the temporal sequence of exposure and outcome. While the clinical relevance of Hb level changes is challenging, anemia threshold suggests a significant association. Meta-analysis found no PM2.5-anaemia association, consistent with previous DHS findings, possibly due to limited sample size and residual confounding. Inadequate air monitoring in certain countries could introduce errors in PM2.5 exposure estimates.	Children, >5 years (6 - 59 months), Outdoor pollutant (PM 2.5)
1.	Increased Outdoor PM2.5 Concentration Is Associated with Moderate/Severe Anemia in Children Aged 6–59 Months in Lima, Peru	Longitudinal Study	Peru	2012 to 2016	Children	>5 years (6 - 59 months)	Outdoor pollutant (PM 2.5)	Positive	A slight decrease in hemoglobin (Δ) (β: −0.03, 95% CI: −0.05 to −0.02; SQ β: −0.04, 95% CI: −0.06 to −0.01) and an increase in the probability of moderate/severe anemia (ΔOR: 1.18, 95% CI: 1.10–1.27; SQ OR: 1.18, 95% CI: 1.08–1.29) were observed with increased exposure to PM...	Anemia prevalence rates in the study only reflect the population attended at public health care centres, excluding those in private health care and covered by the Social Health Insurance. The absence of assessment of inflammatory markers, such as CRP and hepcidin levels, limits understanding of the mechanism linking increased PM2.5 exposure and anemia prevalence. Future studies should include these markers to provide a more comprehensive explanation.	Children, >5 years (6 - 59 months), Outdoor pollutant (PM 2.5)
1.	Passive smoking as a risk factor of anemia in young children aged 0-35 months in Jordan	Cross Sectional	Jordan	Not specified	Children	0–35 months	Indoor Pollutant (Passive smoking)	Positive	Results indicated that independent of other risk factors and confounding factors, anemia in young children was strongly positively associated with exposure to passive smoking from both parents (OR: 2.96, p <0.01).	The first potential limitation of the study is its inability to analyze for the dose of passive smoking. The second potential limitation of our study is that it did not account for highly polluting cooking fuels.	Children, 0–35 months, Indoor Pollutant (Passive smoking)
1.	Reducing the burden of anaemia in Indian women of reproductive age with clean-air targets	Cross Sectional	India	Not specified	Women of reproductive age	15 - 49 Years	Outdoor pollutant (PM 2.5)	Positive	For every 10 μg/m−3 increase in ambient PM2.5 exposure, the average anemia prevalence among Indian WRA increases by 7.23% (95% uncertainty interval, 6.82–7.63). Among PM2.5 species, saline and black carbon are more associated with anemia than organics and dust.	None	Women of reproductive age, 15 - 49 Years, Outdoor pollutant (PM 2.5)
1.	Biofuel smoke and child anemia in 29 developing countries: a multilevel analysis	Cross Sectional	Multi Country	Not specified	Children	>5 Years (0 - 59 months)	Indoor (Biofuel)	Positive	Both moderate and high exposure to biofuel smoke at the country level are associated with moderate/severe anemia (odds ratio [OR], 2.36; 95% confidence interval [95% CI], 1.28–4.36 vs OR, 2.80; 95% CI, 1.37–5.72) after adjusting for covariates. Exposure to biofuel smoke at home is associated with mild anemia (OR, 1.07; 95% CI, 1.01–1.13), and there are interactions between biofuel smoke exposure and child age in months on mild anemia (OR, 1.004; 95% CI, 1.002–1.006) and moderate/severe anemia (OR, 1.006; 95% CI, 1.004–1.008). There are also interactions between biofuel smoke exposure at home and diarrhea on mild anemia (OR, 1.22; 95% CI, 1.10–1.34) and on moderate/severe anemia (OR, 1.11; 95% CI, 1.01–1.22), and fever on moderate/severe anemia (OR, 1.33; 95% CI, 1.22–1.45).	Not Specified	Children, >5 Years (0 - 59 months), Indoor (Biofuel)
1.	Association between ambient beta particle radioactivity and lower hemoglobin concentrations in a cohort of elderly men	Cohort	Boston, MA	1981–2017	Elder Men	21 - 81	Outdoor pollutant - PRB radioactive beta particle associated with PM2.5	Positive	An IQR of 0.83 × 10−4 Bq/m3 of ambient PRB was associated with a 0.12 g/dL decrease in hemoglobin concentration (95% CI: −0.18 to −0.05). The effects of PRB were similar when the models were adjusted for ambient BC or PM2.5. Per IQR of ambient PRB over 28 days, there was a 0.14 (95% CI: −0.21 to −0.07) g/dL decrease in hemoglobin concentration adjusted for PM2.5 and 0.12 decrease (95% CI: −0.18 to −0.05) g/dL adjusted for BC	The daily PRB data were estimated from the original EPA RadNet data collected over 5 to 7 days. We could not calculate the total amount of environmental radiation exposure from PM (including alpha, beta and gamma), although PRB is also considered a surrogate for alpha-emitting radionuclides which are more toxic	Elder Men, 21 - 81, Outdoor pollutant - PRB radioactive beta particle associated with PM2.5

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