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Application of biomonitoring approaches to evaluate multimetal exposure among residents of Chennai – a preliminary study

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Abstract

Multimetal, naturally occurring elements, have a widespread distribution in the environment due to industrial, agricultural, and technological applications, which has raised concerns about potential health impacts. This study aimed to explore multimetal exposure in 100 adults aged 20-60 years in Chennai, using human biomonitoring techniques. Blood samples were analyzed for arsenic, cadmium, chromium, lead, and vanadium concentrations using ICP-MS, and matrix-matched certified reference material was used for quality control and assurance. Questionnaires were collected for exposure information. The limits of detection (LOD) for trace metals were: As 0.26, Cd 0.23, Cr 0.36, Pb 0.29, and V 0.29 µg/L, respectively. The Seronorm-certified reference values for whole blood trace metals showed accuracy between 96 - 100%. Geometric mean concentrations were: As 0.3, Cd 0.03, Cr 0.87, Pb 4.65, and V 0.23 µg/dL, correspondingly. Cadmium concentration was associated with socioeconomic status ($p = 0.02$). Smoking demonstrated an association with chromium ($p = 0.012$) and vanadium ($p = 0.003$). Furthermore, vehicular traffic was associated with cadmium ($p = 0.005$) and chromium ($p = 0.004$), and lead concentration was associated with water treatment ($p = 0.051$). This study provides evidence of multimetal exposure risks in Chennai residents. Further large-scale biomonitoring studies are warranted to elucidate exposure sources and health impacts.

Keywords: Analytical, Blood, Certified Reference Material, Chennai, Exposure, ICP-MS, Matrix-matched, Microwave digestion, Multimetal, Human biomonitoring.

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1. Background

Multimetals are naturally occurring elements, and their extensive distribution in the environment has resulted from industrial, residential, agricultural, medical, and technological applications, raising concerns about their possible detrimental impacts on human health and the environment. The World Health Organization (WHO) has identified ten chemicals or chemical groups that pose significant public health risks, including arsenic, asbestos, benzene, cadmium, dioxins, fluoride, lead, mercury, and highly hazardous pesticides [1]. The International Agency for Research on Cancer (IARC) has classified arsenic (As), cadmium (Cd), and chromium (Cr) as Group I human carcinogens [2], and lead (Pb) is classified as probably carcinogenic (Group 2A) to humans [3]. High levels of these toxic metals are linked to increased risks of bladder, kidney, liver, lung, and skin cancers. Emerging research indicates that toxic metals may negatively affect health outcomes even at low concentrations, especially in pregnant women, infants, and children, which are likely present in many regions across the globe [4, 5].

India's rapid industrialization, urbanization, and increased reliance on vehicle transportation have led to pollution in both urban and rural areas [6]. Additionally, direct urban runoff and sewage discharge into freshwater ecosystems such as rivers, lakes, and reservoirs pose significant threats to water quality and the ecological health of these environments. Heavy metals are introduced into river systems from both anthropogenic and natural sources, and they can be found in the water column, suspended particles, or riverbed sediments [7]. Many rivers in India, especially the Ganges River, experience contamination arising from various industries, including mining, galvanization of iron products, paint and pigment production, varnishes, pulp and paper manufacturing, tanneries, distilleries, rayon and cotton textile production, rubber manufacturing, thermal power plants, steel plants, and the negligent use of heavy metal-containing pesticides and fertilizers in agriculture [8]. These heavy metals can accumulate at low concentrations in drinking water and groundwater, posing significant health risks [9]. Groundwater plays a crucial role in meeting India's water demands. However, sewage and industrial waste are contaminating groundwater at an alarming rate [10, 11].

Chennai is one of the metropolitan cities hosting various industries, including cotton mills, tanneries, chemical plants, refineries, and pesticide and fertilizer production. Additionally, several areas of the Chennai district feature geological formations of crystalline rocks that serve as deep aquifers, while others are covered with alluvium and sediments [12]. Research on metal contamination in groundwater across different regions of Chennai revealed that levels of heavy metals such as lead, cadmium, copper, and iron exceeded the WHO guidelines at many locations. The highest levels of lead pollution were recorded in the north and west zones, measuring 0.1 mg/l and 0.06 mg/l, respectively. Cadmium levels were elevated in nearly all zones except the central zone. Meanwhile, chromium, manganese, zinc, and iron levels were found to be within acceptable ranges [13].

Ennore and Pulicat Lake in Chennai showed elevated levels of chromium (Cr), lead (Pb), arsenic (As), and cadmium (Cd) [14]. In Besant Nagar, a study found increased concentrations of heavy metals, including iron (Fe), lead (Pb), zinc (Zn), chromium (Cr), cobalt (Co), and manganese (Mn), in groundwater during the post-monsoon season compared to the pre-monsoon season [15]. Buckingham Canal also reported high concentrations, with chromium at 0.006 to 0.012 mg/L, copper at 1.04 to 1.34 mg/L, iron at 0.23 to 1.75 mg/L, lead at 0.013 to 0.035 mg/L, and zinc at 0.125 to 1.6 mg/L, all exceeding allowed limits [16]. The high concentrations of metals in the water bodies, their entry into the ecological food chain, and the resulting health effects are of great concern to researchers in the areas of ecology [17]. Heavy metals accumulate in soil from various sources, including irrigation water, leading to ecosystem damage and health risks. They can be absorbed by the edible parts of vegetables, entering the food chain and contributing to chronic illnesses in humans [18].

Additionally, an Indian study summarizes that the use of alternative medicine is often associated with high levels of heavy metal contamination, and the population frequently consumes these herbal medications. The study strongly recommended avoiding harmful substances in herbal remedies, particularly lead, cadmium, mercury, and arsenic in alternative medicines [19]. Even children's toys and lead-based paints can contribute to significant exposure in the community [20, 21].

Environmental contaminants can enter the body through various pathways and may be stored and distributed across different tissues. This accumulation can lead to internal concentrations that result in a range of adverse effects, including health issues and diseases. Therefore, testing biological samples (blood, urine, saliva, hair, breast milk, and nails) is a more reliable method for estimating toxic contaminant levels and understanding environmental exposure.

Many Indian studies have assessed the metal concentration in biological fluids. A study conducted in Chennai reported that the average blood lead level among children was 11.47 μg/dL (2.6–40.5) ± SD = 5.33. Notably, 54.5% of the toddlers had blood lead levels above 10 μg/dL [22]. In a related study from Vellore [23], increased blood lead levels in children were found. They analyzed a total of 226 blood samples from 15-month-old children, revealing blood lead levels (BLL) that ranged from 2.4 to 29.7 μg/dL, with an average concentration of 10.3 μg/dL ± SD = 5.0. Additionally, 138 blood samples from 24-month-old children showed levels ranging from 1.5 to 66.8 μg/dL, with an average concentration of 11.8 μg/dL ± SD = 8.6. Furthermore, a study assessed blood lead levels in a cohort of 222,668 individuals, finding that levels of ≥150 μg/L were high in 1.16% of cases. The prevalence was significantly higher in males compared to females [24]. Another study of 205,530 individuals identified blood arsenic levels of ≥5 μg/L, with 1.37% categorized as high. The highest levels were reported in Kerala and Mumbai [25]. A positive correlation was found between blood lead levels and hair lead content among autoworkers in Rohtak City, India. Their blood lead levels, ranging from 13.80 to 65.51 μg/dL, were significantly higher than those of the control subjects. In contrast, blood cadmium levels showed no significant difference between the groups. Both lead and cadmium were elevated in hair samples, with lead levels ranging from 12.98 to 124.13 μg/g and cadmium levels from 0.31 to 1.96 μg/g [26]. Additionally, a Kerala study investigated elevated levels of arsenic, mercury, and lead in blood, analyzing their relation to age, gender, and dietary patterns [27]. Another study found that children who used kohl (an eye cosmetic) and traditional Ayurvedic treatments had higher blood lead levels. The study included 29 children with a mean age of 3.8 years, resulting in an average blood lead level of 6.7 mg/dL (SD = 3.5; range, 3.5–20.2) [28].

Human biomonitoring (HBM) is a valuable tool for assessing the body burden of multiple metals. It provides population-based baseline data that helps countries evaluate environmental exposure and its health impacts, leading to effective policies and control strategies. However, in our region, HBM is not well recognized, and the lack of baseline data hinders policy development. HBM data offer insights into total body burden and biological effects from various exposure routes, accounting for individual differences in exposure, metabolism, and excretion. This data is crucial for assessing the health impacts of bioaccumulating chemicals, which can persist in the body for long periods. For rapidly excreted chemicals, cross-sectional data reveals recent exposures, while repetitive sampling is needed to understand long-term exposure patterns at the individual level [29].

ICP-MS (Inductively Coupled Plasma Mass Spectrometry) is commonly used for multimetal analyses at parts per billion (ppb) levels in human biomonitoring. This technique requires samples such as blood, urine, hair, and nails to undergo high-temperature processing and digestion with concentrated acids. To obtain reliable quantitative data, it is essential to use matrix-matched Certified Reference Materials (CRMs) that have identical compositions [30]. In ICP-MS, matrix-matched quality control (QC) involves aligning the sample's matrix with that of the calibration standards. This approach significantly enhances the accuracy of the results. For this purpose, Seronorm Trace Elements Whole Blood L-1 (SERO AS, Norway) was utilized as the matrix-matched quality control material. In this study, matrix-matched quality control is used to estimate the values of multimetal concentrations in blood matrices and recognize multimetal exposure in Chennai.

2. Materials and Methods

2.1. Study Design and Participants

A cross-sectional study was conducted in Chennai between 2021 and 2022. The study included 100 participants selected through convenient sampling methods. Participants had lived in Chennai for at least five years, were between the ages of 20 and 60, and had no prior history of occupational metal exposure or chronic illnesses. Individuals with chronic health conditions or a history of metal poisoning were excluded from the study, and written informed consent was obtained from all participants. During the study, 3 to 4 ml of venous blood were drawn using BD Vacutainer® tubes. The blood samples were separated into two vials and stored at -20 °C: one vial for analysis and the other archived for future reference. For quality control purposes, duplicate samples were included in each batch in the multimetal analysis. The entire study was accepted by the Institutional Ethics Committee of the Sri Ramachandra Institute of Higher Education & Research, Porur, Chennai.

2.2. Data Collection

Data on socio-demographics, residence history, occupation history, and information about the sources of multimetal exposure were obtained from the standard questionnaire used in air pollution studies.

2.3. Measurement of Multimetal

Trained phlebotomists collected 3-4 mL of venous blood from each participant using lead-free needles and metal-free vacutainers containing ethylenediaminetetraacetic acid (EDTA) as an anticoagulant. After collection, the samples were stored at 4°C and transported to the laboratory within 24 hours. The analysis utilized the Agilent 7800 High Matrix Introduction (HMI) inductively coupled plasma mass spectrometry (ICP-MS) system based in Santa Clara, CA, USA. The samples were digested using a microwave and Suprapur® nitric acid (65%) from Merck KGaA, which has a purity of 99%. For calibration and standardization, trace element standards and certified reference materials (CRM-NIST) from Merck were employed. Additionally, a certified reference sample was obtained from SERO AS, Norway, specifically the Seronorm Trace Elements Whole Blood L-1, which was used as matrix-matched quality control.

2.4. Statistical Analysis

Microsoft Excel was used for data entry, and R software (version 4.3.3; Bell Laboratories, Hill and Mackenzie [31], US) was used for analysis. The distribution and traits of multimetal in the study population were summarized using descriptive statistics. The continuous variables are provided as Mean ± SD, while the categorical variables are shown as frequencies and percentages. A Pearson's Correlation Coefficient of multimetal concentration was conducted to evaluate the strength and direction of linear relationships between the concentrations of various metals in a sample set. Correlation coefficients were calculated between all possible pairs of metal biomarkers.

3. Results and Discussion

3.1. Multimetal Distribution

The study included 100 participants with a mean age of 32.82 years (SD = 11.13), of the participants, 90% were female and 10% were male. Multimetal analysis was performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) with a microwave digestion method. The analytical parameters included the Limit of Detection (LOD), Limit of Quantification (LOQ), calibration, linearity, and the use of matrix-matched certified reference material for quality control and assurance. The values for LOD, LOQ, linearity, and recovery are presented in Table 1. All metals showed a linearity of 0.9999. Additionally, matrix-matched quality control and recovery rates ranged from 96% to 100%. According to the manufacturer's protocol, the acceptable recovery range is between 90% and 100%. The geometric mean concentration of all metals compared to CDC reference values is displayed in Table 2. The concentration of lead (Pb) was found to be the highest in the blood samples, while cadmium (Cd) had the lowest concentration. The study also identified the pattern of multimetal toxicity in human blood within the Chennai population as follows: Pb > Cr > As > V > Cd.

Table 1.
Method validation parameters for multimetal in blood samples.

Parameter (µ/l)	75As	111Cd	52Cr	208Pb	51V
Calibration Range	1.351 – 29.898	1.250 – 30.005	1.276 – 29.867	1.292 – 29.926	1.346 – 29.872
Linearity	0.9999	0.9999	0.9999	0.9999	0.9999
LOD	0.26	0.23	0.36	0.29	0.29
LOQ	0.81	0.70	1.10	0.89	0.90
Recovery (%)	97	96	97	100	98

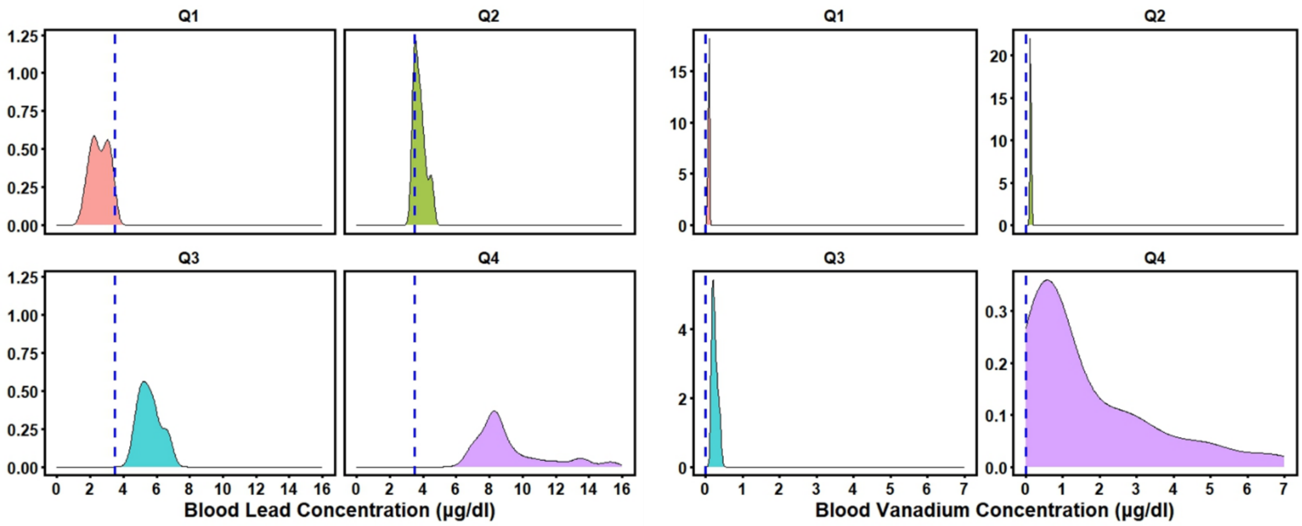
Table 2.
Comparison of multimetal concentration with Reference value.

(N = 100)	Mean (µg/dl)	G. mean (µg/dl)	Min (µg/dl)	Max (µg/dl)	Reference Value (CDC) (µg/dl)
Arsenic	0.36	0.3	0.07	1.61	<1
Cadmium	0.03	0.03	0.001	0.31	0.01 – 0.4
Chromium	1.54	0.87	0.05	9.43	2.0 – 3.0
Lead	5.28	4.65	1.57	15.29	3.5
Vanadium	0.52	0.23	0.03	6.63	0.005

3.2. Multimetal Concentration in Quartile Wise

In descriptive analysis, means ± standard deviation (SD) and counts (percentages) are used to describe quantitative and qualitative data, respectively. Spearman's rank correlation analysis was conducted to examine the correlations among blood toxicant concentrations. Due to some individuals having values below the detection limit, blood toxicant concentrations were categorized into four quartiles (Q1, Q2, Q3, and Q4) as categorical variables. The quartile containing the CDC value served as the reference point. Table 2.

Lead and vanadium concentrations are exceeding all four quartiles, whereas chromium exceeds only the fourth quartile. For other metals, all four quartiles are less than the CDC reference value. Quartile-wise graphs are shown in Figure 1. The study indicated that the exposure levels of lead, vanadium, and chromium are exceeding CDC reference values. Cadmium concentration was shown to be at the lower limits of the reference range. The study proves that the prevalence of metal exposure exists in the study area; however, the source of exposure could not be determined in this sample size.



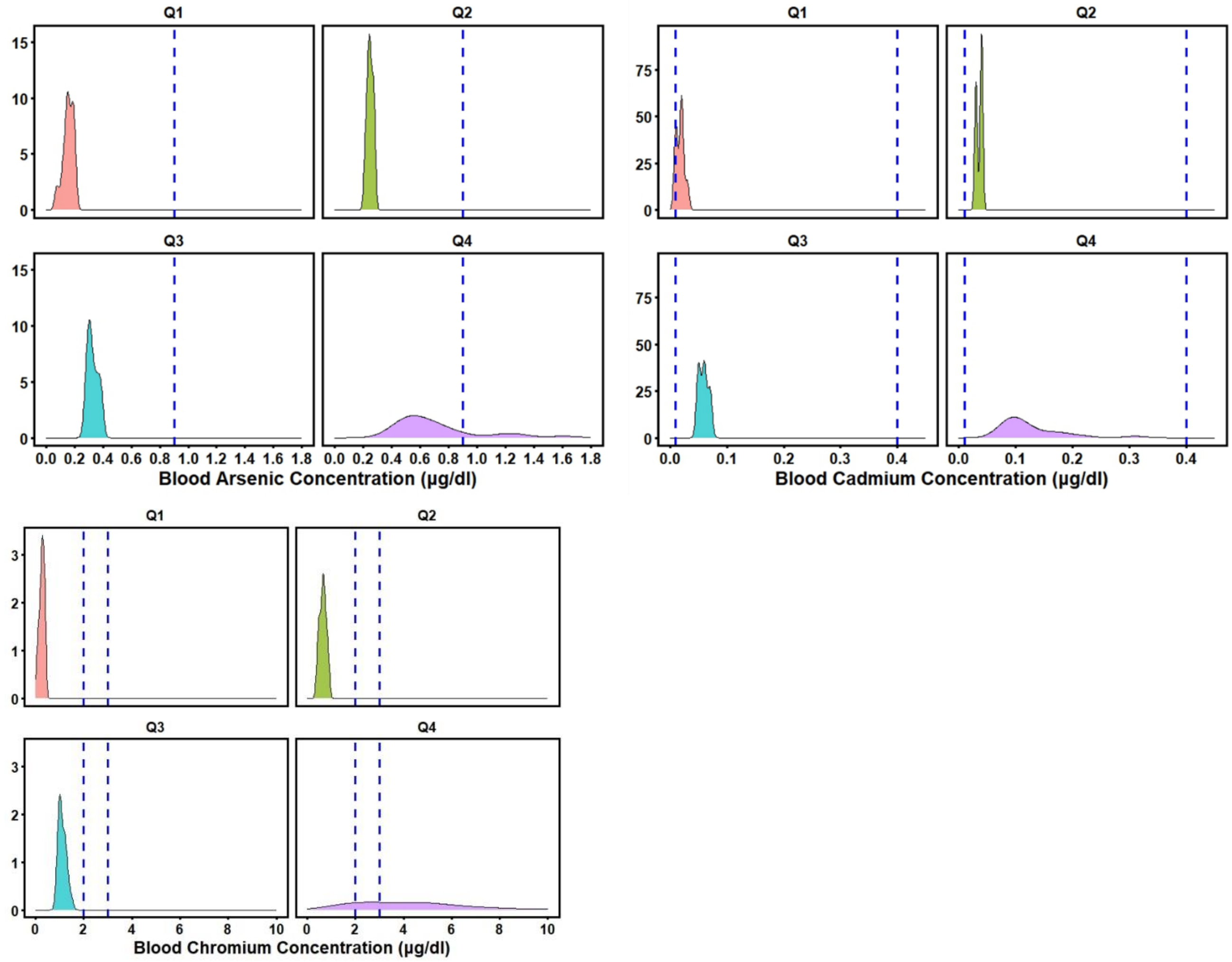


Figure 1.
Multimetal concentration in Quartile wise.

3.3. Characteristics of the Study Population

The general characteristics of the study population are summarized in Table 3. A 't' test was used to analyze the association of metal concentrations of arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and vanadium (V) with various factors, including gender, age category, BMI, years of residence, socioeconomic status, and proximity to industrial sites. No significant associations were found between genders, age, BMI, years of residence, or proximity to industrial sites. Notably, socioeconomic status was associated with cadmium (p=0.02) concentrations, while the other metals did not show significant associations.

The association between metal concentrations and common exposures in the general population, such as smoking, waste burning, cooking, water storage containers, cosmetic use, and local vehicular traffic, has been summarized in Table 4. The analysis results indicated that smoking was significantly associated with chromium (p=0.012) and vanadium (p=0.003). Additionally, vehicular traffic showed a significant association with cadmium (p=0.005) and chromium (p=0.004). Other forms of passive exposure did not show a significant correlation.

Multimetal toxicity is a global issue. However, the incidence and severity of toxicity from individual heavy metals vary depending on factors such as geographical location, natural soil composition, local customs, the presence of industries, regulatory measures to control pollution, and individual characteristics like nutritional status and genetics. When multimetal are released into the air, water, or soil, they can be absorbed by plants and crops. Livestock and fish can then consume these contaminated plants, ultimately making their way into the human food chain [32].

Expanding a similar study with an adequate sample size might help to effectively detect the source of exposure to a greater extent. The findings of the current study limit the clear understanding of the identification of the source and other exposures that could influence or contribute to this. The evidence indicating the effects of low exposure was strongest for arsenic, chromium, lead, and vanadium, while it was less certain for cadmium.

Long-term exposure to arsenic, even at low levels, can lead to skin lesions, cardiovascular, respiratory, neurological, and endocrine diseases, as well as adverse pregnancy outcomes and cognitive dysfunction in children. The International Agency for Research on Cancer (IARC) classifies arsenic as a Group 1 carcinogen, linking high exposure to cancers such as lung, bladder, and skin [33]. Chronic exposure to chromium, a heavy metal, can lead to toxicity and various pathophysiological issues. These effects may include allergic reactions, anemia, burns, and sores, particularly in the stomach and small intestine. Additionally, chromium can damage sperm and negatively impact the male reproductive system, as well as affect multiple biological systems. The pollution caused by chromium can have serious consequences for both water and soil environments [34].

Low levels of lead exposure in children can significantly affect their development, even without noticeable symptoms. It can harm the brain, impair learning and attention, and lead to behavioral issues, as there is no safe level of lead in a child's blood [35]. In adults, chronic lead exposure can cause hypertension and contribute to atherosclerosis by inactivating nitric oxide, increasing hydrogen peroxide, and promoting blood clots. Higher blood lead levels are linked to hypertension, heart abnormalities, peripheral arterial disease, left-ventricular hypertrophy, and increased cardiovascular mortality [36]. Vanadium (V) is an element that has a significant impact on mammalian organisms and is one of the most studied metals for its potential therapeutic applications. However, it is also a well-known environmental and occupational pollutant that can have harmful effects on human health. As a strong pro-oxidant, vanadium can generate oxidative stress, which is associated with neurodegeneration [37]. Chronic exposure to low-level cadmium (Cd) is known for its nephrotoxicity and has been linked to various health issues, including end-stage renal failure, early onset of diabetic renal complications, osteoporosis, dysregulated blood pressure, and an increased risk of cancer. In this study, the concentration of cadmium is very low, primarily because most of the participants are women.

Table 3.
Characteristics of the study population.

Characteristics		N (%)	Pb		As		Cd		Cr		V	
			Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value
Gender	Female	90 (90%)	4.65 (1.68)	0.895	0.3 (1.84)	0.472	0.04 (2.22)	0.77	0.9 (3.02)	0.29	0.24 (2.96)	0.44
	Male	10 (10%)	4.73 (1.45)		0.33 (1.46)		0.04 (1.86)		0.67 (2.17)		0.19 (2.44)	
Age	20-29	53 (53%)	4.2 (1.67)	0.075	0.27 (1.81)	0.123	0.04 (2.24)	0.677	0.84 (3.09)	0.482	0.24 (2.82)	0.794
	30-39	19 (19%)	4.82 (1.58)		0.38 (1.82)		0.05 (2.08)		1.22 (2.75)		0.26 (3.45)	
	40-49	18 (18%)	5.97 (1.61)		0.3 (1.67)		0.04 (2.2)		0.79 (2.29)		0.19 (2.52)	
	50+	10 (10%)	4.87 (1.61)		0.36 (1.87)		0.05 (2.11)		0.7 (3.75)		0.2 (3.31)	
BMI	<=25	68 (68%)	4.67 (1.72)	0.949	0.3 (1.92)	0.949	0.04 (2.23)	0.42	0.88 (3.01)	0.987	0.24 (2.9)	0.837
	25-29.9	27 (27%)	4.7 (1.55)		0.3 (1.61)		0.05 (1.92)		0.85 (2.79)		0.22 (2.81)	
	>=30	5 (5.0%)	4.34 (1.41)		0.28 (1.2)		0.04 (2.95)		0.89 (3.39)		0.29 (4.12)	
Years of Living	<10	67 (67%)	4.44 (1.68)	0.401	0.28 (1.84)	0.433	0.04 (2.02)	0.977	0.92 (3.25)	0.617	0.25 (3.31)	0.616
	10-20	20 (20%)	5.1 (1.55)		0.34 (1.87)		0.04 (2.12)		0.71 (2.35)		0.19 (2.13)	
	20+	13 (13%)	5.19 (1.66)		0.33 (1.48)		0.04 (3.17)		0.9 (2.3)		0.21 (2.01)	
Socio economic status	Lower	30 (30%)	5.73 (1.65)	0.019	0.34 (1.85)	0.363	0.06 (2.06)	0.02	0.84 (2.74)	0.614	0.17 (2)	0.161
	Middle	11 (11%)	4.73 (1.93)		0.28 (1.73)		0.06 (2.78)		0.67 (3.6)		0.22 (3.06)	
	Upper	59 (59%)	4.18 (1.56)		0.28 (1.8)		0.04 (2.06)		0.94 (2.95)		0.27 (3.27)	
Locality	Non Residential	11 (11%)	5.57 (1.65)	0.229	0.34 (2.21)	0.576	0.06 (2.25)	0.303	1 (2.28)	0.6	0.26 (2.05)	0.591
	Residential	89 (89%)	4.56 (1.65)		0.3 (1.76)		0.04 (2.16)		0.86 (3.03)		0.23 (3.01)	

Table 4.
Multimetal Concentration across different activities with possible exposures.

Exposure	Levels	N (%)	Pb Mean (SD)	Pb P value	As Mean (SD)	As P value	Cd Mean (SD)	Cd P value	Cr Mean (SD)	Cr P value	V Mean (SD)	V P value
Waste Burnt	No	68 (68%)	4.6 (1.68)	0.698	0.3 (1.87)	0.907	0.05 (2.27)	0.314	0.86 (3.24)	0.877	0.24 (2.95)	0.853
	Yes	32 (32%)	4.79 (1.61)		0.3 (1.68)		0.04 (1.99)		0.89 (2.34)		0.23 (2.85)	
Smoking	No	95 (95%)	4.62 (1.67)	0.299	0.31 (1.81)	0.171	0.04 (2.21)	0.9	0.9 (2.99)	0.012	0.24 (2.95)	0.003
	Yes	5 (5.0%)	5.41 (1.33)		0.21 (1.6)		0.04 (1.64)		0.47 (1.46)		0.13 (1.31)	
Cooking vessels	Both	38 (38%)	4.72 (1.55)	0.401	0.34 (1.73)	0.284	0.05 (2.07)	0.223	0.94 (2.6)	0.646	0.24 (2.82)	0.502
	Metals	22 (22%)	5.19 (1.56)		0.29 (2.01)		0.05 (2.22)		0.72 (2.55)		0.18 (2.28)	
	SS/Plastics	40 (40%)	4.34 (1.8)		0.27 (1.76)		0.04 (2.23)		0.9 (3.52)		0.25 (3.33)	
Water Storage	Both	12 (12%)	5.48 (1.48)	0.339	0.31 (2.07)	0.89	0.04 (2.05)	0.756	0.96 (3.51)	0.947	0.21 (3.09)	0.744
	Metals	3 (3.0%)	5.84 (1.58)		0.26 (1.24)		0.06 (1.44)		0.9 (1.31)		0.15 (1.26)	
	SS/Plastics	85 (85%)	4.52 (1.68)		0.3 (1.79)		0.04 (2.22)		0.86 (2.94)		0.24 (2.94)	
Water treated	Non Treated	54 (54%)	5.1 (1.6)	0.051	0.32 (1.88)	0.333	0.05 (2.18)	0.134	0.91 (2.74)	0.653	0.25 (2.86)	0.595
	Treated	46 (46%)	4.19 (1.68)		0.28 (1.72)		0.04 (2.15)		0.83 (3.2)		0.22 (2.97)	
Cosmetics	No	36 (36%)	4.5 (1.68)	0.612	0.29 (1.65)	0.6	0.04 (2.23)	0.462	0.67 (2.89)	0.073	0.21 (2.91)	0.411
	Yes	64 (64%)	4.75 (1.64)		0.31 (1.9)		0.05 (2.15)		1.01 (2.91)		0.25 (2.9)	
Vehicular Traffic	Heavy	23 (23%)	4.98 (1.53)	0.471	0.35 (1.71)	0.263	0.07 (1.96)	0.005	1.47 (2.66)	0.004	0.29 (3.19)	0.105
	Light	25 (25%)	4.2 (1.68)		0.32 (1.74)		0.04 (2.24)		0.53 (2.09)		0.16 (1.77)	
	Moderate	52 (52%)	4.75 (1.7)		0.28 (1.87)		0.04 (2.09)		0.88 (3.19)		0.25 (3.22)	

3.4. Pearson's Correlation Coefficients of Multimetal Concentration

The correlation analysis between the metal biomarkers resulted in low values, except for chromium (Cr) and vanadium (V). The highest Pearson correlation coefficient was observed between chromium (Cr) and vanadium (V) (r = 0.72), indicating either a common exposure source or a potential shared pathway of interaction between these metals. Other pairwise correlations remained low; most of them had correlations below 0.3, indicating largely independent exposures. Figure 2 shows Pearson's correlation coefficients of multimetal concentration.

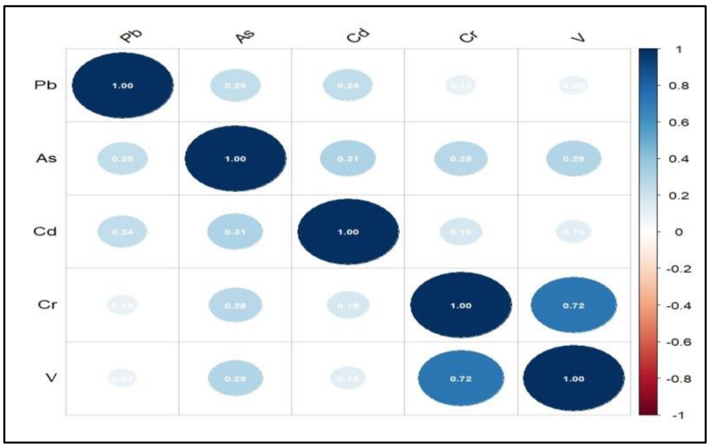


Figure 2.
Pearson's correlation coefficients of multimetal concentration.

4. Conclusion and Recommendations

Many research studies have shown that natural and anthropogenic activities cause large levels of heavy metal contamination in the environment, but they have been unable to determine the exposure pathway. Several questions about the risks of metal contamination and exposure to the population living in the impacted area remain unanswered. Although the current study's design and sample size of 100 makes extrapolating intoxication conclusions to the full local community impractical, this preliminary HBM study provides important evidence of the population's potential risks. Thus, larger and more extensive HBM studies are required to link toxicological outcomes.

This study highlights the significant risk of multimetal exposure in Chennai, India, revealing key risk factors and vulnerable groups. It emphasizes the need for urgent action to reduce multimetal exposure and protect public health through a comprehensive prevention strategy that includes public awareness, regulatory measures, targeted interventions, and regular biomonitoring. The research underscores the value of human biomonitoring as a tool for assessing exposure to environmental toxicants and shaping public health policies. Integrating biomonitoring with epidemiological data can enhance understanding of exposure and health outcomes. In summary, this study calls for collaborative efforts among researchers, healthcare professionals, and policymakers to address the burden of multimetal exposure and work towards a metals-free future in India.

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