Brick Kilns, Anemia & Residential Proximity: Evidence from Bihar

Parul Jain[1] & Sangeeta Bansal[2]

Abstract

Anemia is one of the major health issues in India. Exposure to ambient air pollution (particularly PM2.5) is considered a potential factor for anemia. The present paper examines the impact of pollution emitted during the firing of brick kilns on the anemic status of women and men in the state of Bihar, India. We geocoded the health data from National Family and Health Survey (2015–2016) with the spatial locations of brick kilns and determined the residential proximity to the nearest kiln for each individual. Using the Probit regression framework and using a host of control variables, we find that individuals living within 15km of an operational brick kiln have a 4% more chance of becoming anemic compared to those living with no brick kiln in their area. The likelihood of becoming anemic gets attenuated with the increase in distance from the kilns. The findings of this paper throw light on one of the possible reasons for high rates of anemia among men and women across the districts of Bihar.

Key Words: Anemia, Brick Kilns, Air Pollution, Women, Residential Proximity

JEL Codes: I15, O12, Q32, Q53

Declarations of interest: none

[1] Centre for International Trade & Development, Jawaharlal Nehru University, New Delhi, India
[2] Centre for International Trade & Development, Jawaharlal Nehru University, New Delhi, India

[PRELIMINARY DRAFT]

I. Introduction

Anemia is the most prevalent health issue in the world today. As per the WHO estimates (2015 Report), about two billion people are anemic in the world with almost half of the cases are due to iron deficiency. Anemia is characterized by low hemoglobin concentration in blood which results in reduced oxygen-carrying capacity of the blood (Nielssen, 2007). Anemia is commonly found in the population groups consuming diet which is low in iron density, animal proteins, and high in whole wheat or rice (Zijp et al., 2000). Given the evidence of consumption of this type of diet is quite common among the Indian households (ICMR, 2020; Benoist et.al, 2008), the burden of anemia is largely attributed to iron deficiency. As per the National Family and Health Survey 2015–2016 (NFHS-4), in India around 53.1% women and 23.1% men under 15-49 years of age were anemic[3]. These staggering figures have important health and economic consequences for the country.

Iron deficiency anemia (IDA) in adults has been associated with fatigue (Haas & Brownlie, 2001), cognitive decline (Peters et al., 2008) and low productivity (Lozoff et al., 2006; Penninx et al., 2004). In the case of the pregnant women, anemia can result in low-birth weight, miscarriage and even child mortality (Stoltzfus, 2001). In some cases, anemia among adults has been linked with onset of chronic diseases like heart or kidney ailments (Nurko, 2006).

There are various factors that can cause anemia which includes nutritional deficiency (particularly iron), hemoglobin disorders and acute and chronic infections (WHO, 2017). Anemia can arise due to iron deficiency (IDA) or through chronic systematic inflammation (Morales et.al, 2019). Inflammatory anemia (IA) is considered as one of the leading cause of anemia across the world after IDA, however the two are not mutually exclusive (Weiss et.al, 2019). In less developed countries, IA is particularly related to infectious diseases (Wirth et.al, 2018), but evidence also

[3] The NFHS categorizes men and women to be anemic if their hemoglobin levels are less than 11g/dl and 12g/dl respectively.

suggests that chronic kidney and pulmonary disease and obesity can also induce inflammation (Weiss et.al, 2019, Flynn et.al, 2018).

However, recent studies (Honda et.al; 2017, Seaton et al., 1999, Stankovic et al., 2006, Morales et al., 2019) and medical literature (Nikolic et al., 2008; Elbarbary et al., 2019) have shown that exposure to ambient PM2.5 concentrations can potentially cause IA. Exposure to the air pollutants increases the hepcidin levels, the main regulator of iron absorption and its distribution in the body. The increased level of hepcidin causes iron restriction in the system and eventually leads to inflammatory anemia (Nemeth & Ganz, 2009). Both short-term and long-term exposure also causes oxidative stress-dependent inflammation in the lungs which further aggravates anemia (Yang et.al, 2018, Honda et.al, 2017). Long term exposure to PM2.5 abridges the iron absorption capacity of the human body and aggravates the impact of nutrient deficiency thereby increasing the likelihood of anemia (Weiss et.al, 2005).

The recent study by Honda et.al (2017) has shown association between anemia and exposure to ambient air pollution in adult population through a C-reactive protein agent which leads to inflammation. The results of the study has shown moderate/severe anemia among adults related to air pollution. Majority of the studies (Honda et.al,2017; Seaton et.al, 1999; Ha et.al, 2015; & Mehta et.al, 2021) focusing on exposure to air pollution and anemia outcomes have been undertaken in Europe, China, United States and most recently India also have observed strong association between increased prevalence of anemia among children and exposure to particulate matter (PM). Few studies have observed strong association between biofuel smoke and anemia among pregnant women and children. Mishra et.al (2007) study in 29 countries revealed that children living in households using biofuels were more likely to have moderate and severe anemia (Odds ratio 2.36). In Nagpur, Page et.al (2015) found prevalence of mild to severe anemia among pregnant women due to exposure to biomass smoke. For the case of India, the association between stationary source of PM2.5 and anemia among the varied age groups have not been examined yet (except Datt[4] et.al, 2021). More specifically, the health impact of brick kiln emission on human health is under-researched, which needs immediate attention.

[4] Their paper explores the impact of coal based thermal power plant on the anemic status of children and women in India.

The brick kilns are responsible for emitting harmful pollutants such as particulate matter (PM2.5 and PM10), BC, SO2 etc. These pollutants are deleterious to human health and are associated with cardiovascular and respiratory issues such as bronchitis, asthma, and emphysema (Eri et.al, 2020). According to Report No.21 by Health Effects Institute[5] (2018), about 24,100 deaths were attributed to brick production in India, with rural areas have larger share (18,100 deaths) in comparison with urban areas (5,900 deaths). As per the Eri et.al (2020) estimations, 13.6 billion cases of acute respiratory infection in children, 70,000 cases[6] of chronic bronchitis among adults have been attributed particulate matter emitted during brick production in India. Apart from that, the operation of these kilns are responsible for 460 million restricted activity days[7] in the country, thereby generating huge economic loss. The authors also estimated the economic cost of the negative health points associated with brick production for India, which was about US$ 2.1 billion (as per 2015 $ estimates). Given these estimates, there is an urgent need to address the negative externalities associated with the operation of the brick kilns.

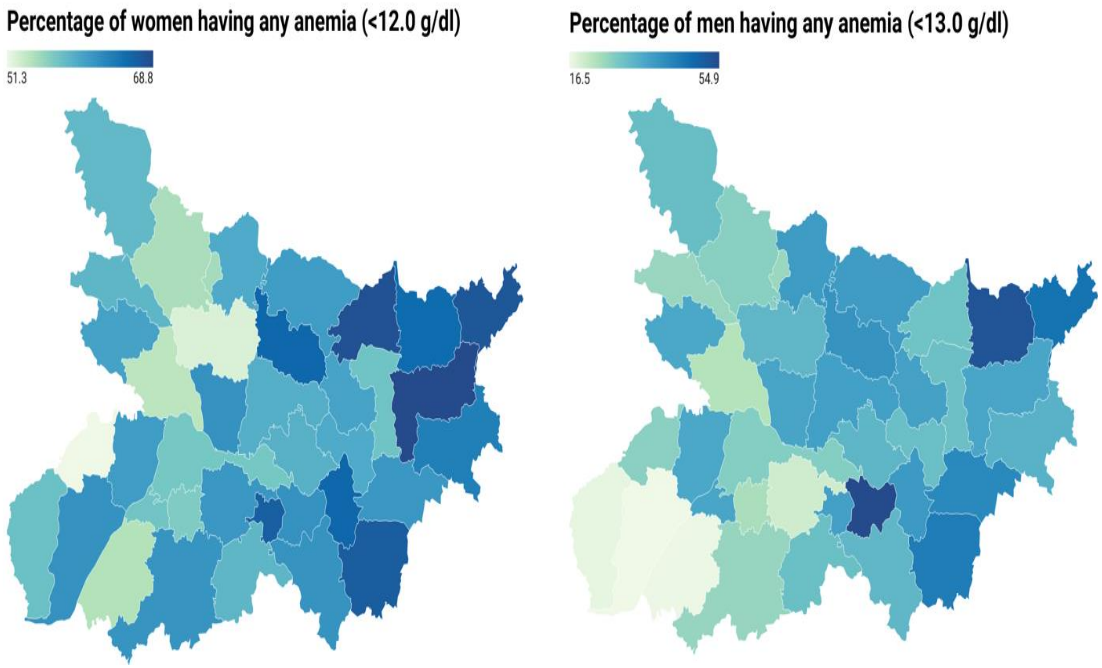
Bihar is the second largest producer of bricks in the country after Uttar Pradesh, which provides us an opportunity to investigate the association between emissions from kiln and adverse health outcomes. From the available database on brick kilns, the majority of kilns are located in the rural areas than urban areas. The findings of the previous paper has shown that large proportion of the population resides near these kilns, hence the impact of smoke emitted from these kilns on health needs to be studied further.

As per the India reports of the NFHS survey 2015-16, anemia is a serious health issue among men and women across the Bihar state. Around 60 % of women and 32 % men are anemic, which is higher than the national average. Women and men residing in the rural areas of the Bihar districts are more likely to be anemic than their urban counterparts. The prevalence of anemia varies across Bihar districts. From Fig.1, the districts bordering Nepal and West Bengal (Kaimur, Gaya, Rohtas, West Champaran, and Siwan) has higher concentration of anemia among women. The districts of Darbhanga, Kishanganj, Purnea, Banka, Sitamarhi, Sheikhpura and Supaul have prevalence rate

[5] REPO, S. (2018). Burden of disease attributable to major air pollution sources in India.
[6] Th ese are all excess cases.
[7] A restricted activity day, is defined as a day in which an individual spends over half of the day in bed, home from work or school, or cutting down on usual activities because of illness or injury.

above 65 % among women. Whereas, in the case of men the rates are more than 40% in the districts of Araria, Banka, Bhagalpur and Kishanganj (Fig.2).

Figure 1: Prevalence of anemia among men and women in Bihar



Source: The map has been drawn using the NFHS-4 data by the author. Hemoglobin levels of both men and women in the age-group of the 15-49 years have been reported. Women includes both pregnant and non-pregnant women.

In this paper, we will investigate the impact of air pollution emitted from brick kilns on the anemic status of men and women under 15-49 years age group across the districts of Bihar. The paper will offer an insight as how people living in close proximity to these kilns have a higher risk of being anemic than those living far away. We hypothesized that operation of kilns near the residence is associated with decreased levels of HBA levels and increased odds of becoming anemic among men and women after adjusting for the covariates.

This paper will add to the growing literature on the impact of air pollution on human health. Although the negative externalities associated with air pollution is a well-researched topic (Currie and Neidell, 2005; Chay and Greenstone, 2003; Gupta and Spears, 2017; Greenstone and Hanna, 2014; Singh et.al, 2021), but very few have focused on the exposure from stationary sources such as coal based thermal power plant or brick kilns. More specifically, the health impacts associated with smoke emitted from brick kilns focused on the occupational health of the workers in these kilns (Blackman et.al, 2000; Skinder et.al, 2011; Khan & Vyas, 2008; Bandyopadhyay & Sen, 2016; Vaidya et.al, 2015). These studies have found that those working in these kilns tend to have higher chances of developing acute respiratory infection, musculoskeletal disorders, body-ache, and problems with vision, cough and breathlessness. However, we did not find any relevant study looking at the impact of the operation of brick kilns on the population residing in close vicinity to these kilns. Instead of focusing on the standard health outcomes such as morbidity or mortality, we have look into how living near the brick kilns increases the likelihood of anemia among men and women. However, to the best of our knowledge, ours is the first study to look into the association between anemia and operation of kilns for the local population in Bihar state by using the econometric tools. More specifically, this paper will address the gap in the literature the factors responsible for high prevalence of anemia among men and women.

The rest of the paper is organized as follows. Section II discuss the theoretical background of the health outcome. Section III provides the information on data used for analysis. Section IV gives a preview of the estimation framework. Section V presents the results followed by specification analysis in Section VI. Section VII concludes the paper.

II. Theoretical Framework

The prevalence of anemia in an individual is determined by various factors such as nutritional and non-nutritional such as social, environmental and biological factors (Lean et al., 2009). For an individual biological factors such as body mass, history of chronic ailment and consumption intake of the nutritious diet are strong factors that plays an important role in increasing the likelihood of anemia (WHO, 2020). The socio-economic factors like residence, wealth status, education also affects the anemia (Thankachan et al., 2007; Chandrakumari et al., 2019). In our analysis all these variable have been taken into consideration. For assessing the impact of air pollution on the anemia status, we have used proximity from brick kiln as an indicator for the source of pollutant. As discussed in the previous section, population living near the brick kilns increases their risk of having negative health points.

We now define the dependent variable used in the analysis. The main health outcome variable is the anemic status of an individual. We measure the health outcome variable using two alternative indicators – anemic status and hemoglobin levels (HBA) measured in g/dl (ordinal measure). For the first measure, we use the anemic status[8] as the outcome variable which takes value 1 if an individual is anemic and 0 otherwise.

For the second measure, we assign ordinal values to the HBA levels and stratified them into four categories. From the blood test reports of the individual, we have the following categories of anemia for both men and women:

i. Non-anemic: If HBA levels are above 12 g/dl for women and 13 g/dl for men.
ii. Mildly anemic- If HBA levels are in the range of 10-11.9 g/dl for women and 12.0-12.9 g/dl in the case of men.
iii. Moderately anemic- If HBA levels is between 7.0-9.9 g/dl for women and 9.0-11.9 g/dl for men.
iv. Severely anemic- If HBA levels is lower than 7.0 g/dl and 8.9 g/dl for women and men respectively.

In the ordinal measure of anemia, we assign value 0 for non-anemic, 1 to severe anemia, 2 to mild anemia and 3 to moderate anemia. Using the HBA levels[9] of both men and women in our sample will allow us to determine the severity of anemia which will enable us to quantify the effect of residential location near brick kiln on the likelihood of anemia.

Our main explanatory variable of interest is an individual's proximity to brick kiln. We control for a rich set of covariates both at the individual level as well as at household level that are likely to

[8] Anemia is defined differently for men and women. In determination of anemic status, the cut-off range for both men and women has taken into consideration.

[9] The HBA levels and their cut off are specified according to the World Health Organization (WHO) guidelines. Accessed from: http://whqlibdoc.who.int/trs/WHO_TRS_405.pdf

affect the risk of becoming anemic. Additionally, we control for the district fixed effects. The next section, discusses the sources of data used in this paper.

III. Data

For the estimation, we utilize dataset from various sources. The figures on prevalence of anemia at the individual-level is obtained from the 4th round of the National Family Health Survey (NFHS-4) for the region of Bihar from 2015-16 corresponding to pre-covid period. The geo-coordinates of the brick kilns have been taken from the District Survey Report (DSR).

Anemia Prevalence estimates

In our study, we have used biomarker data at the household level for the 38 districts of Bihar. The data has been obtained from NFHS-4, 2015-16. Data for the state of Bihar were collected between the periods March 2015 –June 2015. For our analysis, we have used information on men and women in the age-group of 15-49 years. The survey data was collected using a two-stage stratified random sampling based on the census (2011) by the NFHS. In the survey, villages in the rural areas and blocks in urban areas corresponds to the Primary Sampling Units (PSUs). These PSUs were further classified into clusters and data on 22 households from each cluster were obtained using systematic sampling[10]. The sample consists of 1648 clusters and the GPS coordinates are available for all these clusters.

In our estimation framework, we utilized information on anemia prevalence, our primary outcome variable among men and women in the household. We have used altitude adjusted hemoglobin concentration[11] (HBA) in g/dl[12] to measure the anemic status. Using the WHO's guidelines, women and men were categorized as anemic/not anemic from their measured HBA reports. Table 1 depicts the HBA levels and anemic status among men and women across the 38 districts. About 60% of the women and 32% of men in the sample are anemic. From the total sample about 57.3%

[10] For further information about sampling design, see the National Family and Health Survey IV Report by the International Institute for Population Sciences.

[11] The NFHS adjust the HBA levels for altitude in the enumeration areas that are above 1,000 meters. This is because people living at high altitudes and smokers have higher levels of hemoglobin as a result of the human body's natural adaptation mechanisms.

[12] Haemoglobin in g/dl = grams per decilitre.

have any anemia and 42.6% does not have any anemia. Even the altitude adjusted HBA levels among men is fairly higher than women in our sample. In terms of severity of anemia, men are more severely anemic than women. However, as compared to men, majority of women are either mildly or moderately anemic. The overall data suggests that the men fare marginally better than women.

Table 1: Anemia prevalence rates (%)

	Men (1)	Women (2)
Altitude adjusted hemoglobin level (g/dl)	13.553	11.405
Severely anemic	1.3	0.6
Moderately anemic	13.8	13.7
Mildly anemic	17.2	46.2
Any Anemia	32.3	60.5
Sample Size	5,170	40,703

Source: NFHS data.

In the survey, individual consent were obtained for the hemoglobin test. Blood samples were collected for all the eligible the members residing in the household by the NFHS team and hemoglobin levels were measured using the HemoCue Hb 201+ analyzer on-site by the team of medical personnel in each district[13]. The HBA levels of all the participants were ascertained by taking into account the smoking status of the individual and adjustment of altitude by using the formulae given by the US Centers for Disease Control and Prevention.

In our sample, we considered HBA levels below 4 g/dL and above 20 g/dL as missing on account of measurement error. Further, pregnant women and usual visitors to the households were excluded from the sample. Thus, our final sample size is 45,852, smaller than the NFHS-4 report.

Confounding Variables

The information on the other confounding variables that could potentially affect the likelihood of being anemic were obtained from household questionnaire of the NFHS administered to both men and women in the survey. We included variables such as age in years, gender (female/ male),

[13] NFHS Guideline Manual for the instructor.

educational attainment of the individual, type of residence (location in rural or urban), marital status, source of water, type of toilet facility in the household, consumption of tobacco, and method of cooking. Apart from this, the data on the dietary consumption of the individuals has been taken into account as a proxy for iron deficiency (Krebs-Smith et al., 1987).

Also, exposure to biofuel smoke is also associated with anemia (Mishra et.al; 2007, Page et.al; 2015), we adjusted for the type of cooking fuel used in the household. The Body mass index (BMI) was included in the analysis as body weight of the person is considered to important factor for inflammatory anemia and it also disrupts the iron absorption in the body (Ghosh et.al, 2019). The BMI was calculated as the ratio of weight of an individual in kilograms by the square of height measured in meters (kg/m^2). We classified the BMI into three categories: under-weight, normal and obese[14] following the WHO's guidelines.

As per the available literature, there exists a strong correlation between socioeconomic status and anemia (Kim et.al, 2014; Thankachan et.al, 2007; & Gompakis et.al, 2007). All these studies have shown that prevalence rates of anemia are higher among the low-income households. In our analysis, the socio-economic status of the individual was quantified into four levels: "poorest," "poorer," "middle," "richer," and "richest." The survey created household and individual level wealth quintiles based on the principal component analysis[15]. The housing characteristics such has flooring and roof materials and ownership of 25 consumer durable goods were factored in to arrive at the wealth index in both the rural and the urban areas.

In order to reduce bias in our estimation analysis, we control for chronic diseases history for each respondent which is strongly linked with anemia of inflammation (Weiss et.al, 2019). The NFHS-4 survey provides the information on self-reported status on diseases such as cancer and heart issues. We created a dummy variable to account that whether the individual is currently suffering from heart or cancer ailment.

[14] As per the WHO classification, if BMI is below 18.5 then individual is considered as underweight, between 18.5-24.9 as normal weight and more than 25 as obese. https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi.

[15]

Brick Kiln Locations

The information on the number of operational brick kilns has been taken from the district survey report published by Bihar Mines and Geology Department for the year 2015-16. It contains geo-coordinates of the kilns that were manually mapped by District Environment Impact Assessment Authority (DEIAA)[16]. It also provides details on the year of commence of brick kiln and whether it is currently operational. Figure 1 depicts the geographical spread of brick kilns across the districts. The central part of the Bihar state i.e. Patna, Siwan, Gaya & Muzaffarpur have highest concentration of the brick kilns. While the eastern part has very few brick kilns.

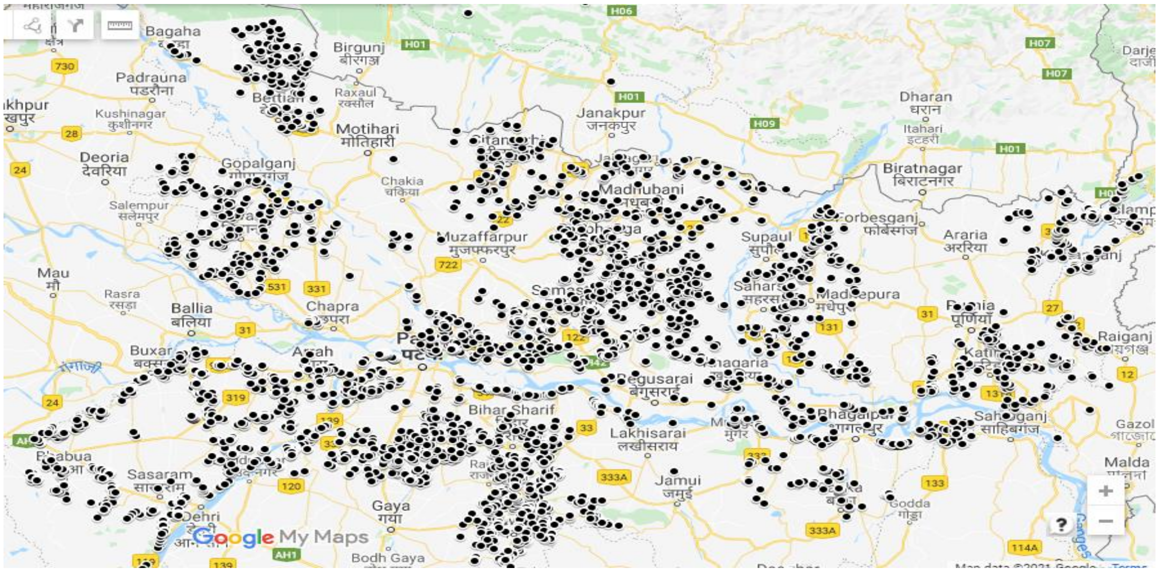
To determine the residential proximity to the kilns, we utilized the GIS information of the clusters and calculated the number of kilns for different radii (15, 20, 25 and 30 km[17]) using ArcGIS V10.1. In the NFHS survey, for ensuring the respondent confidentiality, the clusters are displaced from their true location. The urban clusters in the sample are displaced by 2km and a rural cluster by 5km from their existing location. About 1% of the rural clusters are displaced by more than 10km. However, the displacement is undertaken in such a manner that the cluster remains within the same boundary of the district and the state. For the Bihar state, 85% of the respondents are residing in the rural areas, hence for our analysis, we take the minimum distance from the kiln as 15 km which takes into account the displacement factor into consideration.

Figure 2, indicates graphical representation of our identification of households located near the brick kilns. We have created a buffer around the cluster/ village to locate if there is presence of brick kiln within a specified radius.

[16] As per the Gazette notification[16] by Ministry of Environment, Forest and Climate Change, the districts of all the State unions are required to prepare a District Survey Report (DSR) once in five year period. The DSR helps the state and central government in identification of mineral wealth in each district, areas where mining should be prohibited, identifying areas of erosion etc.

[17] We choose these proximity cut offs as they show significant discrimination in the analysis.

Figure 1: Brick Kiln location across the districts of Bihar (2015-16)



Source: The google map has been created by the author using the GPS coordinates from the DSR report. The black-dot represent the location of the kilns.

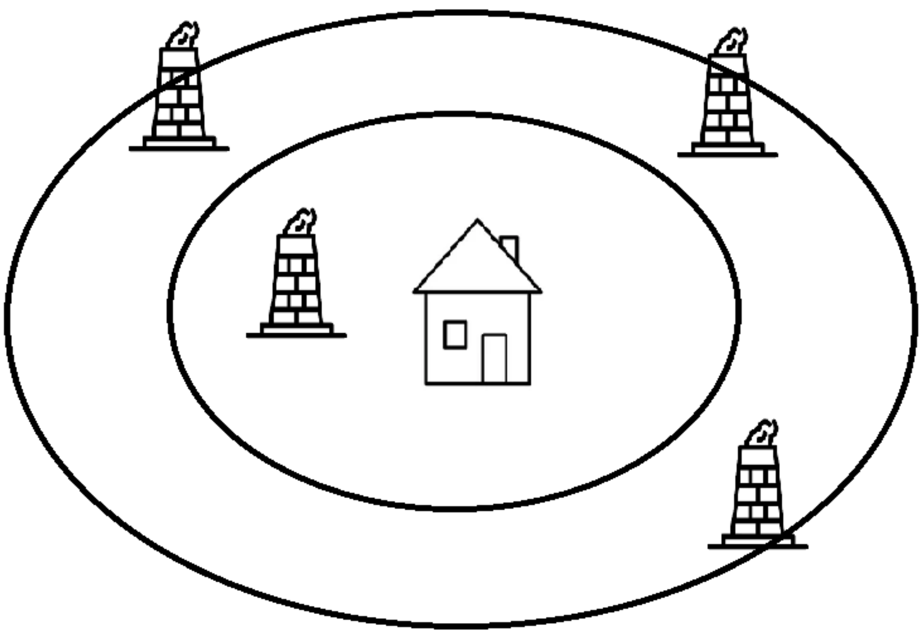


Figure 2: Figure: Identification of residential proximity to brick kiln

Source: Author. The inner ring represents a radius of 15km around the household. It depicts the presence of brick kiln within the radius. As the radius increases, i.e 20km (outer ring) the number of kilns also increases.

IV. Estimation Framework

The available literature (Vyas, 2019; Ha et.al, 2015; Datt et.al, 2021) discusses extensively on proximity to coal based thermal power plant and adverse health outcomes including anemia, low birth weight, pre-term delivery and stunting among the children. The cost of emissions are concentrated on those live closest to the coal plants. In our estimation framework, we focus on emissions from brick kilns and its impact on health outcomes of men and women in the age-group 15-49 years. We used probit and ordered probit model to examine the association between proximity to a brick kiln and prevalence of anemia among men and women. The analysis answer the question: whether individuals residing near kilns are more likely to be anemic than their counterparts living further away from the kilns.

Residential proximity and anemic status: Probit Model

For the analysis, we constructed our sample in the following manner. We matched the proximity to the kilns with the DHS cluster location within the specified radii using the NFHS-4 database. We use two measures for our outcome variable, anemic status of individuals, and altitude adjusted hemoglobin levels (HBA) in g/dl. As per the WHO's guidelines (2015) the status of anemia differs for both men and women. A women was considered anemic if HBA levels were lower than 12 g/dl and for men it was less than 13 g/dl. We analyze the anemic status of the individual by using a dichotomous value as "0" if individual has anemia and "0" otherwise.

For the anemic status of the respondent as binary variable, we estimated the following equation using the Probit model:

$$Y_i^* = \beta' \, X_i \, + \, u_i$$

Where,

$$Y_i \; = \begin{cases} \;\; 1 \; if \; respondent \; is \; anemic \\ 0 \;\; if \; respondent \; is \; not \; anemic \end{cases}$$

i = 1, 2, ..., n, represents i^{th} individual

Y_i^* represents the latent variable which is the anemic status of the i^{th} individual in the cluster that remains unobserved; X_i is the main explanatory variable which measures the residential proximity to kiln in different buffers and other covariates that can increase the risk of becoming anemic. u_i is the error term that has standard normal distribution and is independent of X_i .

The distance from the nearest kiln was measured in kilometers. We categorized the proximity to kilns into different buffers: within 15 km radius, 15-19.9km, 20-24.9km, 25-29.9km and 30-35km.We created a categorical variable for residential proximity with a value “0” if there is no brick kiln in that buffer and “1”if it is present for the analysis.

Using eq. 1, we estimated the probit model F $(\beta' X)$ which is the cumulative distribution function (cdf) of the standard normal distribution. The probit model is estimated using the maximum likelihood method. We run the model for the outcome variable after adjusting for potential confounders based on the available literature that can affect the outcome variable. The final results were reported in terms of the average marginal effects of the residential proximity of the household near kilns on the likelihood of becoming anemic.

Residential proximity and Hemoglobin Levels (g/dl): Ordered Probit Model

To determine the severity of anemia, we will used the HBA levels measured during the survey by NFHS team. As the severity of anemia is a categorical variable with more than two ordered categories, we estimate an Ordered Probit model (Boes and Winkelmann, 2006 and Chiburis and Lokshin, 2007). We used the similar strategy defined above, with the outcome variable as H_i^* :

$$H_i^* = \gamma' X_i + \varepsilon_i$$

Where, the HBA levels (H_i) are classified into three categories:

$$H_i = \begin{cases} 0 \; if \; H_i^* \leq \alpha_0 \\ 1 \; if \; \alpha_0 < H_i^* \leq \alpha_1 \\ 2 \; if \alpha_1 < H_i^* \end{cases}$$

With $H_i = j \; if \; \alpha_{j-1} < H_i^* \leq \alpha_j$; j=0, 1 &2.

Here, α_j are the threshold points. The probability that an individual *i* will belong to any of the j categories using the maximum likelihood method is:

$$P_{ij} = P(H_i = j)$$

$$= \mathrm{P}\ (\alpha_{j-1} < H_i^* \leq \alpha_j)$$

$$= \mathrm{F}\ \left(\alpha_j - \gamma' X_i\right) - F\ (\alpha_{j-1} - \gamma' X_i)$$

The main explanatory variable is the residential proximity to kilns at varying distance levels from each DHS cluster. We control for a rich set of covariates both at the individual level as well as at household level that are likely to affect the risk of anemia. The individual specific controls include age of the respondent, educational attainment, BMI, marital status, and other behavioral risk factors including tobacco and alcohol consumption which can reduce the hemoglobin levels. Household level variables include caste and religion identifiers, type of cooking fuel used, household wealth status, type of residence (rural/urban) and other covariates. Further, the equation is also controlled for unobserved district level variables using the district-fixed effects.

There are three caveats to our estimation framework. First, we assume that each brick kiln operating in different distance bins has a homogenous effect, which might not be true. Since, the capacity to produce bricks and quality of coal used for the process differs for each kiln, it is possible that kiln with large capacity emit large amount of smoke. We do not have access to this information and hence cannot control for them. Second, we assumed that there is no diffusion or spillovers of the smoke emitted from brick kiln across different distance bins. This assumption can lead to a bias in our results, which might be depict underestimation. Lastly, the residential addresses of the individual were geocoded to determine the proximity to kilns. This method assumes that men and women are staying and working within a specified distance bins in our analysis. However, there might be strong possibility that the workplace might be far away from the kiln locations which may lead to potential exposure misclassification. Due to non-availability of the mobility and workplace information, we assume that the individuals are working at the same distance bin throughout the survey period. Additionally, literature on mobility and air pollution exposure assessment (Oudin et.al, 2012) suggest a low degree of misclassification.

V. Results

Descriptive Statistics

Table 2 presents descriptive statistics of the population residing in the 36 districts of Bihar. The mean HBA levels among men and women is 11.72 g/dl. The sample comprises of 87% women with mean age of 28.07 years. Around 40% of the population in our sample has received no formal education and only 6% were able to attain higher education levels. Among these only 3% were suffering from any chronic disease. Looking at the household characteristics, the majority of the households (80 percent) were using traditional solid fuels such as coal, wood, charcoal, agriculture residues and straw for cooking purposes. About 86% of the population was residing in the rural areas with most of them belonging to the poorest section of the society (46%). Large number of people (62%) does not have access to clean toilet facilities. The main religion of the sampled population is Hinduism (85%) with 59% of them belonging to the other backward classes.

We stratified the data based on the anemic status of the individuals (Table 3). The hemoglobin concentration adjusted for altitude levels (HBA) is on average 13.12g/dl among the non-anemic with corresponding figure 10.67 g/dl for the anemic individuals. The anemia prevalence rate differs for both men and women. Women are 92% more likely to be anemic as compared to men. In our sample, the respondents having anemia are more likely to be younger, less educated and have low BMI than those who are not anemic. Also, anemic individuals are more likely to be suffering from chronic diseases which is considered as an important factor in inducing inflammatory anemia. On the household front, respondents with anemia belongs to low socio-economic status and are more likely to live in rural areas, using traditional solid fuel for cooking, and less likely to defecate in open. Across the different distance bins for determination of the residential proximity to kilns in our sample, we find that persons having anemia are more likely to live near the kilns than their counterparts. Apart from that, among those with anemia (96.4%), the percentage of people who lived within 20km radius is significantly higher than those who doesn’t have anemia (95%).

Table 2: Summary statistics of the complete sample observations

Variables	Mean	SD	Min	Max
Individual Specific				
HBA levels (g/dl)	11.72	1.63	4	19.9
Age in years	28.07	9.11	15	45
Body Mass Index (in kg/m2)				
Smoking status	0.087	0.282	0	1
Drinking status	0.038	0.193	0	1
Education				
No education	0.415	0.49	0	1
Primary	0.12	0.32	0	1
Secondary	0.40	0.49	0	1
Higher	0.06	0.24	0	1
Gender	0.87	0.32	0	1
Chronic Diseases	0.025	0.156	0	1
Household Characteristics:				
Religion				
Hindu	0.85	0.36	0	1
Muslim	0.15	0.35	0	1
Others	0.001	0.034	0	1
Residence (rural/urban)	0.857	0.35	0	1
Open defecation	0.62	0.48	0	1
Traditional solid fuel used in cooking	0.79	0.40	0	1
Wealth Index				
Poorest	0.46	0.49	0	1
Poorer	0 .24	0.42	0	1
Middle	0 .15	0.36	0	1
Richer	0.10	0.30	0	1
Richest	0.03	0.19	0	1
Caste				
Scheduled caste	0.19	0.39	0	1
Scheduled tribe	0.02	0.16	0	1
Other backward class	0.59	0.49	0	1

Note: The estimations are made using the NFHS-4 survey for Bihar district. The sampled observations are 45,852.

Table 3: Summary statistics grouped by anemic status

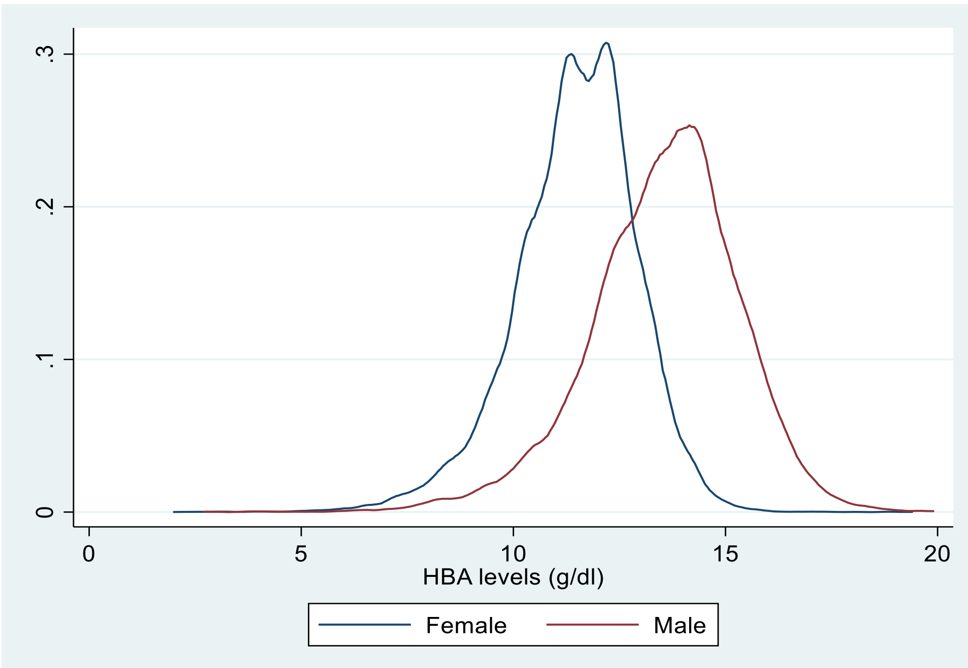
Variables	Non-Anemic	Anemic	Difference (t statistic)
Individual Specific			
HBA levels (g/dl)	13.12 (.007)	10.67 (.007)	2.44***(237.48)
Age in years	29.64 (.072)	29.24 (.062)	0.396*** (4.168)
Body Mass Index (in kg/m2)	21.15 (.037)	20.6 (.032)	.550***(11.16)
Smoking status	0.121 (.002)	0.062 (.001)	0.059***(22.38)
Drinking status	0.062 (.001)	0.021 (.0008)	0.0406***(22.50)
Education	1.2 (.007)	1.06 (.006)	0.136***(13.75)
Gender	0.81 (.002)	0.929 (.001)	-0.119***(-39.49)
Chronic Diseases	0.023 (.001)	0.026 (.0009)	-0.002 (.001)
Household Characteristics:			
Religion	1.15 (.0026)	1.14 (.002)	0.014**(4.42)
Residence (rural/urban)	0.846 (.002)	0.865 (.002)	-0.019***(-5.871)
Open defecation	0.604 (.003)	0.641 (.002)	-0.0375***(-8.27)
Traditional solid fuel in cooking	0 .78 (.0029)	0.81 (.002)	-0.029***(-7.75)
Wealth Index	2.08 (.008)	1.96 (.007)	0.115***(10.54)
Caste/Tribe	2.036 (.008)	2.02 (.007)	0.015 (1.31)
Brick Kiln Specific:			
Within 15 km radius	0.841 (.002)	0.845 (.001)	-0.004 (-1.42)
Between 15-19.9 km	0.959 (.001)	0.963 (.001)	-0.004** (-2.25)
Between 20-24.5 km	0.97 (.001)	0.974 (.0009)	-0.0037**(-2.45)
Between 25-29.9 km	0.9816 (.0009)	0.9813 (.0008)	0.0003 (0.289)
Between 30-35 km	0.986 (.0008)	0.984 (.0007)	0.002**(2.165)

*** and ** indicates significance at 1% and 5% significance level.

Difference = mean (Non-Anemic)—mean (Anemic). A positive value indicates that the mean is higher for overweight or obese population while a negative value indicates that the mean is higher for non-overweight population. The t-statistic is obtained from two-sample mean-comparison test with equal variances. The total sample size is 45,873.

Figure 4, depicts hemoglobin distribution amongst men and women in Bihar (as measured during the survey). As seen in the graph that the HBA levels for women lies to the right of the men indicating that women are more likely to be anemic.

Figure 4: Hemoglobin (g/dl) distribution of men and women



Source: Figure constructed by author based on NFHS data for year 2015–16.

Main results

In this section, we first present the estimation results for the Probit using the anemic status as the outcome variable. We then present the results obtained from the estimation of an Ordered Probit model in which the ordinally defined hemoglobin levels of the individuals is the outcome of interest.

Effect of residential proximity on anemic status of the individual: Probit estimates

This sub-section contains results pertaining to the outcome variable anemic status of the adult population. Table 4 presents the average marginal effect of residential proximity to kiln on the anemic status of the individual. Based on the estimated Probit model, we computed the average marginal effect of distance from the kiln on the prevalence of anemia. The respondents were classified into anemic or non-anemic based on the WHO's guidelines. The proximity to kilns was categorized into several buffers: <15 km, 15-19.9 km, 20-24.9km, 25-29.9 km and 30-35km. The selected buffer categories showed the best discrimination in the regression analysis[18]. After adjusting for the potential confounders, the association between the residential proximity to brick kilns and anemic status remains consistent.

From the table we find that households having operational brick kiln within 15km radius are 4% more likely to become anemic as compared to households that does not have kilns. As the distance from the kiln increases, the likelihood of becoming anemic also decreases. Within 15-19.9 km the chances are 3.7% which reduces to 1.5% between 20-24.9km radiuses. After 25km the impact of smoke emitted from kilns on anemia is not significant (.05% for 25-29.9 km) and even negative in 30-35km distance bin (.03%). The findings suggest that residents living in close proximity to kilns have higher chance of becoming anemic in comparison to the individuals living farther away. Specifically, for each 5km increase in the distance from the brick kiln, the likelihood of becoming anemic also decreases.

Table 4: Average Marginal Effect of the residential proximity to kiln on anemic status

Marginal Effects	Coefficient
Residential Proximity to kilns	
Within 15 km radius	0.040***(.014)
Between 15-19.9 km	0.0376***(0.012)
Between 20-24.5 km	0.0148**(.007)
Between 25-29.9 km	0.005 (.017)
Between 30-35 km	-0.0028 (.020)
Observations	
Controls	Yes
District Fixed Effects	Yes

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. Controls include individual and household covariates. The district fixed effects are for 38 districts across the state of Bihar.

[18] Beyond 35 km radius we did not find any significant effect of the kiln on anemia outcomes.

The confounding variables in the Probit model also give consistent estimates[19]. Across all the distance bins, we find that anemia depicts a significant decreasing status with an increase in BMI. The results suggest that underweight individuals are 4% more likely to become anemic in comparison to normal-weight individuals and overweight category individuals 3.8% less chance of becoming anemic. Our findings are consistent with epidemiology literature which states that increased BMI is associated with reduced chances of becoming anemic (Ugwuja et.al; 2015, Trinh et.al; 2007). The individual behavioral risk factors such as smoking had a 0.1-0.2% marginal effect on anemia, whereas the consumption of alcohol was significantly associated with anemia. Individuals who were consuming alcohol had 5-6% less chance of becoming anemic than who don't consume alcohol. Since, the mild or moderate consumption of alcohol is associated with increase in the iron stores in the body which reduces the prevalence of iron deficiency anemia (Ioannou et.al; 2004, Whitfield et.al, 2001), our results remain consistent.

In our sample, individuals who have secondary or higher levels of education have 2-5% less chance of reporting anemia than those individuals who are illiterate. We also observed in our analysis that as the age of the resident increases, the probability of becoming anemic also declines by .02% (not significant). The household covariates did not had a significant impact on the prevalence of anemia. The use of traditional cooking fuel as our control for indoor air pollution though positive does not show any significant association with the anemia status. However, the religious ethnicity had a positive impact with those belonging to Hindu community has 2% chance of becoming anemic vis-à-vis other religion background[20] while in among Muslims it was 1.6%. Respondents belonging to different tribes and caste had no impact on their anemic status.

There was no significant association between the prevalence of anemia and the socio-economic status of the individuals (SES). There might be a possibility that households with low SES are residing near the brick kiln than high SES (as they can afford housing in cleaner areas) or they lack access to the better health facilities and treatments which can lead to difference in the anemic rates. However, the results suggest that individuals belonging to richest and middle income households

[19] The detailed results of the average marginal effects are given in Appendix.
[20] The other religion include Parsi, Sikh, Jain and other religious minorities.

have 1.6% and 1.4% respectively have lesser chance to become anemic than their counterparts living in the poorest and poor households.

Effect of residential proximity on ordinal hemoglobin levels: Ordered Probit Model Estimates

The marginal effects for the ordered probit model also gave the results similar to the previous sub-section. Our estimations shown that across the different distance bins, both men and women have high probability of developing mild to moderate anemia. The chances of severe anemia among the population residing near kilns are very less. Table 5 provides the regression results. We find that the households within 15 km radius and in the 15-19.9 km distance from the kiln have 0.14% probability of developing severe anemia and 1.6% chance of mild and moderate anemia. As the distance from the kiln increases, the marginal effects shows declining trend, which is consistent with the assumption that households farther from kilns are less likely to be anemic than those living nearby. The effects remain significant and positive till the 25km radius. After 25km the effect reduces in magnitude and even negative in the 30-35km radius. The marginal effect of covariates in the ordered probit regression also gave results similar to the previous analysis[21].

Our findings show similar trends in comparison to the other studies where the association between the residential proximity from coal plants or industrial units on the adverse health outcomes has been assessed. Studies by Ha et.al (2015), Tsai et.al (2004), Mangones et.al (2013) and Brender et.al (2011) have shown that people residing in close proximity to a major air pollution source have strong association with adverse health outcomes such as low birth weight, cardiovascular diseases, respiratory problems etc. Though, there are no published reports of adverse health outcomes for smoke emitted from brick kilns and the population residing nearby, our estimations raises the concern on the adverse health outcomes associated with the operation of the kilns.

[21] The marginal effects of covariates can be seen from the Table: of the Appendix.

Table 5: Average marginal effects of the residential proximity to kilns on ordinal anemia levels: Ordered Probit model

	Severe Anemia#	Mild Anemia#	Moderate Anemia#	Non-anemic#
Within 15 km radius	0.00139** (.0005)	0.016** (.0062)	0.0159** (.006)	-0.0334*** (.0129)
Between 15-19.9 km	0.0014*** (.00047)	0.0168*** (.0053)	0.0166*** (.0052)	-0.0349*** (.011)
Between 20-24.9 km	0.00053** (.0002)	0.0061** (.003)	0.0060** (.0031)	-0.0126** (.0065)
Between 25-29.9 km	0.00034 (.0006)	0.004 (.007)	0.0039 (.007)	-0.0083 (.015)
Between 30-35 km	-0.001 (.0007)	-0.0119 (.0083)	-0.0117 (.0082)	0.0247 (.0172)
Controls	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. Controls include individual and household covariates. The district fixed effects are for 38 districts across the state of Bihar. The ordered Probit model is run using the NFHS-4 database of the Bihar district with n=45,873 observations.

Severe anemic- If HBA levels is lower than 7.0 g/dl and 8.9 g/dl for women and men respectively.
Mildly anemic- If HBA levels are in the range of 10-11.9 g/dl for women and 12.0-12.9 g/dl in the case of men.
Moderately anemic- If HBA levels is between 7.0-9.9 g/dl for women and 9.0-11.9 g/dl for men.
Non-anemic: If HBA levels are above 12 g/dl for women and 13 g/dl for men.

VI. Specification Analysis

In order to further strengthen our results we conducted the sensitivity analysis to determine whether residential proximity is affecting the likelihood of anemia. We undertake the following changes in the given regression equation as described below:

i. Spatial clustering of Brick Kilns.

In our previous regression results, the distance from a kiln might not serve as a good measure of exposure owing to the spatial clustering of brick kilns in a particular location. To rule this concern, we estimated a Probit and an ordered probit regression using the number of kiln in lieu of the residential proximity as measure of exposure assessment. From the previous regression result, we observed that kiln farther than 25km from the household does not have any impact on the likelihood of anemia. To further strengthen this, we constructed a 25km buffer around each household and determined the number of kilns within that buffer. The association between anemia and number of brick kilns within 25km was determined. We constructed a categorical variable for these kilns taking value '0' for no kiln, '1' for number of kilns between 1 to 100 and value of '2' for more than 100 kilns in the buffer.

Within the 25km radius, compared with those individuals who lived with no brick kilns, the individuals surrounded by less than 100 kilns, had the 6% chances of becoming anemic whereas, if there were more than 100 operational kilns the chance increases to 7% (Col.1, Table 6). Our results are consistent with the fact that as the number of kilns increases, the level of air pollution also rises which further aggravates the likelihood of becoming anemic. With the ordered probit model, we find the similar results. In both the cases of the number of kilns, we find that the chances of developing mild anemia ranges between 2-3% (Col.3, Table 4), while the population residing within 25 km buffer have higher chances of being moderately anemic (3-4%). In this specification, though the results are significant but they differ in magnitude in comparison to the main findings of this paper.

Table 6: Average Marginal Effect of the number of kilns on the prevalence of anemia

	Whether person is anemic or not	Ordered Probit Regression			
		Severe Anemia	Mild Anemia	Moderate Anemia	Non-anemic
	(1)	(2)	(3)	(4)	(5)
Number of Kilns					
0	Reference	Reference	Reference	Reference	Reference
Between 1 to 100	0.059** (.023)	0.0017**(.0006)	0.022**(.008)	0.027**(.012)	-0.051** (.021)
>100	0.068**(.024)	0.0024***(.0006)	0.030**(.008)	0.034**(.012)	-0.067 **(.022)
Controls	Yes	Yes	Yes	Yes	Yes

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. Controls include individual and household covariates. The district fixed effects are for 38 districts across the state of Bihar.

ii. Dietary Intake

In our analysis, we have focused on the inflammatory anemia. However, anemia due to iron deficiency should be taken into consideration while determining its association with smoke from kilns. Hence, dietary intake of the individual (specifically dietary iron) plays an important role in the prevalence of anemia. Both plant-based and animal-based foods consist of dietary iron. However, iron found in animal-based foods (meat, chicken, and fish) is absorbed more easily into the body than found in plant-based foods (Tseng et.al, 1997). Certain nutrients such as phyates (found in legumes and grains), polyphenols (tea and coffee), and eggs have an inhibiting effect and reduces the iron absorption in the body (Latham, 1997). Additionally, the anemic status of an individual also impacts the iron uptake of the body (Hunt, 2000).

We computed the Dietary Diversity Score (DDS) as a proxy measure for nutrient deficiency based on the index created by Smith et.al, 1987. The NFHS data provides information on the frequency of consumption of various food items. These categories were further sub-classified into six food groups such as Vitamin A foods (dark green leafy vegetables), legumes/pulses, meat/fish or chicken, milk or curd, eggs and fruits. Respondents were assigned a value 1 for every food group consumed and 0 otherwise. Using the dietary classification method from Arimond et al (2009) and Wiesmann et.al (2009) the information on the given food groups were summed to derive at DDS for an individual. The DDS take values between 0 to 6 with "0" being no consumption and "6" indicating highest dietary consumption.

The focus of this paper is on systemic inflammatory anemia due to air pollution emitted by the kilns. Hence, for the robustness check we will look into the fact the likelihood of anemia among residents living in close proximity is not due to nutrient deficiency. We did a specification analysis to determine whether anemic status differs after including the dietary intake of the individual. The preliminary findings (Table 7) suggest that the inclusion of dietary intake into the analysis has no significant impact on the likelihood of anemia. The coefficients of the distance bins remain same even after including the DDS score.

Table 7: Average marginal effects of DDS on the prevalence of anemia (Probit estimates).

		(1)	(2)	(3)	(4)	(5)
Distance bins						
Within 15 km		0.04**(.014)				
Between 15-19.9 km			0.037**(.012)			
Between 20-24.5 km				0.014**(.007)		
Between 25-29.9 km					0.005 (.017)	
Between 30-35 km						-0.027 (.020)
DDS Score						
	1	-0.020 (.019)	-0.020 (.019)	-0.021 (.019)	-0.021 (.019)	-0.021 (.019)
	2	-0.018 (.018)	-0.019 (.018)	-0.019 (.018)	-0.019(.018)	-0.019(.018)
	3	-0.015 (.017)	-0.015 (.017)	-0.015 (.017)	-0.015 (.017)	-0.015 (.017)
	4	-0.013 (.018)	-0.014 (.018)	-0.014 (.018)	-0.014 (.018)	-0.014 (.018)
	5	-0.013 (.018)	-0.013 (.018)	-0.013 (.018)	-0.013 (.018)	-0.013 (.018)
	6	-0.017 (.019)	-0.017 (.019)	-0.017 (.019)	-0.018 (.019)	-0.018 (.019)
Controls		Yes	Yes	Yes	Yes	Yes

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. Controls include individual and household covariates. The district fixed effects are for 38 districts across the state of Bihar. The total observations is 45,873. The DDS takes the value in the range of 0 to 6.

VII. Conclusion

In this paper, we found an association between residential proximity to brick kilns with anemic association across the districts of Bihar. We tried to address the relevant policy question: what are the negative health externalities associated with brick kilns. We combined the unique database using the geo-coordinates of the kiln, an informal sector industry with the health indicators from NFHS-4. The focus of this paper is on the prevalence of anemia among men and women aged 15-54 years and how it aggravates due to the smoke emitted from the kilns.

Bihar is the second largest producer of bricks in India, and analyzing the negative health points associated with operation of the kilns becomes further important owing to poor health indicators among men and women in the state[22]. Our main findings suggests that individuals living within 15km of an operational brick kiln have 4% more chance of becoming anemic compared to those living with no brick kiln. When stratified with severity of anemia, the chances of moderate or mild anemia are 1.6%. This effect gets attenuated with the increase in distance. We also performed a sensitivity analysis by using the number of kilns within 25km buffer and the dietary intake of individuals (DDS). The analysis yielded a consistent result with exposure to brick kilns. We identify the effect of brick kilns on the anemic status through the air pollutants emitted from these kilns as the primary channel. The findings of this paper throw a light on one of the possible reasons for high rates of anemia among men and women across the districts of Bihar.

The study also has several limitations. First, in our analysis we did not take into consideration the operational season of the brick industry. Our analysis could be further strengthened if we compare the health indicators of the same individuals during the season and off-season of the brick kilns. Second, the buffer size should be within the 5km radius of the kiln to establish the association between residential proximity and anemia. However, due to confidentiality of the respondents in the survey, we were not able to take the true location and small buffer size into account.

The study adds to the growing literature on the adverse health impacts associated with the burning of fossil fuels. A large section of the available literature focuses on coal based thermal power plants, with few on other industries using the coal as a primary fuel. In Indian context, the brick

---

22

industry is the third largest consumer of coal after steel and power sector. Due to its informal nature of operations, the information on the operational brick kilns and its true operation sites is seldom available. Hence, not much attention has been paid on this sector. By providing evidence on the likelihood of anemia associated with these kilns, we add to the existing evidence on morbidity and mortality associated with air pollution. The results from this paper calls for further investigation and to look into the specific pollutants generated from the kilns that might be responsible for this association. The present study underlines the need for a shift towards more advanced technology for manufacturing of the bricks and a greater role of the government in regulating the establishment of these kilns near the residential areas.

Appendix

Table A1: Probit regression analysis on anemic status of an individual

Distance bins	Within 15 km	15-19.9 km	20-24.9 km	25-29.9 km	30-35km
Individual covariates					
Body Mass Index: (Normal as base category)					
Under weight	0.113*** (.013)	0.113*** (.013)	0.113*** (.0137)	.113*** (.013)	0.113*** (.013)
Obese	-0.101*** (.02)	-0.101*** (.02)	-0.101*** (.0197)	-0.101*** (.019)	-0.101*** (.019)
Age	-0.0006 (.0006)	-0.0006 (.0006)	-0.0006 (.0007)	-0.0006 (.0006)	-0.0007 (.0007)
Education: (No education as base category)					
Primary	-0.01 (.021)	-0.01 (.020)	0.01 (.020)	-0.01 (.020)	-0.01 (.020)
Secondary	-0.057*** (.016)	-0.057*** (.016)	-0.057*** (.016)	-.057*** (.016)	-0.058*** (.016)
Higher	-0.147*** (.029)	-0.148*** (.029)	-0.147*** (.0298)	-0.147*** (.029)	-0.15*** (.03)
Gender (Male=0 & Female=1)	0.643*** (0.24)	0.643*** (0.24)	0.642*** (.0239)	.642*** (.023)	.643*** (.024)
Currently smokes (Yes=1 & No=0)	0.004 (.028)	0.004 (.028)	0.004 (.028)	0.004 (.028)	0.004 (.028)
Drinks Alcohol (Yes=1 & No=0)	-0.150*** (.039)	-0.149*** (0.04)	-0.150*** (.038)	-0.150*** (.039)	-0.150*** (.038)
Chronic Disease	.010 (.038)	.010 (.038)	.010 (.038)	.010 (.038)	.010 (.038)
Household Characteristics					
Wealth Quintile: (Poorest as base category)					
Poorer	-0.006 (.016)	-0.007 (0.016)	-0.006 (.016)	-0.006 (.016)	-0.007 (.016)
Middle	-0.038 (.024)	-0.039 (.024)	-0.039 (.024)	-0.039 (.024)	-0.041 (.024)
Distance bins	Within 15 km	15-19.9 km	20-24.9 km	25-29.9 km	30-35km
Richer	-0.0006 (.032)	-0.0004 (.032)	-0.0005 (.032)	-0.0004 (.032)	-0.0006 (.032)
Richest	-0.041 (.043)	-0.042 (.043)	-0.042 (.043)	-0.042 (.043)	-0.042 (.043)

Open Defecation	-0.0006 (.018)	-0.001 (.018)	-0.0005 (.0184)	-0.0009 (.018)	-0.001 (.018)
Uses traditional fuel for cooking	0.003 (.021)	0.002 (.021)	0.002 (.0215)	0.002 (.021)	0.002 (.021)
Religion:					
Hindu	0.614*** (0.174)	.613*** (.175)	.611*** (.175)	0.608** (.175)	0.606*** (.175)
Muslim	.450** (.175)	0.448** (.182)	0.446** (.175)	.443** (.175)	0.441** (.175)
Place of residence (Urban=0 & Rural=1)	0.0027 (0.020)	0.0012 (0.020)	0.004 (.020)	0.004 (.020)	0.004 (.020)
Caste/Tribe					
Schedule Caste	.017 (0.021)	.017 (0.021)	0.017 (.0213)	.017 (0.021)	.017 (0.021)
Schedule Tribe	-0.035 (.04)	-0.034 (.04)	-0.033 (.0395)	-0.035 (.039)	-0.037 (.04)
Other Backward Caste	-0.032** (.017)	-0.031 (.0169)	-0.031 (.0169)	-0.032** (.016)	-0.032** (.017)
Residential Proximity to kilns					
Within 15 km radius	0.107** (.038)				
Between 15-19.9 km		0.0997** (.033)			
Between 20-24.5 km			.0394** (.0198)		
Between 25-29.9 km				0.014 (.047)	
Between 30-35 km					-0.074 (.054)

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. The district fixed effects are for 38 districts across the state of Bihar. The number of observations is 45,873.

Table A2: Average marginal effect of residential proximity to kiln on anemic status

Distance bins	Within 15 km	15-19.9 km	20-24.9 km	25-29.9 km	30-35km
Individual covariates					
Body Mass Index: (Normal as base category)					
Under weight	0.042*** (.005)	0.042*** (.005)	0.042*** (.005)	0.042*** (.005)	0.042*** (.005)
Obese	-0.038*** (.007)	-0.038*** (.007)	-0.038*** (.007)	-0.04*** (.008)	-0.04*** (.008)
Age	-0.0002 (.0002)	-0.0002 (.0002)	-0.0002 (.0003)	-0.0002 (.0003)	-0.0002 (.0002)
Education: (No education as base category)					
Primary	0.004 (.007)	0.003 (.007)	0.003 (.007)	0.004 (.007)	0.003 (.007)
Secondary	-0.021*** (.006)	-0.021*** (.006)	-0.021*** (.006)	-0.021*** (.006)	-0.021*** (.006)
Higher	-0.056*** (.011)	-0.056*** (.011)	-0.055*** (.011)	-0.056*** (.011)	-0.056*** (.011)
Gender (Male=0 & Female=1)	.242*** (.008)	.242*** (.008)	.242*** (.008)	.242*** (.008)	.242*** (.009)
Currently smokes (Yes=1 & No=0)	0.002 (.010)	0.002 (.010)	0.001 (.010)	0.001 (.010)	0.001 (.010)
Drinks Alcohol (Yes=1 & No=0)	-0.056*** (.014)	-0.056*** (.014)	-0.056*** (.014)	-0.06*** (.014)	-0.06*** (.014)
Chronic disease	.0038 (.014)	.0038 (.014)	.0038 (.014)	.0038 (.014)	.0038 (.014)
Household Characteristics					
Wealth Quintile: (Poorest as base category)					
Poorer	0.002 (.006)	0.002 (.006)	0.002 (.006)	0.002 (.006)	0.002 (.007)
Middle	-0.014 (.009)	-0.014 (.009)	-0.014 (.009)	-0.015 (.009)	-0.015 (.009)
Richer	-0.0002 (.012)	-0.0002 (.012)	-0.0002 (.012)	-0.0002 (.012)	-0.0002 (.012)
Distance bins	Within 15 km	15-19.9 km	20-24.9 km	25-29.9 km	30-35km

Richest	-0.016 (.0165)	-0.015 (.0165)	-0.016 (.0165)	-0.0158 (.0165)	-0.0158 (.018)
Open Defecation	-0.0002 (.006)	-0.0004 (.007)	-0.0002 (.006)	-0.0003 (.007)	-0.0005 (.006)
Uses traditional fuel for cooking	0.001 (.008)	0.0009 (.008)	0.0009 (.008)	0.0009 (.008)	0.0008 (.008)
Religion:					
Hindu	0.23*** (.062)	0.23*** (.062)	0.23*** (.062)	.22*** (.063)	0.23*** (.062)
Muslim	0.168*** (.063)	0.17** (.063)	0.168*** (.063)	0.167** (0.62)	0.17** (.063)
Place of residence (Urban=0 & Rural=1)	0.001 (.007)	0.0004 (.007)	0.0016 (.007)	0.0009 (.008)	0.0016 (.007)
Caste/Tribe					
Schedule Caste	0.006 (.008)	0.006 (.008)	0.006 (.008)	0.006 (.008)	0.006 (.008)
Schedule Tribe	-0.013 (.015)	-0.013 (.015)	-0.012 (.014)	-0.013 (.015)	-0.014 (.015)
Other Backward Caste	-0.012 (.006)	-0.011 (.006)	-0.012** (.006)	-0.012** (.006)	0.012** (.006)
Residential Proximity to kilns					
Within 15 km radius	0.040*** (.014)				
Between 15-19.9 km		0.0376 ***(0.012)			
Between 20-24.5 km			0.0148** (.007)		
Between 25-29.9 km				0.005 (.017)	
Between 30-35 km					-0.0028 (.020)

*** represents significance at 1% significance level and ** at 5% level. Delta-Method standard errors are reported in parentheses. The district fixed effects are for 38 districts across the state of Bihar. The number of observations is 45,873.

References

Arimond, M, D Wiesmann, LE Torheim, M Joseph and A Carriquiry. 2009. Dietary Diversity as a Measure of the Micronutrient Adequacy of Women's Diets: Results from Rural Bangladesh Site. Washington, DC: FANTA-2 at FHI 360.

Bandyopadhyay, B., & Sen, D. (2016). Assessment of energy balance against the nutritional status of women carriers in the brickfields of West Bengal. *International Journal of Occupational Safety and Ergonomics*, *22*(3), 399-404.

Blackman, A., Newbold, S. C., Shih, J. S., & Cook, J. H. (2000). *The benefits and costs of informal sector pollution control: Mexican brick kilns* (No. 1318-2016-103071).

Brender, J. D., Maantay, J. A., & Chakraborty, J. (2011). Residential proximity to environmental hazards and adverse health outcomes. *American journal of public health*, *101*(S1), S37-S52.

Chay, K. Y., & Greenstone, M. (2003). The impact of air pollution on infant mortality: evidence from geographic variation in pollution shocks induced by a recession. *The quarterly journal of economics*, *118*(3), 1121-1167.

Currie, J., & Neidell, M. (2005). Air pollution and infant health: what can we learn from California's recent experience?. *The Quarterly Journal of Economics*, *120*(3), 1003-1030.

Datt, G., Maitra, P., Menon, N., Ray, R., Dey, S., & Chowdhury, S. (2021). *Coal Plants, Air Pollution and Anemia: Evidence from India*. Working Paper. Accessed from: https://www.monash.edu/__data/assets/pdf_file/0011/2770517/WP2021n07_V1.pdf

De Benoist, B., Cogswell, M., Egli, I., & McLean, E. (2008). Worldwide prevalence of anaemia 1993-2005; WHO global database of anaemia.

Development Alternatives (DA), 2012. Status of Brick Sector In The State of Bihar - A Baseline Study. dmg events, 2015. Construction Market in India - A report by dmg events India. Accessed via http://www.arbinternational.es/ARCHIVO/documentos/sectorial/1431507298_construction-market-report.pdf

Eil, A., Li, J., Baral, P., & Saikawa, E. (2020). Dirty stacks, high stakes: An overview of brick sector in South Asia. Accessed from: https://elibrary.worldbank.org/doi/abs/10.1596/33727

Elbarbary, M., Morgan, G., Guo, Y., & Negin, J. (2019). Ambient air pollution association with anaemia prevalence and hemoglobin levels in Chinese older adult; cross-sectional study from the WHO wave 1 study on global aging and adult health (sage). *Environmental Epidemiology*, *3*, 109-110.

Flynn, A. C., Begum, S., White, S. L., Dalrymple, K., Gill, C., Alwan, N. A., & Poston, L. (2018). Relationships between maternal obesity and maternal and neonatal iron status. *Nutrients*, *10*(8), 1000.

Ghosh, S., Sinha, S., Thomas, T., Sachdev, H. S., & Kurpad, A. V. (2019). Revisiting dietary iron requirement and deficiency in Indian women: Implications for food iron fortification and supplementation. *The Journal of Nutrition*, *149*(3), 366-371.

Gompakis, N., Economou, M., Tsantali, C., Kouloulias, V., Keramida, M., & Athanasiou-Metaxa, M. (2007). The effect of dietary habits and socioeconomic status on the prevalence of iron deficiency in children of northern Greece. *Acta haematologica*, *117*(4), 200-204.

Greenstone, M., & Hanna, R. (2014). Environmental regulations, air and water pollution, and infant mortality in India. *American Economic Review*, *104*(10), 3038-72.

Gupta, A., & Spears, D. (2017). Health externalities of India's expansion of coal plants: Evidence from a national panel of 40,000 households. *Journal of environmental economics and management*, *86*, 262-276.

Guttikunda, S. K. (2012). Air pollution in Delhi. *Economic and Political Weekly*, 47, 24-27.

Guttikunda, S. K. (2014). Particulate pollution and its health impacts from brick kiln clusters in South Asian cities, *Centre for Science and Environment*, New Delhi.

Guttikunda, S. K., & Calori, G. (2013). A GIS based emissions inventory at 1 km× 1 km spatial resolution for air pollution analysis in Delhi, India. *Atmospheric Environment*, *67*, 101-111.

Ha, S., Hu, H., Roth, J., Kan, H., & Xu, X. (2015). Associations between residential proximity to power plants and adverse birth outcomes. *American journal of epidemiology*, *182*(3), 215-224.

Haas, J. D., & Brownlie IV, T. (2001). Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. *The Journal of nutrition*, *131*(2), 676S-690S.

Honda, T., Pun, V. C., Manjourides, J., & Suh, H. (2017). Anemia prevalence and hemoglobin levels are associated with long-term exposure to air pollution in an older population. *Environment international*, *101*, 125-132.

Hunt, J. R., & Roughead, Z. K. (2000). Adaptation of iron absorption in men consuming diets with high or low iron bioavailability. *The American journal of clinical nutrition*, *71*(1), 94-102.

ICMR (2020): "Health and Economic Impact of Air Pollution in the States of India: The Global Burden of Disease Study 2019," Lancet, December 21, https://doi.org/10.1016/S2542-5196(20)30298-9.

Ioannou, G. N., Dominitz, J. A., Weiss, N. S., Heagerty, P. J., & Kowdley, K. V. (2004). The effect of alcohol consumption on the prevalence of iron overload, iron deficiency, and iron deficiency anemia. *Gastroenterology*, *126*(5), 1293-1301.

Khan, R., & Vyas, H. (2008). A study of impact of brick industries on environment and human health in Ujjain City (India). *Journal of Environmental Research and Development*, *2*(3), 421-425.

Kim, J. Y., Shin, S., Han, K., Lee, K. C., Kim, J. H., Choi, Y. S., & Ko, B. J. (2014). Relationship between socioeconomic status and anemia prevalence in adolescent girls based on the fourth and fifth Korea National Health and Nutrition Examination Surveys. *European journal of clinical nutrition*, *68*(2), 253-258.

Krebs-Smith, S. M., Smiciklas-Wright, H., Guthrie, H. A., & Krebs-Smith, J. (1987). The effects of variety in food choices on dietary quality. *Journal of the American dietetic association*, *87*(7), 897-903.

Lozoff, B., Beard, J., Connor, J., Felt, B., Georgieff, M., & Schallert, T. (2006). Long-lasting neural and behavioral effects of iron deficiency in infancy. *Nutrition reviews*, *64*(suppl_2), S34-S43.

Mangones, T., Visintainer, P., & Brumberg, H. L. (2013). Congenital anomalies, prematurity, and low birth weight rates in relation to nuclear power plant proximity1. *Journal of perinatal medicine*, *41*(4), 429-435.

Mehta, U., Dey, S., Chowdhury, S., Ghosh, S., Hart, J. E., & Kurpad, A. (2021). The Association between Ambient PM2. 5 Exposure and Anemia Outcomes among Children Under Five Years of Age in India. *Environmental Epidemiology*, *5*(1).

Mishra, V., & Retherford, R. D. (2007). Does biofuel smoke contribute to anaemia and stunting in early childhood?. *International Journal of Epidemiology*, *36*(1), 117-129.

Morales-Ancajima, V. C., Tapia, V., Vu, B. N., Liu, Y., Alarcón-Yaquetto, D. E., & Gonzales, G. F. (2019). Increased outdoor PM2. 5 concentration is associated with moderate/severe anemia in children aged 6–59 months in Lima, Peru. *Journal of environmental and public health*, *2019*.

Nemeth, E., & Ganz, T. (2009). The role of hepcidin in iron metabolism. *Acta haematologica*, *122*(2-3), 78-86.

Nielssen, A. (2007). 66. Immune-Mediated Hemolytic Anemia. *Canine Internal Medicine Secrets E-Book*, 381.

Nikolić, M., Nikić, D., & Stanković, A. (2008). Effects of air pollution on red blood cells in children. *Pol J Environ Stud*, *17*(28), 267.

Nurko, S. (2006). Anemia in chronic kidney disease: causes, diagnosis, treatment. *Cleveland Clinic journal of medicine*, *73*(3), 289-297.

Oudin, A., Forsberg, B., Strömgren, M., Beelen, R., & Modig, L. (2012). Impact of residential mobility on exposure assessment in longitudinal air pollution studies: a sensitivity analysis within the ESCAPE project. *The Scientific World Journal*, *2012*.

Page, C. M., Patel, A., & Hibberd, P. L. (2015). Does smoke from biomass fuel contribute to anemia in pregnant women in Nagpur, India? A cross-sectional study. *PloS one*, *10*(5), e0127890.

Penninx, B. W., Pahor, M., Cesari, M., Corsi, A. M., Woodman, R. C., Bandinelli, S., & Ferrucci, L. (2004). Anemia is associated with disability and decreased physical performance and muscle strength in the elderly. *Journal of the American Geriatrics Society*, *52*(5), 719-724.

Peters, R., Burch, L., Warner, J., Beckett, N., Poulter, R., & Bulpitt, C. (2008). Haemoglobin, anaemia, dementia and cognitive decline in the elderly, a systematic review. *BMC geriatrics*, *8*(1), 1-6.

Seaton, A., Soutar, A., Crawford, V., Elton, R., McNerlan, S., Cherrie, J., Watt, M., Agius, R. and Stout, R. (1999). Particulate air pollution and the blood. *Thorax*, *54*(11), 1027-1032.

Singh, P., & Dey, S. (2021). Crop Burning and Forest Fires: Long-term Effect on Adolescent Height in India. *Resource and Energy Economics*, 101244.

Skinder, B. M., Sheikh, A. Q., Pandit, A. K., & Ganai, B. A. (2014). Brick kiln emissions and its environmental impact: A Review. *Journal of Ecology and the Natural Environment*, *6*(1), 1-11.

Stanković, A., Nikić, D., & Nikolić, M. (2006). Relationship between exposure to air pollution and occurrence of anemia in pregnancy. *Facta Univ Ser Med Biol.*, *13*(1), 54-57.

Stoltzfus, R. J. (2001). Defining iron-deficiency anemia in public health terms: a time for reflection. *The Journal of nutrition*, *131*(2), 565S-567S.

Thankachan, P., Muthayya, S., Walczyk, T., Kurpad, A. V., & Hurrell, R. F. (2007). An analysis of the etiology of anemia and iron deficiency in young women of low socioeconomic status in Bangalore, India. *Food and nutrition bulletin*, *28*(3), 328-336.

The Automotive Research Association of India (ARAI), 2010. Air Quality Monitoring and Emission Source Apportionment Study for city of Pune, February 2010. http://mpcb.gov.in/ereports/pdf/pune_report_cpcb.pdf

Trinh, L. T. T., & Dibley, M. (2007). Anaemia in pregnant, postpartum and non pregnant women in Lak district, Daklak province of Vietnam. *Asia Pacific journal of clinical nutrition*, *16*(2).

Tsai, S. S., Yu, H. S., Chang, C. C., Chuang, H. Y., & Yang, C. Y. (2004). Increased risk of preterm delivery in women residing near thermal power plants in Taiwan. *Archives of Environmental Health: An International Journal*, *59*(9), 478-483.

Tseng, M., Chakraborty, H., Robinson, D. T., Mendez, M., & Kohlmeier, L. (1997). Adjustment of iron intake for dietary enhancers and inhibitors in population studies: bioavailable iron in rural and urban residing Russian women and children. *The Journal of nutrition*, *127*(8), 1456-1468.

Ugwuja, E. I., Ogbonnaya, L. U., Obuna, A. J., Awelegbe, F., & Uro-Chukwu, H. (2015). Anaemia in relation to body mass index (BMI) and socio-demographic characteristics in adult Nigerians in Ebonyi state. *Journal of clinical and diagnostic research: JCDR*, *9*(1), LC04.

Vaidya, V. G., Mamulwar, M. S., Ray, S. B., Beena, R., Bhathlawande, P. V., & Ubale, S. (2015). Occupational Health Hazards of Women Working in Brick Kiln and Construction Industry. *Journal of Krishna Institute of Medical Sciences (JKIMSU)*, *4*(1).

Vyas, S. (2019). The child health impacts of coal: evidence from India's coal expansion. *Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3507883*

Weiss, G., & Goodnough, L. T. (2005). Anemia of chronic disease. *New England Journal of Medicine*, *352*(10), 1011-1023.

Whitfield, J. B., Zhu, G., Heath, A. C., Powell, L. W., & Martin, N. G. (2001). Effects of alcohol consumption on indices of iron stores and of iron stores on alcohol intake markers. *Alcoholism: Clinical and Experimental Research*, *25*(7), 1037-1045.

WHO. The global prevalence of anaemia in 2011. Geneva: World Health Organization; 2015.

Wiesmann, D, M Arimond and C Loechl. 2009. Dietary Diversity as a Measure of the Micronutrient Adequacy of Women's Diets: Results from Rural Mozambique Site. Washington, DC: FANTA at FHI 360

World Health Organization. (2017). *World health statistics 2017: monitoring health for the SDGs, sustainable development goals*. World Health Organization.

World Health Organization. The global prevalence of anaemia in 2011. WHO. 2015; 43.
Available at:
http://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011/en/.

Yang, F., Liu, X., & Zha, P. (2018). Trends in socioeconomic inequalities and prevalence of anemia among children and non-pregnant women in low-and middle-income countries. *JAMA network open*, *1*(5), e182899-e182899.

Zijp, I. M., Korver, O., & Tijburg, L. B. (2000). Effect of tea and other dietary factors on iron absorption. *Critical reviews in food science and nutrition*, *40*(5), 371-398.