IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

Preeclampsia and Metal Burdens: Comparative Analysis of Maternal and Cord Blood in Northern India

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Abstract : This study examines the concentrations of various metals (Mg, Fe, Mn, K, Ni, Pb, Zn, B, Al, Ba, Cd, Ca, Co, Cu, and Cr) in the umbilical cord and maternal blood of women, distinguishing between those with and without preeclampsia. We collected blood samples from 10 mother-child pairs and used ICP-OES to measure metal levels. We also utilized statistical analysis to look at fetal anthropometric data such birth weight, height, and head circumference. There were significant differences ($p<0.05$) between the study and control groups for most metals in both maternal and cord blood. These metals were Fe, K, Mg, Mn, Ni, Pb, Zn, Ba, Ca, Cd, Co, Cr, and Cu in maternal blood, and Fe, K, Mg, Mn, Ni, Pb, Zn, Al, Ba, Ca, Cd, Co, Cr, and Cu in cord blood. There was no significant difference ($p>0.05$) between Al in maternal blood and B in cord blood. Initial findings from this limited cohort reveal a notable disparity in the number of children and the stature of females, indicating a potential correlation between elevated levels of specific metals and preeclampsia. These elevated metal concentrations appear to adversely affect fetal anthropometric growth, resulting in a slight reduction in birth height, weight, head circumference, and ponderal index in preeclamptic cases relative to control groups. Linear regressions indicated significant positive correlations ($p<0.05$) between birth weight and Mn/Cu levels in cord blood, as well as Cu/Ca/Mg levels in maternal blood. This pilot study offers foundational multi-metal insights into preeclampsia in Northern India**.**

Keywords : Heavy Metals, Preeclampsia, Cord blood, Maternal blood, Birth weight, Environmental Toxicology

I. INTRODUCTION

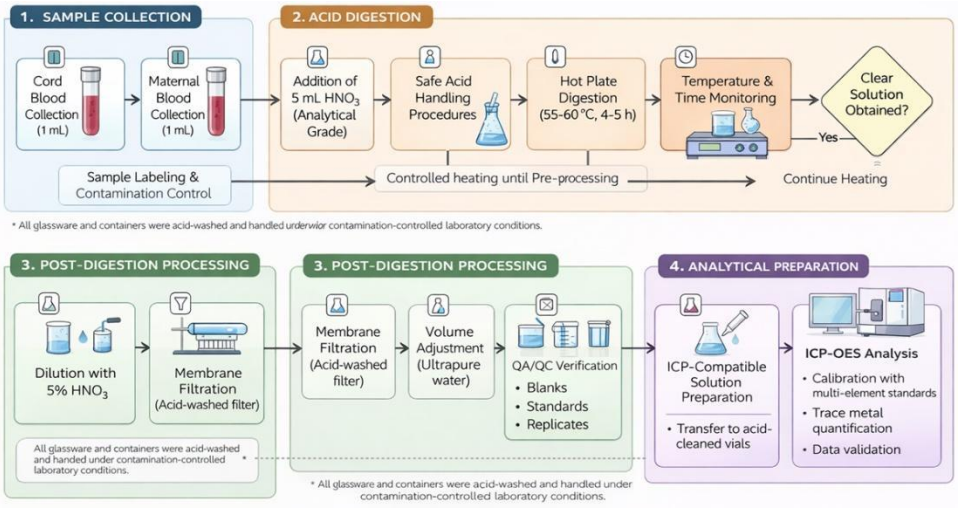
Pregnancy stands as a crucial period and eagerly awaited stage in every woman's life, often marked by dietary adjustments due to rapid growth and cell differentiation resulting from healthy pregnancies (Wang et al., 2018). Certain metals are crucial for sustaining metabolism in the human body; however, they can pose a risk of poisoning due to their tendency to accumulate in biological tissues. The industrial revolution, which has increased the opportunities for women to be exposed to metals at work and in the community, has revealed their negative effects on pregnancy (Daston, 1994). In recent years, research has increasingly focused on investigating the health implications of exposure to trace amounts of metals, which may exhibit toxicity even at concentrations previously considered safe for humans (Chen et al., 2022). Established predisposing factors contribute to the onset of preeclampsia, where the risk is contingent upon individual elements and the aggregation of related factors (Gajewska et al., 2020). Preeclampsia is a condition unique to pregnancy marked by high blood pressure and proteinuria, presenting as a multisystem syndrome typically developing after twenty weeks of gestation (Craici et al., 2014). It represents a significant public health issue across both developing and developed nations, resulting in perinatal and maternal mortality and morbidity on a global scale (Osungbade and Ige, 2011). Preeclampsia is a probable disease with several conjectures and theories, but its etiology remains unknown. The occurrence of this disease might be influenced by environmental factors (Li et al., 2024). The seasonal variation observed in the prevalence of preeclampsia, peaking during winter months and reaching a minimum in summer, indicates the potential influence of environmental factors on the occurrence of this disease (Vigeh et al., 2006). Cadmium (Cd) and lead (Pb) in preeclampsia have been recently studied (Liu et al., 2019). Elevated levels of lead (Pb) and cadmium (Cd) in the blood have been linked to negative pregnancy outcomes, including a higher risk of preeclampsia. Additionally, there are significant (nonlinear or linear) relationships between lead (Pb), selenium (Se), and mercury (Hg) levels and the occurrence of preeclampsia (Hansson et al., 2015). Additionally, exposure to Cd during pregnancy may disturb Ca or Mg metabolism (Ibrahimou et al., 2014). Micronutrient deficiencies such as low levels of selenium (Se), copper (Cu), zinc (Zn), and manganese (Mn) during pregnancy might affect the mother's antioxidant capacity and raise the possibility of unfavorable pregnancy outcomes such as preeclampsia (Mistry et al., 2015). Magnesium (Mg) and calcium (Ca) are crucial micronutrients essential for regulating blood pressure. A lack of micronutrients such as calcium (Ca) and magnesium (Mg) is associated with higher absorption of cadmium (Cd) and an elevated risk of preeclampsia (Dakshinamurti and Dakshinamurti, 2001). Preeclampsia has detrimental impacts on maternal and perinatal health, which emphasizes the significance of assessing risk factors, especially in low-resource settings where the consequences are thought to be more prominent (Gernand et al., 2016). On the contrary, a different study found no correlation between lead (Pb) levels in cord blood and the incidence of preeclampsia (Yazbeck et al., 2009). Factors that increase the likelihood of developing preeclampsia include being a young or older woman over

40 years old, being pregnant for the first time, having pregnancies spaced either less than 2 years apart or more than 10 years apart, having a pregnancy with a new partner instead of the father of previous children, having high blood pressure before pregnancy, having a history of preeclampsia, and having a history of obesity or multiple pregnancies (South African National HIV Prevalence, Incidence, Behaviour and Communication Survey, 2010). Over the past decade, there have been studies indicating significant advancements in understanding the pathophysiology of preeclampsia (Manten et al., 2007). Theories revolving around endothelial cell dysfunction have been extensively explored. Various factors such as vascular and angiogenic factors, oxidative stress, insufficient trophoblastic invasion, genetic and immunological elements, and environmental influences contribute to the validation of these hypotheses (Sánchez-Aranguren et al., 2014). Worldwide, the occurrence of preeclampsia varies between 2% and 10% of pregnancies. Each year, more than half a million women succumb to pregnancy-related causes, with 99% of these fatalities occurring in developing countries (Duley, 2009). However, it is believed that the severity of this condition is more pronounced in developing countries (Selwyn, 1990). Research findings have revealed that preeclampsia prevalence in developing nations varies from 1.8% to 16.7%, with at least 16% of maternal fatalities linked to this condition (Wu et al., 2021). The occurrence of preeclampsia is reported to be 8–10% in Canada (Steiner and Lushbaugh, 1986). According to another study, 7.8% of the study population in India experienced hypertensive disorders of pregnancy, with preeclampsia occurring in 5.6% of cases (Sharma et al., 2019). Another thesis study reported the prevalence of preeclampsia at 10.7% (Sampada, 2017). In one study, 7.8% of pregnant women had hypertensive problems, and 5.4% of the Indian population under investigation had preeclampsia. Despite the adverse impact of preeclampsia on maternal and neonatal outcomes, understanding the etiology and causes of the disorder remains a significant challenge (Sajith et al., 2014). The significance of risk and severity may multiply several times with a prior history of preeclampsia in a previous pregnancy. Women with chronic renal disease have a 20:1 chance of developing preeclampsia, whereas women with critical hypertension have a 10:1 chance. Predominantly, Agra's economy relies on agriculture, supplemented by small-scale industries, businesses, and trade (Agra District Website, 2026). Over recent decades, Agra has experienced industrial growth, leading to an increase in both licensed industrial units and the population. Therefore, anthropogenic causes in the city include emissions from industrial processes, which also lead to the contamination of water resources with toxic metals (Parveen et al., 2018; Daszak et al., 2001). A previous study conducted in the Agra region reported that exposure to metals becomes more adverse for people residing in low-income households and comes with increased exposure to these sources of metal contamination (Paul, 2017). Toxic metals should be considered crucial pollutants posing risks during pregnancy, as they are associated with the onset of proteinuria and hypertension typically occurring after the twentieth week of gestation (Ness and Roberts, 1996). Toxic metals in the environment, such as nickel, lead, and cadmium, are well-known confounding variables and represent one of the main causes of maternal mortality and morbidity, as well as factors related to pregnancy, such as intrauterine growth restriction, preterm birth, and fetal death (Sandal et al., 2025). A World Health Organization report showed that India stands at the top of the list among developing nations in terms of preterm deliveries. The present study constitutes a thorough and regionally specific case-control examination, uniquely positioned to elucidate metal-related risks in preeclampsia within an Indian setting where such detailed biomonitoring data remain scarce. There has been a scarcity of research focusing specifically on evaluating metal concentrations in both cord and maternal blood samples of women with or without preeclampsia, as well as identifying the risk factors linked to the development of preeclampsia among pregnant women in developing nations. The aim of this study was to investigate the correlation between the concentrations of metals including Zn, Fe, K, Mn, Mg, Ni, Pb, Al, B, Ca, Ba, Cd, Co, Cu, and Cr, as well as the characteristics of the newborns and the epidemiologic data gathered from the pregnant women using a questionnaire study. This work fosters a future with reduced environmental toxicant burdens and improved maternal and perinatal outcomes.

II. Materials and Methods

This rigorous hospital-based case-control study, involving matched mother-infant pairs from diverse rural and urban backgrounds in Agra, Uttar Pradesh, India, enables a detailed comparative assessment of metal burdens and their associations with preeclampsia and fetal anthropometrics in an underrepresented Indian context. It provides a complete and in-depth profile of essential and toxic metal levels in maternal and cord blood, generating region-specific evidence on environmental exposures relevant to maternal and neonatal health outcomes in northern India. The study was conducted at three antenatal clinics and delivery units in and around Agra, Uttar Pradesh, India. The study population consisted of pregnant women residing in the Agra region. Inclusion criteria were singleton pregnancy, maternal age ≥20 years, and delivery at term or late preterm (mean gestational age: 39±1 weeks). Exclusion criteria included assisted reproductive technology, pre-existing chronic hypertension, diabetes mellitus, renal disease, cardiac disease, or any major fetal anomaly. Ten mother-child pairs were monitored after delivery, with the initial aim of investigating chronic exposure to metals in mothers and infants. Participants were recruited at 28 weeks of gestational age via convenience sampling; response rate ~70% from antenatal clinics; those selected and willing to participate were enrolled. The study comprised two groups: the preeclampsia group (study group) with five women (from rural and urban areas) diagnosed with preeclampsia, and the control group with five randomly selected healthy pregnant women from the general population in the study area. Blood samples were collected from pregnant women in good health who reported no accidental or occupational exposure to pollutants. For the participants enrolled in this study, their informed consent was obtained after explaining the study purpose, and this study was approved by the ethics committee of the university, and all participants were interviewed post-delivery. Case histories included maternal age, education, occupation, residential area, preeclampsia history, and associations with preeclampsia and preterm birth. The questionnaire also covered socioeconomic status, parity, dietary patterns, alcohol consumption, smoking, gestational age, reproductive history, and past illnesses. Neonatal outcomes documented included birth weight, sex, height, head circumference, ponderal index (kg/m^3), and categorization of prematurity (gestational age ≤36 weeks).

Figure 1. Flow Chart of Blood Sample Preparation for ICP-OES Metal Analysis.



Sample selection and collection of cord and maternal blood samples from women with or without preeclampsia were performed (Fig. 1). The blood samples were collected after parturition. Sample selection and collection of cord and maternal blood samples from women with or without preeclampsia were performed (Fig. 1). The blood samples were collected after parturition. Approximately 1.0 ml of blood was gathered from each subject in pre-heparinized vials, which prevented blood clotting, and transported to the laboratory for further analysis. The samples were immediately stored in a deep freezer (Blue Star Model; CHFSD100D) until metal extraction. All collection materials were previously acid-washed (10% v/v HNO_3 for ≥48 h) and rinsed with Milli-Q water to avoid contamination. Metal analysis was performed using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry) (Perkin Elmer Optima CP-OES 5300V) at CIMAP (Central Institute of Medicinal and Aromatic Plants, Lucknow). We adhered to the metal extraction method as outlined by (Singh et al., 2016). In the extraction process, 1 ml of cord or maternal blood was gathered in an Erlenmeyer flask and combined with 5 ml of HNO_3. The solution underwent additional digestion on a hot plate at 55–60ºC with concentrated nitric acid until a clear solution was obtained. Following digestion, the solution was diluted to 5 ml using 5% HNO_3 in decontaminated test tubes and stored at 4ºC until analysis. Determination of Mg, Fe, Mn, K, Ni, Pb, Zn, B, Al, Ba, Cd, Ca, Co, Cu, and Cr in maternal and cord blood was carried out using inductively coupled plasma-optical emission spectrometry (ICP-OES; Perkin Elmer Optima 5300V) at the Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow. Quality assurance/quality control (QA/QC) included limits of detection (LOD)/quantification (LOQ) per metal (e.g., Pb: LOD 0.01 µg/dL, LOQ 0.03 µg/dL; similar for others based on instrument standards), calibration curves with $R^2 > 0.99$, and validation against NIST SRM 966 certified reference material (recovery 95–105%). Quality control measures included analysis of procedural blanks (n=6 per batch of 10 samples) and sample duplicates (20% of total samples) in triplicate with every analytical run. Spike recoveries ranged between 90 and 110%, and relative percentage differences for duplicates were <10% for all elements. The data obtained were subjected to further statistical analysis. Values are represented as mean ± SD. A univariate analysis of continuous data was performed utilizing an independent samples T-test to compare quantitative variables between the study and control groups, with Cohen's d effect sizes reported. We used chi-square tests for categorical variables and calculated correlations between metals and birth outcomes with Pearson's r (for normally distributed data) or Spearman's rho (for non-normal data; values were similar due to the small sample). Because this was a small pilot study (n=10), we only computed simple univariate odds ratios for key metals (like Pb above 0.07 µg/dL), adjusted for age, BMI, parity, and rural/urban area; more advanced analyses (such as metal mixture models) are planned for future larger studies (n>100), and post-hoc power analysis showed low power (~11%) for medium effects but moderate to good power (25–88%) for the large effects we actually found in significant metals. A significance level of a p-value below 0.05 was considered indicative of statistical significance. The analyzed questionnaire survey covered various aspects such as age, height, weight, BMI, number of children, duration of lactation, weight gain during pregnancy, birthplace, hospital of reference, lifestyle, education, eating patterns, and prior health conditions. Additionally, the questionnaire survey included crucial inquiries regarding the newborns, encompassing details such as the baby's weight, height, head circumference, ponderal index, and sex.

III. Results and Discussion

The general features of the subjects in the research work are presented in Tables 1 and 2, which demonstrate the characteristics of all participants categorized as women and infants in both the control group and the study group. In the control group, mothers experienced an average weight gain of 9.8 kg during pregnancy, whereas in the study group, the average weight gain was 11.2 kg. In the control group, 60% of pregnant women were from rural areas and 40% from urban areas, all having completed their education up to the 12th grade. In the study group, 20% were from rural areas and 80% from urban areas, with educational attainment of less than high school. The numbers of male and female babies in this population were 80% and 20%, respectively, in the control group, and 40% male and 60% female were found in the study group. In the control group, the average birth weight of newborns was 2.61 kg, with a range from 1.5 kg to 3.5 kg. In contrast, in the study group, the average birth weight was 2.88 kg, with a range from 2.4 kg to 3.5 kg. There were no statistically significant variances found in the weight, height of newborns, ponderal index, or head circumference between the case and control groups ($p > 0.05$). The average head circumference was 30 cm in both groups. The range of the ponderal index was 14.44–63.78 kg/m³, and the mean value was 32.53 kg/m³ in the control group. The range of the ponderal index was 21.7–35.5 kg/m³, and the mean value was 30.95 kg/m³ in the study group. These data support previously

conducted studies (Singh et al., 2020). The study group exhibited a higher gestational age compared to the control group. Additionally, the body mass index (BMI) was 18.64 kg/m² in the control group and 24.44 kg/m² in the case group. A high maternal body mass index is related to a large number of pregnancy-related difficulties, such as preeclampsia and preterm and post-term delivery (Wilson, 2018). Numerous studies have indicated that overweight women face an elevated risk of developing preeclampsia, and those with a higher BMI during pregnancy are more prone to hypertension compared to those with lower BMIs (Habibi et al., 2020). We also observed differences in the BMIs of both groups.

Table 1. General characteristic of the women in study and control group

Characteristics		Control group Mean±SD	Study group Mean±SD	p-value	Cohen's d
Gestational age (weeks)		39±1	38±1	0.12	-1.0
Age (year)		29±7.74	23.2±1.30	0.14	-1.05
Height (m)		1.61±0.02	1.57±0.03	0.04	-1.57
Weight (Kg)		48.8±9.23	60.6±10.99	0.10	1.16
BMI (Kg/m^2)		18.64±3.46	24.44±4.46	0.05	1.45
Number of children		2.4±0.54	1.2±0.44	<0.01	-2.44
Duration of lactation (Months)		10±11.31	1±0	0.11	-1.13
Weight gain during pregnancy (Kg)		9.8±1.48	11.2±2.77	0.35	0.63
Dietary habits	Vegetarian	4(80%)	2(40%)	--	--
	Non-vegetarian	1(20%)	3(60%)	--	--
Education	≥High school	3(60%)	3(60%)	--	--
	<High school	2(40%)	2(40%)	--	--
Abode	Rural	3(60%)	1(20%)	--	--
	Urban	2(40%)	4(80%)	--	--

Table 2. Characteristics of infants in control group and study group

Variables		Control group Mean±SD	Study group Mean±SD	p-value	Cohen's d
Weight of baby (gm)		2610±0.72	2880±0.56	0.53	0.42
Height (cm)		44±0.45	45±0.45	<0.01	2.22
Head circumferences (cm)		30±2.38	30±1.22	1.0	0.00
Ponderal Index (kg/m^3)		32.53±18.45	30.95±6.24	0.86	-0.11
Gender	Male	4	2	--	--
	Female	1	3	--	--

We further investigated and compared metals like K, Fe, Mn, Mg, Pb, Ni, Al, Zn, Ba, B, Ca, Cd, Cr, Co, and Cu levels in the cord blood and maternal blood samples of the study and control groups (Table 3). Several studies have described the concentration of toxic metals like cobalt, aluminum, chromium, nickel, cadmium, and lead in maternal blood and cord blood of women (Gamelin et al., 2009). The metal content in cord blood suggests passive diffusion through the placenta, potentially contributing to abnormal placental function. This can hinder the proper transfer of essential nutrients to the fetus, which is crucial for optimal fetal development. Mothers transmit their chemical load to the fetus, so sampling both normal and preeclamptic maternal blood during childbirth enables an assessment of the fetus's varying exposure levels at different stages of growth. The trend obtained in maternal blood concentrations of metals was Ca > K > Fe > Mg > Al > Cr > Zn > Ni > Cu > Mn > Ba > Pb > Cd > Co > B for the control group and K > Fe > Ca > Zn > Cr > Mn > Al > Ni > Cu > Pb > Ba > B > Mg > Co > Cd for the study group, and K > Ca > Fe > Mg > Al > Cr > Zn > Ni > Cu > Ba > Pb > B > Mn > Cd = Co for the control group and K > Fe > Ca > Cr > Al > Mn > Zn > Ni > Cu > Pb > Ba > B > Co > Cd > Mg for the study group

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Table 3. Levels of Metals in Cord and Maternal Blood of Study Group and Control Group

		Maternal blood			Cord blood		
S.No.	Metals	Study group Mean±SD µg/dL	Control group Mean±SD µg/dL	p-value (MB: Study vs Control)	Study group Mean±SD µg/dL	Control group Mean±SD µg/dL	p-value (CB: Study vs Control)
1	Fe	92.12±16.90	54.06±19.96	P<0.001	82.54±34.88	59.06±33.48	P=0.010
2	K	233.34±53.02	191.31±95.81	P=0.041	248.94±61.92	179.92±167.47	p=0.041
3	Mg	0.18±2.67	18.26±10.91	p<0.001	0.02±2.70	10.62±4.42	p<0.001
4	Mn	7.53±4.90	0.18±0.19	p<0.001	7.12±5.36	0.01±0.05	p<0.001
5	Ni	2.96±1.79	1.07±0.61	p<0.001	3.12±2.63	0.62±0.27	p<0.001
6	Pb	0.31±0.05	0.07±0.14	p<0.001	0.30±0.039	0.04±0.05	p<0.001
7	Zn	12.34±7.95	1.18±0.89	p<0.001	6.70±6.11	0.93±0.20	p<0.001
8	Al	7.38±6.17	6.82±4.73	p=0.695 (ns)	7.98±9.74	3.94±1.38	p=0.032
9	B	0.19±0.07	0.00±0.18	p<0.001	0.08±0.29	0.02±0.33	p=0.458 (ns)
10	Ba	0.20±0.10	0.08±0.26	p=0.024	0.23±0.08	0.08±0.06	p<0.001
11	Ca	61.56±15.87	202.7±63.19	p<0.001	59.94±13.96	163.30±158.5	p=0.001
12	Cd	0.04± 0.01	0.02±0.015	p<0.001	0.04±0.016	0.00±0.01	p<0.001
13	Co	0.05± 0.03	0.00±0.01	p<0.001	0.05± 0.054	0.00±0.01	p<0.001
14	Cr*	12.1±7.96	1.45±0.99	p<0.001	11.18±9.12	0.94±0.29	p<0.001
15	Cu	2.59±1.46	0.41±0.18	p<0.001	2.46±1.56	0.19±0.08	p<0.001

ns = not significant (typically p>0.05).

Higher concentrations of metals were found in preeclamptic females (study group) in comparison to normal females (control group), except for Ca. Ca deficiency in preeclamptic mothers can be cured by Ca supplementation, which works as an anticipant for preeclampsia, as stated in WHO guidelines (Omotayo et al., 2016). We also observed that blood concentrations of K, Zn, Mn, Pb, Al, Cr, and Cu were related to preeclampsia and birth weight. Certain associations were only evident when examining exposure at specific prenatal time intervals, indicating periods of vulnerability to exposure effects (Ashrap et al., 2020). A reduced head circumference of 30 cm was observed in the control group, and weight loss in newborns was associated with Pb, Mn, and Mg. Therefore, the combined impact of lead (Pb) was identified as the most significant forecaster of preterm birth (Doyle et al., 1989). Similar to the findings of Luo et al. reported in 2017 (Luo et al., 2017), Cd was negatively associated with BW (Signes-Pastor et al., 2019). Additionally, all blood samples (maternal and cord blood from both the study and control groups) in this study were found to have lead (Pb) concentrations lower than the threshold of concern set by the Centers for Disease Control and Prevention (CDC) for pregnant women (Ettinger and Wengrovitz, 2010). There was no notable correlation found between Cd, As, Ba, and B and birth weight. In the control group, the lowest concentration was 0.41 µg/dL for copper (Cu) in maternal blood and 0.19 µg/dL in cord blood. In contrast, the concentrations were 2.59 µg/dL and 2.46 µg/dL in maternal blood and cord blood, respectively, in the study group. Manganese (Mn) is a vital trace element for humans, yet both insufficiency and excessive intake can lead to negative developmental consequences, including reduced birth weight (Eum et al., 2014). We found a significant association between Mn and preeclampsia, which could be responsible for fetal death. The higher values of elemental exposure to Cu and Zn in the study group in comparison with the control group revealed inconsistent results concerning pregnancy outcomes. Fig. 2 depicts the combined concentration of metals in both the cord and maternal blood of both normal and preeclamptic females, indicating that maternal metal concentrations surpassed those found in cord blood. In the control group of pregnant women, higher concentrations of essential elements like calcium (Ca) and magnesium (Mg) were observed, likely due to supplementation. Conversely, in the study group of pregnant women addressing preeclampsia, elements such as iron (Fe), manganese (Mn), potassium (K), and zinc (Zn) were administered to manage the condition.

Figure 2. Total Burden of Metals in Cord and Maternal Blood of Normal and Preeclamptic Females

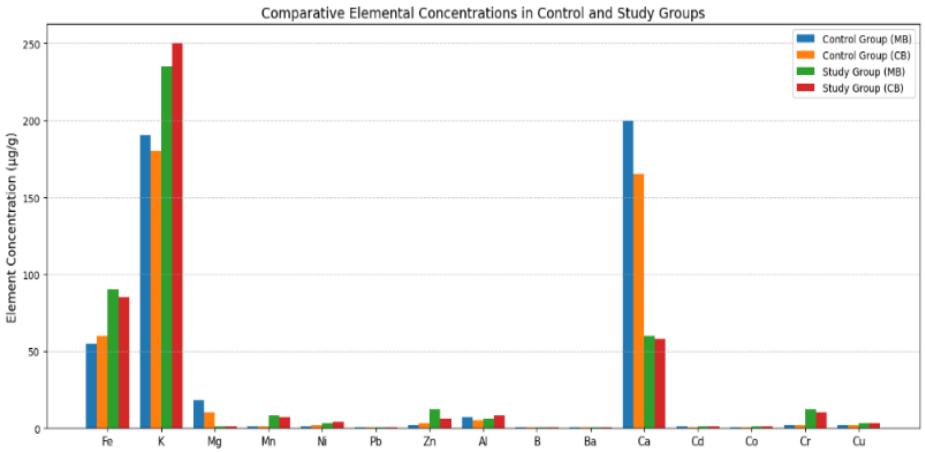
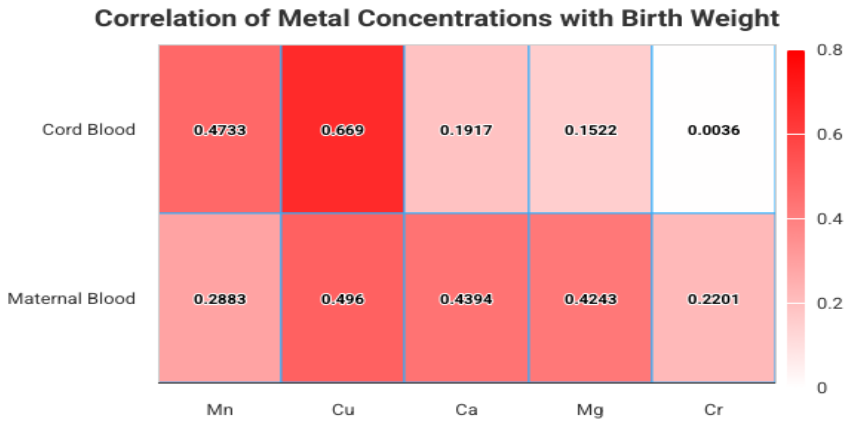


Figure 3. Correlation of metals with birth weight in cord blood and maternal blood samples of control and study group females.



CB= Cord blood, MB= Maternal blood

To understand the relationship and chemical characteristics of various metals and birth weight, the correlation coefficient is explained by using the metal concentration and birth weight data, and their outputs are shown in Fig. 3. A positive correlation was established for Mn, Cu, Ca, Mg, and Cr (R^2 = 0.4733, 0.6690, 0.1917, 0.1522, and 0.0036, $p < 0.05$) in cord blood samples and (R^2 = 0.2883, 0.4960, 0.4394, 0.4243, and 0.2201, $p < 0.05$) in maternal blood samples (Table 4). There was no notable correlation found between birth weight and the metal levels of Fe, K, Ni, Al, Cd, Pb, Zn, B, Ba, and Cu in the maternal and cord blood samples. The findings align with those of previous studies (Dahiri et al., 2023; Felicia, 2016). These values indicated a relatively weak correlation and were notably low (Howe et al., 2022), suggesting that the placenta functions as a barrier, effectively obstructing the passage of these specific metals. Additionally, the estimation revealed that the correlation between Cu and Mn was comparatively better than that between Ca, Mg, and Cr. This suggests a restricted transplacental passage of Ca, Mg, and Cr from the mother to the fetus, and that Mn and Cu levels in cord blood might stem from maternal circulation, facilitated by the placenta. Further, our research found that, with the exception of Fe and Zn, which are found in larger concentrations in the maternal matrix than in the cord blood, the average values of the metals examined are very similar for Mg, Mn, Ni, K, Pb, Al, B, Ba, Ca, Cd, Cu, Cr, and Co in maternal and cord blood samples. This finding suggests that the measured metals may traverse the placental barrier, reach the cord blood, and affect the fetus (Bocca et al., 2019). Notably, potassium (K) is an exception, as its levels are lower in maternal matrices than in cord blood. These values may also be associated with physiological changes experienced by pregnant women, such as elevated plasma volume, bone resorption, body fat, excretion, and factors such as sociodemographic characteristics and lifestyle habits (Li et al., 2019). It is significant to recognize that the present sample size is insufficient for accurately estimating the risk factors associated with preeclampsia, given the limited number of collected samples. The observed differences must be interpreted cautiously because of the small sample size and limited statistical power. However, this preliminary study underscores the need for detailed and long-term investigation. The findings point to the necessity of conducting a more detailed investigation to learn more about the harmful health impacts of these contaminants on fetuses and to examine correlations with other parameters, such as oxidative stress, maternal supplement intake during pregnancy, diet, pollution-related factors, and other possible sources that were not considered in our investigation.

Table 4. Linear Regression Analysis of Metal Concentrations vs. Birth Weight

Metal	R^2 Value	Calculated p-value	Interpretation
		Cord Blood Samples	
Mn	0.4733	0.0279	Positive correlation; significant ($p < 0.05$)
Cu	0.6690	0.0038	Positive correlation; highly significant ($p < 0.01$)
Ca	0.1917	0.2057	Positive correlation; not significant ($p > 0.05$)
Mg	0.1522	0.2651	Positive correlation; not significant ($p > 0.05$)
Cr	0.0036	0.8692	Positive correlation; not significant ($p > 0.05$)
Fe	Not reported (low)	> 0.05	No notable correlation
K	Not reported (low)	> 0.05	No notable correlation
Ni	Not reported (low)	> 0.05	No notable correlation
Al	Not reported (low)	> 0.05	No notable correlation
Cd	Not reported (low)	> 0.05	No notable correlation
Pb	Not reported (low)	> 0.05	No notable correlation
Zn	Not reported (low)	> 0.05	No notable correlation
B	Not reported (low)	> 0.05	No notable correlation

Ba	Not reported (low)	> 0.05	No notable correlation
		Maternal Blood Samples	
Mn	0.2883	0.1095	Positive correlation; not significant ($p > 0.05$)
Cu	0.4960	0.0230	Positive correlation; significant ($p < 0.05$)
Ca	0.4394	0.0367	Positive correlation; significant ($p < 0.05$)
Mg	0.4243	0.0413	Positive correlation; significant ($p < 0.05$)
Cr	0.2201	0.1714	Positive correlation; not significant ($p > 0.05$)
Fe	Not reported (low)	> 0.05	No notable correlation
K	Not reported (low)	> 0.05	No notable correlation
Ni	Not reported (low)	> 0.05	No notable correlation
Al	Not reported (low)	> 0.05	No notable correlation
Cd	Not reported (low)	> 0.05	No notable correlation
Pb	Not reported (low)	> 0.05	No notable correlation
Zn	Not reported (low)	> 0.05	No notable correlation
B	Not reported (low)	> 0.05	No notable correlation
Ba	Not reported (low)	> 0.05	No notable correlation
Co	Not reported (low)	> 0.05	No notable correlation

IV Conclusions

This case-control study from the Agra region of India offers a thorough evaluation of various trace metals in maternal and cord blood during preeclampsia. It indicates elevated concentrations of toxic metals and diminished concentrations of essential metals in preeclamptic pregnancies relative to normal pregnancies. These imbalances may be involved in the disease process and suggest that increasing essential metal intake through diet or supplements could help prevent or control preeclampsia. As one of the most detailed multi-metal profiles in maternal-cord pairs from this part of northern India, the study offers important baseline data for developing countries like India.

Acknowledgements

The authors thank the H.O.D. of the Department of Chemistry, Dr. Bhimrao Ambedkar University, Agra, for their generous support and provision of facilities and the Women Post-Doctoral Fellowship (F.15-1/2016-17 PDFWM-2015-17) awarded by the University Grants Commission, New Delhi, Government of India, to one of the authors.

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