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Relationships Between $PM_{2.5}$ and Hemoglobin Among Reproductive Women in Africa

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Abstract: The effects of toxic air in the form of air pollution are known to harm women's health. New data has shown that air pollution has effects on maternal anemia. Yet the effects of particulate matter $_{2.5}$ ($PM_{2.5}$) on hemoglobin among reproductive maternal (15-49 years) has been understudied. In this population-based study, we study the region-specific associations between prevalence of hemoglobin among reproductive women and $PM_{2.5}$ in 43 countries of Africa from 2000-2019. Using generalized linear regression models, we found that after adjusting for key covariates, $PM_{2.5}$ had a slight negative association with hemoglobin among reproductive women. Other studies are needed in other low-income settings to expand our findings.

Keywords: women anemia; maternal anemia; maternal hemoglobin; air pollution; Africa; low-income

Introduction

Hemoglobin (Hb) is the protein contained in red blood cells that is responsible for delivery of oxygen to the tissues, and when the hemoglobin level is low, the patient has anemia1. Anemia—a condition in which the red blood cell count is decreased, impairing the body's ability to meet the oxygen needs of tissues—is a public health problem [1,2] where women are some of the most affected; in 2019, the World Health Organization reported around 30% of women 15-49 years of age worldwide had anemia [3]. The WHO-defined hemoglobin (Hb) cut-offs, specific to age, sex, and pregnancy status, are most widely used to diagnose anemia, with the threshold being <120 g/L for non-pregnant and <110 g/L for pregnant women of 15–49 years of age [4]. Anemia also has a high association within low-income countries, notably in Africa, where, in 2019, an estimated 106 million women were affected by anemia [5].

Among pregnant women, maternal anemia can cause symptoms such as headaches and fatigue along with more severe cases, hemoglobin levels <6g/dL, causing a possibility of more dangerous effects secondary to decreased tissue oxygenation [6]. Pregnant and lactating women are especially susceptible to decline in hemoglobin [7], thus, it is important to analyze all risk factors that may have an impact on this. Beyond this, low maternal hemoglobin levels during pregnancy can also cause lasting effects such as fetal deaths [6,8] and an increased risk of limited cognitive development for infants after birth [9]. There are many risk factors that have been associated with the prevalence of maternal anemia and maternal hemoglobin decline such as education [10], income [11], and diet [12], however, research on the association between maternal hemoglobin and environmental factors is in its infancy.

Only a handful of studies have shown the relationship between environmental pollutants and maternal hemoglobin or anemia. One study showed that exposure levels to PM_{10}, SO_2, and CO for

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one and two years were significantly associated with decreased hemoglobin concentrations (all $p < 0.05$) [13]. In this study, exposure levels to PM10, for instance, had an OR of 1.039 [95% CI : 1.001–1.079], highlighting the link between air pollutants and decreased hemoglobin [13]. Additionally, carbon monoxide (CO) exposure during a two year period was closely related to anemia OR = 1.046 [95% CI: 1.004–1.091] [13]. On the other hand, a study involving particulate matter $_{2.5}$ ($PM_{2.5}$) found no association with anemia prevalence during the one year exposure period [13], yet other studies have found a negative association with hemoglobin levels which may contribute to maternal hemoglobin decline [14,15]. Fine toxic pollutants such as $PM_{2.5}$, primarily from vehicle emissions and industrial activities, are more likely to travel into and deposit on the surface of the deeper parts of the lung, which can induce tissue damage16. Furthermore, a previous study found that $PM_{2.5}$ particles can lead to a biological response due to motor emissions that can penetrate deep into the lungs, enter the bloodstream, and induce systemic inflammation [17,18]. Addressing these environmental factors and their impact on hemoglobin is crucial for improving maternal health outcomes and developing effective public health interventions.

This study aims to address regional differences in Africa and the association between $PM_{2.5}$ and maternal reproductive hemoglobin. Our hypothesis is that $PM_{2.5}$ will have varying effects on reproductive maternal hemoglobin levels based on different regions of Africa. The findings from this study can serve as a foundation for developing future policies aimed at improving maternal hemoglobin levels.

Methods

This is a population-based study for Africa from 2000-2019. Data for the annual mean prevalence hemoglobin (in grams per litre) of reproductive women between the ages of 15-49 years for 43 African nations. This outcome data was obtained from the World Health Organization (WHO). Aside from our primary outcome, exposure data for country-specific annual mean particulate matter $_{2.5}$ ($PM_{2.5}$) from 2000-2019 was obtained from World Bank: https://www.stateofglobalair.org/data/#/air/plot.

We included covariate data on country-specific annual mean air pollution (specifically household air pollutants as percentage), cereal yield (in tonnes per hectare), gross domestic product (GDP), prevalence of reproductive women with anemia (moderate levels), low body-mass index (<18.5 kg/m^2) of whole population, and annual trend.

We modelled the region-specific associations between the annual prevalence of reproductive women hemoglobin levels and annual $PM_{2.5}$ using generalized linear model, specifically negative binomial regression using autocorrelation order 1 (i.e. AR1). This is because the outcome's variance was much greater than its mean, leading to overdispersion of data. Model coefficients were exponentiated to be interpreted as rate ratios (RR) for each 10 $\mu g/m^3$ rise in pollution levels. 95% confidence intervals were evaluated at $P<0.05$ using Student's two-sided t-tests. Microsoft Excel (V.2021) and RStudio (V.4.1.1) were used for computation, analyses and figure composition.

Results

Over the twenty years of our study from 43 countries, within four regions of Africa, the average prevalence of hemoglobin among reproductive maternal is 120.8 g/L.

On a geographic perspective, the prevalence of reproductive women hemoglobin is lowest over Western Africa and highest over Southern Africa (Figure 1A). Similarly annual mean $PM_{2.5}$ are highest in Western Africa throughout the 2000 to 2019 period (Figure 1B).

Our models suggest that for each annual 10 $\mu g/m^3$ rise in $PM_{2.5}$ the RR for reproductive maternal hemoglobin found was no association for Western, Eastern, and Southern Africa, yet only Central Africa had the significant results [0.999 (P=0.035)]. The main findings from this suggests that countries of Central African regions had a negative association between prevalence of maternal reproductive women and $PM_{2.5}$ from 2000-2019.

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Discussion

The results of our study found that only Central Africa is statistically significant in the effect of $PM_{2.5}$ on maternal hemoglobin levels, whereas other regions were insignificant, hence suggesting regional differences in Africa. In a past study that analyzed the pregnancy conditions of Chinese women [20-45 years, n=7932] delivering between 2015-2018, it was found that an increase in $PM_{2.5}$ concentration for all pregnant women (mean: 69.56 μg/m^3, standard deviation: 15.24 μg/m^3) by one interquartile range increase (19.37 μg/m^3) was associated with a decrease in hemoglobin levels in multiparous women (mean age: 32.77±3.75 years, n=2609), but not for primiparous women (mean age: 28.78±3.25 years, n=5323)[14]. Exposure to $PM_{2.5}$ was associated with decreased hemoglobin in the third trimester of multiparous women, but not detrimental to the degree of being associated with anemia [14].

The link between $PM_{2.5}$ exposure and decreased maternal hemoglobin levels is believed to be driven by inflammation as a biological response [14]. $PM_{2.5}$ particles can deeply penetrate the lungs through motor emissions, enter the bloodstream, and trigger systemic inflammation, leading to oxidative stress and vascular dysfunction [17,18]. Pregnant and lactating women are especially vulnerable to hemoglobin decline, which has severe consequences for maternal health, and infant development, including impacts on cognitive function [7]. Additionally, a previous study also shows that decreased hemoglobin levels are linked to cardiovascular disease in pregnant women, which further worsens the effect of $PM_{2.5}$ [19,20]. These factors underscore the importance of addressing $PM_{2.5}$ in strategies aimed at improving hemoglobin levels, particularly among maternal women in regions with poor air quality, such as Africa.

Several epidemiologic studies have confirmed that $PM_{2.5}$ harms pregnant women and leads to more severe impacts on hemoglobin levels [13]. It is confirmed based on availability of data that a mother with low hemoglobin was at risk of delivering a newborn with stunted growth [21]. Additionally, in Africa, a lack of dietary and malnutrition variety during pregnancy doubles the odds of developing maternal anemia, which in turn leads to low child birth weight and therefore low hemoglobin levels [22].

The association between $PM_{2.5}$ and maternal hemoglobin levels observed in this study is limited by confounding factors, such as exposure to other air pollutants like PM1, PM10, and NO2, which have also been linked to decreased hemoglobin levels [12]. Since these pollutants are formed from emissions such as those from motor vehicles, it is difficult to isolate $PM_{2.5}$ from other pollutants that may also affect hemoglobin levels [16]. Moreover, socioeconomic status is another confounding factor that can influence both exposure to air pollution and access to healthcare, which further affects the relationship between $PM_{2.5}$ and hemoglobin levels [2]3. The lack of nutrition education and iron rich food has been associated with decreased hemoglobin levels, which we were not able to control for [24]. This study does not fully reflect the true prevalence or severity of low maternal hemoglobin, and interventions may be less effective due to African areas with limited healthcare access [25].

Nevertheless, this study adds value to the literature that focuses on a specific region - Africa - discussing the association between $PM_{2.5}$ and maternal hemoglobin [11]. This study highlights the regional variance and indicates that $PM_{2.5}$ is negatively associated with hemoglobin levels in maternal women. The study further helps to confirm our hypothesis that $PM_{2.5}$ increases the likelihood of maternal anemia. This is a concern since rising levels of $PM_{2.5}$ are exacerbated with further climate changes leading to clinical implications or reduced hemoglobin levels [26].

Table 1. Regional-specific association models for annual reproductive maternal hemoglobin and $PM_{2.5}$ from 2000-2019.

Region	Adjusted RR (P-value)*
West	1.000 (P=0.70)
East	1.000 (P=0.91)
Central	0.999 (P=0.035)
South	1.000 (P=0.24)

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* adjust for household pollution, cereal yield, GDP, prevalence reproductive women anemia (moderate levels), underweight BMI, and trend.

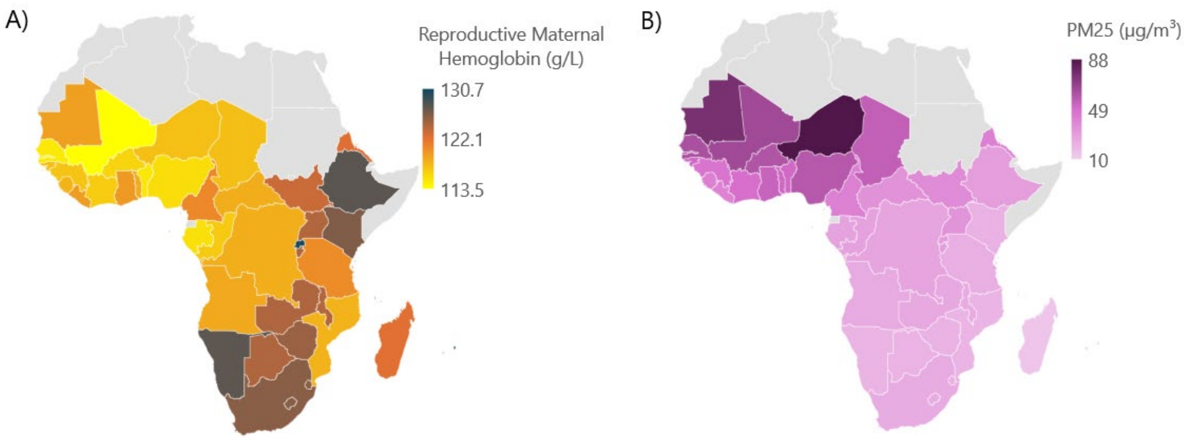

Figure 1. A) Annual country-specific reproductive maternal women (15-49 years) hemoglobin prevalence; B) annual mean $PM_{2.5}$ from 2000-2019.

Conclusion

Therefore, we found regional effects of $PM_{2.5}$ on maternal hemoglobin. In future research, the scope can be expanded to other low-income regions to determine whether this hypothesis holds true globally. Additionally, the study can be used to collaborate with specific African regions' governments to create considerable and lasting regulations. These regulations may decrease the prevalence of anemia among maternal women, reducing the chances of maternal health complications that arise in response to exposure from $PM_{2.5}$.

Author Contributions: Dr. Muhammed Saeed: Original Idea, Paper Review, Data Collection, Data Review, Writing, Final Review. Harris Majid: Original Idea, Paper Review, Data Collection, Writing, Final Review. Mohammad R. Saeed: Data Collection, Writing of draft, Data Review and administration. Harris Khokar: Data Collection; Writing of draft. Adeena Zaidi: Data Collection; Writing of draft and administration. Arav Lohe: Data Collection Writing of draft. Olivea Ali: Data Collection; Draft Writing and administration. Mashael Sayed: Data Collection; Writing of draft and administration.

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