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Assessment of Pollution Load Index and Possible Ecological Risks of Heavy Metal Pollution on Petroleum Products Workers

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ABSTRACT

Occupational workers handling cooking gas and heating kerosene in open yards may be exposed to various heavy metal ions emitted from these petroleum products. This study aimed to assess the blood concentrations of lead (Pb), copper (Cu), and zinc (Zn) among workers from 8 randomly selected petroleum product yards in Baghdad Province, Iraq, between January and May 2024. A total of 30 workers, with varying durations of employment were included in the study, alongside a control group of 20 individuals., Additionally soil samples from all sites were collected to evaluate heavy metal contamination and determine the Pollution Load Index (PLI) using a flame atomic absorption spectrophotometer. The obtained results indicated that the soil at all study sites was classified as having deteriorated on-site quality due to heavy metal contamination. No significant correlation was observed between age and blood heavy metal concentrations. However, there were highly significant differences ($P \leq 0.001$) in the concentrations of all examined heavy metals between occupational workers and the control group. The mean blood concentrations in control sample were 15.335±3.299µg/dL of Pb, 125.55±22.377µg/dL of Cu and 99.1±13.824µg/dL of Zn, while in workers, they were 52.4±5.516µg/dL of Pb, 157.3±22.569µg/dL of Cu and 114.93±12.686µg/dL of Zn. This also identified a significant association ($P \leq 0.01$) between smoking and increased blood heavy metal concentrations. Smoking workers exhibited significantly higher heavy metal levels ($P \leq 0.05$) compared to non-smokers. The duration of employment had a clear and significant ($P \leq 0.01$) impact on blood heavy metal levels. Yet, significant differences were found in some hematological parameters of workers via complete blood count. In conclusion, the findings confirm that soil at all study sites was polluted with heavy metals, which posed health risks

to workers who came into direct contact with petroleum products, as reflected in their altered blood parameters.

1. INTRODUCTION

Pollution has become a global issue, intensifying as technology advances, making it an unintended cost of progress (Otitolaiye & Al-Harethiva 2022). Many studies have established a correlation between heavy metal exposure and various health issues, including digestive, dermal, nervous, and cardiovascular diseases. Heavy metals are recognized as critical pollutants due to their potential toxicity, which arises from human exposure through inhalation, dermal absorption, or ingestion (Hussein et al. 2023). Heavy metal contamination is rapidly increasing across all environmental sectors due to industrial and technological advancements. Unfortunately, a significant portion of the population in developing countries lacks adequate awareness of the environmental health risks posed by these toxic compounds (Khalaf et al. 2025).

For over two decades, Iraq has faced a deteriorating electrical grid system, compelling people to rely heavily on cooking gas and heating fuel (kerosene) as alternative energy sources for daily necessities such as cooking and water heating. This increased dependency has placed additional strain on the domestic fuel supply yards, particularly during the winter months, when demand surges. While consumers obtain fuel quickly from these stations, workers remain in constant contact with the petroleum products, increasing their risk of exposure. These petroleum materials contain heavy metals that pose toxic threats to living organisms due to their bio accumulative nature, however, permissible exposure limits must be under (1.5 ppm, 9 ppm, and 5 µg/dL) for Cu, Zn, and Pb respectively, according to WHO and OSHA guidelines (Kuppusamy et al. 2020; Hussein et al. 2023; Ismail et al. 2023).

Despite their toxicity, heavy metals play essential roles in biological systems (Goel and Trivedy 1998), through their functional role as essential or auxiliary factor in the manufacture of enzymes or maintaining the stable structure of some types of proteins. However, any disruption in the homeostasis of these elements can lead to the emergence of various pathological conditions (Shartooh et al. 2018; Kholikulov et al. 2025). The various health effects of petroleum products have been widely studied worldwide (Sharma et al. 2017; Wang et al. 2024). Several studies have documented studies the impact of occupational exposure to petroleum-related pollutants, particularly in factory workers exposed to vanadium from heavy black oil (Gylany 2005). Other studies have examined the health effects of vanadium released from Al-Dora's raw oil refinery on workers (Al-Hiyaly & Alwan 2013). Ragothaman, and Anderson (2017) examined impact of air pollution from petroleum refineries on workers' blood, while a similar study has examined the health impact of the oil industry on occupational workers of Al-Dora oil refinery (Al-Hiyaly and Alwan 2021). A pharmacological study has examined the effects of heavy metals on antioxidant and physiological parameters in oil refinery workers (Ajeel et al. 2021). Furthermore, other studies have assessed the health risks on people living in the vicinity of these oil establishments, whereas one study carried out in Jordan has assessed adverse health effects of living adjacent to an oil refinery (Khatatbeh et al. 2020). Also, a recent study has analyzed the health impact of pollutants emitted by oil refineries in Oman on civilians near the refinery (Otitolaiye & Al-Harethiva 2021).

Although trace amounts of certain heavy metals, such as copper and zinc, are essential for human health, chronic overexposure can disrupt metabolic processes, impair normal growth, and lead to severe diseases such as Thalassemia and Wilson's disease (Munyeza et al. 2019; Ismail et al. 2023). In many countries, cooking gas is stored and sold in steel or plastic cylinders in open yards, while heating kerosene is kept in large storage tanks. However, these fossil fuels release various pollutants, including hydrocarbons (Lin et al. 2022) and heavy metal ions (Pulles et al. 2012; Qaiser et al. 2019).

Extensive research has investigated the potential health risks faced by workers at fuel stations and distribution points, in addition to effects of household exposure to petroleum products. An early study reported the hazardous impacts of kerosene exposure (Nicholas et al. 2021). Other research has linked occupational exposure to petroleum products in petrol stations with an increased risk of anemia among workers (Riaz et al. 2014). In addition, a recent study examined the prevalence of health issues and fatigue among gas station workers (Yin et al. 2023), while another study assessed the impact of extended working hours on the occupational health and safety of oil and gas workers in Oman (Palathoti et al. 2023). The majority of these studies relied on hematological parameters such as white blood cells (WBCs), red blood cells (RBCs), and platelets to determine the effects of heavy metals on blood composition, as well as their correlation with environmental exposure levels.

Although there are many studies that address the occupational hazards of workers in the field of petroleum products, whether oil fields, refineries, car fuel stations, or residential communities near oil industry facilities, there is not a single study that addresses the impact of these products on workers in home fuel stations, especially in Iraq, as shown in Table 1.

Table 1. Past research summarizing on occupational heavy metal exposure

No.	Study title	Work area	Researchers
1	Occupational exposure to petroleum products and its effects on heavy metal metabolism in automobile mechanics	automobile mechanics yards	Abolape, 2019
2	Assessment of heavy metals and related impacts on antioxidants and physiological parameters in oil refinery workers in Iraq	Oil refinery workers in Iraq	Ajeel et al, 2021
3	Impacts of oil industrial process upon occupationally exposed workers at Al-Dora refinery	Al-Dora refinery workers - Iraq	Al-Hiyaly & Alwan, 2021
4	Exposure to heavy metals (lead, cadmium, and mercury) and its effect on the outcome of in-vitro fertilization treatment	Fertilization treatment factories	Al-Saleh et al, 2008
5	Heavy metal exposure of workers working at petroleum products filling stations and its effects on reduced GSH enzyme level	Petroleum filling stations – Turkey	Gursoy & Atosov, 2020
6	Vanadium effects assessment on a sample of workers of a glass factory in Al-Ramadi, Iraq	Glass factory workers - Iraq	Gylany, 2005

7	Impact of differential occupational LPG exposure on cardiopulmonary indices, liver function, and oxidative stress in Northwestern City of Nigeria	LPG fuel stations - Nigeria	Ismail et al, 2023
8	Adverse health impacts of living near an oil refinery in Jordan	Population near an oil refinery - Jordan	Khatatbeh et al, 2020
9	Health effects of refinery emissions on residents living near refineries: A case study of an undisclosed area in Oman	Residents living near refineries - Oman	Otitolaiye & Al-Harethiva, 2021
10	Emission factors for heavy metals from diesel and petrol used in European vehicles	Workers of diesel and petrol vehicles stations – Europe	Pulles et al, 2012
11	Assessing the ecological impacts of polycyclic aromatic hydrocarbons petroleum pollutants using a network toxicity model	Petroleum population - China	Wang et al, 2024
12	Occupational fatigue and health of gas station workers	Gas station workers - China	Yin et al, 2023

This study examines the potential health effects of exposure to heavy metals among workers in petroleum product yards. It seeks to address several key questions: Do cooking gas and heating fuel contribute to increased heavy metal levels in the blood? How does this increase affect hematological parameters? Are factors such as age, duration of employment, and smoking habits associated with elevated heavy metal concentrations? Also, is there a correlation between workplace conditions and heavy metal accumulation in workers' bodies? By answering these questions, this study aims to highlight the health risks faced by a significant yet understudied group—workers in domestic fuel stations. Notably, all participants in this study reported symptoms such as high blood pressure, headaches, and poor eyesight, prompting further investigation into the underlying causes. This issue is particularly relevant in Iraq, where workers in petroleum product yards have received limited scientific attention compared to those employed at car fuel stations.

2. MATERIALS AND METHODS

2.1 Instruments

A Flame Atomic Absorption Spectrophotometer (FAAS) (Model AA-6300, Shimadzu, Japan), was used for heavy metal analysis. The device was connected to an acetylene gas pressure tank mixed with atmospheric air to generate the required flame. Proper cathode lamps were utilized for each heavy metal, with wavelengths set at 283.3 nm for Pb, 324.7 nm for Cu, and 307.6 nm for Zn. The device settings were adjusted according to the manufacturer's instructions to ensure accurate measurement of heavy metal concentrations. Additionally, a digital pH meter (Model Hanna-24) equipped with a glass electrode was used to adjust and calibrate the pH in the prepared solutions. Other instruments included a centrifuge (Model Hettich) for sample processing, a sensitive balance for precise measurements, and a Complete Blood Count (CBC) analyzer (Model-M, Medonic) to measure the effect of heavy metals on the hematological parameters.

2.2 Reagents and Materials

The following reagents were used for blood analysis: concentrated nitric acid HNO_3 (Fluka), Triton X-100 ($C_{34}H_{62}O_{11}$) (Mumbai) at 10% concentration, ammonium hydrogen phosphate solution ($NH_4H_2PO_4$) (Fluka) at 20% concentration. While concentrated acids (HCl, HNO_3, and H_2SO_4) were used soil sample digestion. Heavy metal salts including lead nitrate ($Pb(NO_3)_2$), zinc nitrate ($Zn(NO_3)_2$), and copper nitrate ($Cu(NO_3)_2$) (Merck) were used to prepare the stock solutions at a concentration of 1000 ppm for each metal. The molecular weights of the salts were used for accurate preparation, and the pH was adjusted to 7 for subsequent tests. However, the heavy metals studied were selected based on previous studies, most of which indicated the confirmed presence of these metals in petroleum products, with reference to the possibility of the presence of other heavy metals, but in small quantities and within the permissible limits.

2.3 Sampling

This study was conducted in the laboratories of the Departments of Biology and Chemistry at the College of Science - University of Anbar. The concentrations of heavy metals (lead, copper, zinc) were measured in both open yard soils and biological blood samples. Eight open-yard fuel stations selling cooking gas and white kerosene were randomly selected within Al-Karkh section/ Al-Mansour district of Baghdad province, Iraq (Table 2). The study included 30 occupational workers, while a control group of 20 individuals who were not exposed to these fuel stations, was also examined. The worker sample included both smokers and non-smokers while the control sample consisted of non-smokers only.

Table 2. Study Site Details

Site number	Domestic fuel station	GPS Data	Number of tested workers
1	Al- Ameriya	33.29771, 44.29508	4
2	Al-Khadhra	33.30735, 44.28839	3
3	Hay Al-Jihad	33.27653, 44.29588	4
4	Hay Al-Amil	33.28172, 44.31430	4
5	Al-Ghazalia	33.35476, 44.27776	4
6	Al-Yarmouk	33.30527, 44.23887	4
7	Al-Mansour	33.31643, 44.36675	4
8	Hay Al- Jameah	33.31447, 44.32611	3

From both the control and worker groups, 5 cc blood was collected using a medical syringe. Each participant underwent three blood draws over a period of nine days, with samples taken once every three days to ensure consistency in measuring heavy metal concentrations. Blood samples were collected in gel tubes to coagulate, then serum was extracted by centrifugation (3000 rpm, 12 min) and utilized to assess heavy metal concentrations after being stored at -20°C until the FAAS analysis. While one milliliter of blood was transferred to EDTA tubes for CBC analysis. Also, occupational workers were surveyed to record their ages, working period, health status, and smoking habits. Nonetheless, six samples of soil and dust were taken from each station using sterile plastic containers and blended to generate a homogenous sample of the study site (for each station). This sampling method was applied uniformly across all eight research locations to ensure reliable assessment of heavy metal contamination.

2.4 Preparing soil samples:

A digestive solution was prepared by mixing concentrated hydrochloric acid (HCl), nitric acid (HNO_3), and sulfuric acid (H_2SO_4) in a 2:2:3 ratio. One gram (1 g) of dry soil from each site was added to the digestive solution and stirred until a homogeneous mixture was obtained. The mixture of 15 mL was then heated at 150 C° for 20 min and subsequently washed with distilled water several times to ensure complete sedimentation of the sample. The washing water was filtered using filter paper to measure the content of heavy metals using Flame Atomic Absorption Spectrophotometry FAAS (Radhi et al. 2021).

2.5 Synthesis of Blood Digestive Solution (BDS)

A digestion solution was prepared as follows:

Solution 1: 10 mL of Triton X-100 solution was mixed with 80 mL of deionized distilled water (DDW) in a glass beaker and stirred using a magnetic stirrer for 60 minutes. The mixture was then transferred to a 100 mL volumetric flask.

Solution 2: 20 g of ammonium hydrogen phosphate was dissolved in 75 mL of DDW in a glass beaker and stored in a 100 mL volumetric flask.

Final Digestion Solution: 1 mL of concentrated nitric acid was mixed with 300 mL of DDW in a 500 mL glass beaker under continuous stirring. Then, 25 mL of Solution 1 and 5 mL of Solution 2 were added to the mixture. The prepared digestion solution was stored in a refrigerator at 4°C (Al-Saleh et al., 2008; Hassan, 2022).

2.6 Main analysis of blood samples

Blood samples were processed by mixing 100 µL of blood with 900 µL of digestion solution (BDS). An appropriate volume of the mixture (20 µL) was injected into the FAAS test tube and the resulting readings were recorded.

2.7 Pollution Load Index (PLI)

The PLI provides an initial assessment of the site quality by determining heavy metal contamination levels in the soil and dust. The index is calculated using the following equations:

$$CF = Cn / Bn \quad \ldots. (1)$$

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n} \quad \ldots.. (2)$$

Where: C*n* is the concentration of the sample, B*n* is the background of the heavy metal, and *n* is the total of the studied metals. However, the PLI has three grades assessing the site quality where PLI<1 indicates perfection, PLI=1 represents baseline levels of pollutants, and PLI>1 indicates deterioration of site quality (Tomlinson et al. 1980).

2.8: Statistical analysis

Statistical analysis was conducted using SPSS software (version 24). The data were analyzed using a t-test and one-way ANOVA to assess significant differences between groups. However, the experimental results were presented as mean ± standard deviation SD, and $p \leq 0.001$ was considered significant (Sandar & Richard 1996).

3. RESULTS AND DISCUSSIONS

3.1 Pollution Load Index (PLI)

The results of soil and dust analysis at the study sites indicates high levels of heavy metal contamination (Fig.1). This pollution is primarily attributed to factors such as gas leakage from cylinders, improper sealing of gas tanks, and repeated spillage and leakage of kerosene, which have not been effectively controlled. These findings strongly indicates that the occupational safety and environmental protection measures are not adequately implemented at these fuel yards, and this was confirmed by the results obtained from PLI tests.

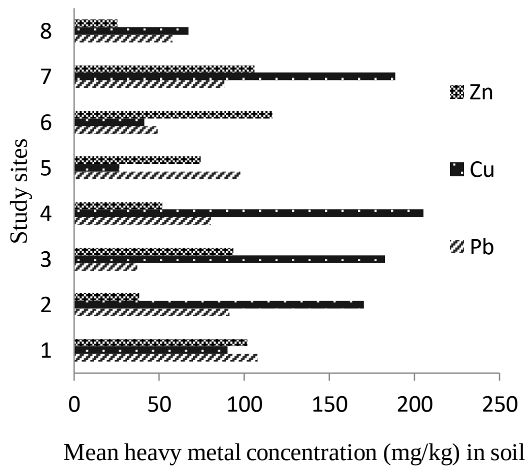

Figure 1. Mean soil heavy metal concentration of all sites under study

PLI aims to assess the degree of overall pollution at sampling sites. The calculated PLI values for lead (Pb), copper (Cu), and zinc (Zn) across the eight study locations are presented in Table 3. Based on the PLI classification, all study sites fall under the category of "Deterioration on-site quality" according to PLI grades, indicating that the soil and dust at these locations are highly polluted.

Table 3. PLI values of heavy metals in study sites

Mean PLI	Min.	Max.	Range	SD
1.84	1.04	2.73	1.69	0.32

The spatial distribution of PLI values for the examined heavy metals is presented in Fig. 2.

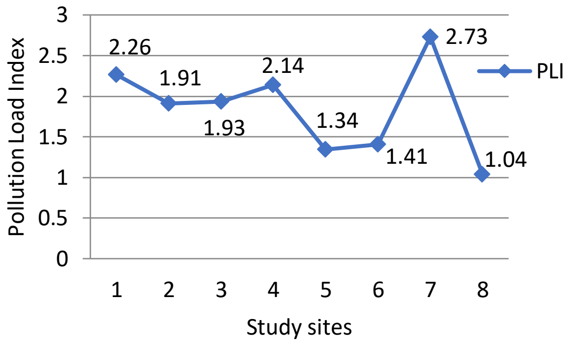

Figure 2. Spatial distribution of PLI of heavy elements in soils of studied domestic fuel yards

3.2 Blood Heavy Metals Analysis

The results indicate that age had no significant effect on blood heavy metal concentrations in both the control and worker groups.The correlation coefficient (r^2) values were found to be not significant ($P \leq 0.05$) for all examined heavy metals.

The mean ± standard deviation of all examined blood heavy metals in the control sample is presented in Table 4 along with mean individual ages and correlation coefficients. Similarly, Table 5 provides corresponding data for occupational workers.

Table 4. Mean ± SD value and correlation analysis between ages and heavy metals blood content (µg/dL) of control sample

Sample size	Mean ± SD			
	Ages	**Pb**	**Cu**	**Zn**
20	31.20±9.92	15.335±3.3	125.55±22.38	99.1±13.82
	r^2 value	0.109	0.103	0.097
	P	Not significant	Not significant	Not significant

Table 5. Mean ± SD value and correlation analysis between ages and heavy metals blood content (µg/dL) of occupational workers

Sample size	Mean ± SD			
	Ages	**Pb**	**Cu**	**Zn**
30	43.433±7.75	15.335±3.3	125.55±22.38	99.1±13.82
	r^2 value	0.2627	0.1764	0.2476
	P	Not significant	Not significant	Not significant

This study has recorded mean values for control as 31.20 ± 9.923 years, 15.335 ± 3.299 µg/dL, 125.55 ± 22.377 µg/dL, and 99.1 ± 13.824 µg/dL of ages, Pb, Cu, and Zn respectively, whereas these mean values of occupational worker sample were 43.433 ± 7.7267 year of worker ages, 15.335 ± 3.299 µg/dL of blood Pb, 125.55 ± 22.377 µg/dL of Cu and 99.1 ± 13.824 µg/dL of Zn (Table 6; Fig. 3). Table 6 contains mean value ± standard deviation of examined blood heavy metal content, sample size and t-test analysis of both control and worker samples results.

Table 6. Mean heavy metals blood content (µg/dL) in control and occupational workers

Examined sample	N	Mean ± SD		
		Pb	**Cu**	**Zn**

Control	20	15.335±3.299	125.55±22.377	99.1±13.824
Workers	30	52.4±5.516	157.3±22.569	114.93±12.686
t-test	value	26.9549	4.8897	2.011
	P	0.001	0.001	0.001

The results indicate, very significant differences (P ≤ 0.001) in Pb, Cu, and Zn concentrations between workers and the control group. The mean blood Pb concentration was notably higher in occupational workers compared to the control group (Fig. 3), indicating increased exposure to heavy metals in the work environment.

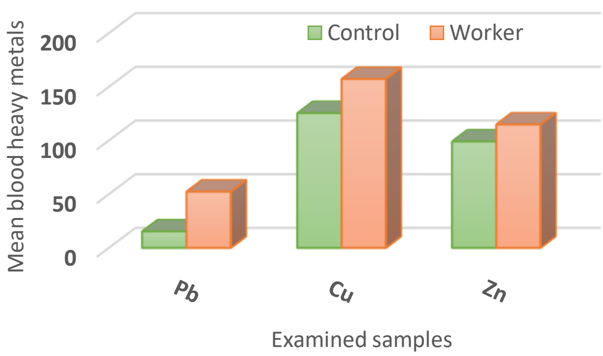

Figure 3. Mean heavy metals content (µg/dL) in control and worker samples

The results indicate that lead Pb had a very significant effect on the blood of occupational workers compared to the control sample. This finding aligns with previous research heavy metal pollutants in petroleum-related environments (Atasov et al. 2020). Although the exact pathophysiologic mechanism of lead poisoning is unknown, lead is known to compete with other minerals, particularly calcium, in cellular processes. When lead enters the cell, it primarily binds to hemoglobin, inhibiting several enzymes required for heme production. This inhibition leads to a drop in blood hemoglobin levels, which in turn causes health symptoms commonly associated with lead exposure, such as high blood pressure and headaches-symptoms observed in many of the examined workers. Additionally, prolonged exposure to elevated lead levels can cause kidney damage and neurological disorders in both children and adults (Abolape 2019; Worlua & Isirima 2024).

Table 7 presents the mean heavy metal blood content ± SD (µg/dL) in smoker and non-smoker occupational workers, along with t-test analysis results. The blood concentrations of Pb, Cu, and Zn were higher in smokers compared to non-smoker workers with mean values of 55.733 ± 4.144 µg/dL, 159.5 ± 19.801 µg/dL, and 119.667 ±11.441 for Pb, Cu, and Zn respectively in smoking workers. In contrast, non-smoking workers exhibited mean values of 50.178 ± 5.1885 µg/dL, 155.833 ± 24.128 µg/dL, and 111.778 ± 12.492 for Pb, Cu, and Zn respectively. However, only the difference in Pb levels was statistically significant (p ≤ 0.001), while Cu and Zn levels did not show significant differences (P ≥ 0.05) (Table 7 and Fig. 4).

Table 7. Mean heavy metals blood content (µg/dL) in smoker and non-smoker workers

Examined sample	**N**	**Mean ± SD**		
		Pb	**Cu**	**Zn**
Smoker	12	55.733±4.144	159.5±19.801	119.667±11.441
Non-smoker	18	50.178±5.188	155.833±24.128	111.778±12.492
t-test	value	3.1027	0.4367	1.7508
	P	0.001	Not significant	Not significant

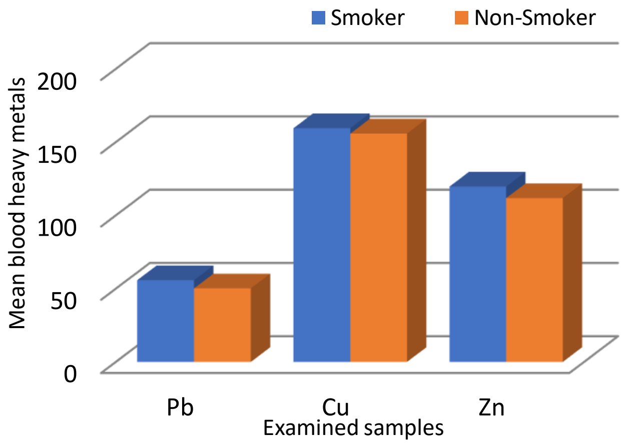

Figure 4. Mean Blood heavy metals content (µg/dL) of examined smoking worker samples

It is well known that smoking cigarettes by an occupational worker influence blood heavy metal levels among occupational workers. A study investigating the effects of heavy metal exposure in oil industry workers reported elevated concentrations of heavy metals in the blood of smokers compared to non-smokers (Sciskalska, et al. 2014; Atasov et al. 2020).

Regarding work duration, correlation analysis between length of employment and blood heavy metal levels among occupational worker samples is presented in Table 7. The findings indicate a strong and statistically significant effect ($P \leq 0.001$) of the working duration on the concentrations of all examined heavy metals. The correlation coefficient (r^2) values were 0.8117 µg/dL for Pb, 0.6212 µg/dL for Cu, and 0.6795 µg/dL for Zn, demonstrating a clear positive relationship between work duration and heavy metal accumulation in the blood of occupational workers (Table 8).

Table 8. Correlation analysis between working duration and blood heavy metal content in occupational workers

Correlation analysis		**Mean ± SD**		
		Pb	**Cu**	**Zn**
Sample Size	30	52.4±5.516	157.3±22.569	114.93±12.686
Correlation Coefficient	df		28	
	value	0.8117	0.6212	0.6795
	P	0.001	0.001	0.001

The results indicate a clear and gradual increase in blood heavy metal concentrations as work duration increased for all examined metals (Fig. 5).

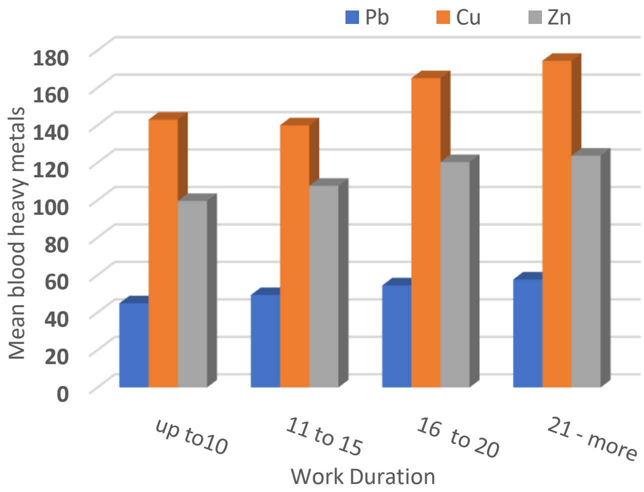

Figure 5. Gradual increase of mean blood heavy metals content (µg/dL) of workers by work duration (years)

Occupational workers in petroleum-related professions are exposed to heavy metal pollution directly or indirectly through inhalation, dermal contact, or digestion during their work period. Once absorbed, heavy metals accumulate in the blood, tissues, and organs, posing significant health risks (Worlua & Isirima 2024).

Research suggests that trace elements play essential roles in metabolism, chronic hyperglycemia, and cellular homeostasis (Al-Hiyaly & Alwan 2021). However, imbalances in these elements have been linked to the development of cardiovascular diseases including hypertension (Khatatbeh et al. 2020). Additionally, recent studies on the relationship between exposure to petroleum products and heavy metals indicate that prolonged exposure can increase liver toxicity risk. Elevated liver enzymes and serum Cu and Zn levels in petroleum product workers suggest a potential link to liver dysfunction (Sharma et al. 2017; Wong et al. 2019). Yet, chronic low-level hazardous metal exposure is a growing global issue. The symptoms of heavy metal toxicity are often non-specific and may take years to manifest (Kuppusamy et al. 2020). The results of this study align with findings from other research that highlight the long-term health risks of occupational heavy metal exposure (Wong et al. 2019; Gursoy & Atosov 2020).

The results of hematological parameters (CBC) examinations indicate significant differences in certain hematological parameters between control subjects and occupational workers. Lymphocyte count was significantly higher in workers ($3.1 \pm 0.82 \times 10^3/\mu L$) compared to controls ($2.3 \pm 0.24 \times 10^3/\mu L$). Eosinophil levels were also elevated in workers ($0.31 \pm 0.11 \times 10^3/\mu L$) compared to controls ($0.12 \pm 0.1 \times 10^3/\mu L$). Basophil count showed a slight but significant increase in workers ($0.042 \pm 0.013 \times 10^3/\mu L$) compared to controls ($0.031 \pm 0.011 \times 10^3/\mu L$).

While no significant differences were observed in other hematological parameters such as WBC, Neutrophils, Monocytes, RBC, and Platelets count (Table 9).

Table 9. Mean values of hematological variables ± SD for controls and workers

Variable	**Controls** (Mean ± SD, $\times10^3/\mu L$)	**Workers** (Mean ± SD, $\times10^3/\mu L$)	**Significancy**
WBCs	7.39±1.42	7.62±0.95	*No sig. diff.*
Neutrophils	4.44±1.1	4.1±1.02	*No sig. diff.*
Monocytes	0.6±0.1	0.7±0.06	*No sig. diff.*
Lymphocyte	2.3±0.24	3.1±0.82	*Sig. diff.*
Eosinophils	0.12±0.1	0.31±0.11	*Sig. diff.*
Basophils	0.031±0.011	0.042±0.013	*Sig. diff.*
RBCs	5.41±0.3	4.98±0.31	*No sig. diff.*
Platelets	274.4±19.2	280.3±24.6	*No sig. diff.*

Sig. diff= Significant difference.

Hematological variables tests indicate significant differences in Lymphocyte Cells, Eosinophil Cells, and Basophil Cells in the blood of workers. This may be attributed to their defensive response against chronic and continuous exposure to petroleum products contaminated with heavy metals. These pollutants accumulate in body tissues, triggering immune and inflammatory responses. This aligns with findings from previous studies (Ajeel et al. 2021; Hassan 2022), which reported that these variables were accompanied by the emergence of some health conditions for workers such as poor vision, headaches, and intestinal disorders.

The presence of elevated heavy metal concentrations in workers' blood and the accompanying health conditions diagnosed during the study, as well as the variations observed in CBC tests, reflects the high level of environmental contamination in the surrounding work areas. The PLI values exceeded the permissible limit indicating a deteriorating state of the soil quality around fuel stations. This necessitates finding solutions to remediate contaminated soils and mitigate heavy metal concentrations using proper techniques such as Bio-pilling, Bio-venting, or Biosorption. Additionally, petroleum derivatives should undergo treatment before distribution to minimize exposure risks and align with sustainable development goals aimed at protecting public health. Nevertheless, the cumulative concentrations of heavy metals in the blood of workers are mainly due to the lack of health awareness in this area among most of the workers participating in this study. Many workers are unaware of the serious and chronic health risks associated with prolonged exposure to petroleum contaminants. Also, the lack of health supervision by the regulatory authorities further exacerbates the problem. There is no established protocol to define an appropriate working duration in these environments, nor is there a regular health monitoring system to conduct periodic blood tests as part of occupational safety programs. Notably, all participating workers suffered from health problems such as high blood pressure, poor eyesight, headaches, digestive disorders and other pathological symptoms which may be directly linked to chronic heavy metal exposure. There is an urgent need to conduct further scientific research in this field, taking into account to increase sample sizes for greater statistical reliability, expand the range of heavy metals analyzed to assess broader exposure risks, comparing the results with workers in car fuel stations to determine differences in exposure levels, and strengthen occupational safety measures, ensuring mandatory health screenings and strict regulatory oversight to mitigate health risks.

4. CONCLUSIONS

This study confirms that all the studied sites were highly polluted as indicated by the PLI values, which confirms the deteriorating environmental conditions of these locations. The findings revealed that the concentrations of lead (Pb), copper (Cu), and zinc (Zn) were significantly higher in occupational workers compared to the control group. The results also clearly indicated that the concentrations of heavy metals in the blood of smoking workers were higher than those of non-smoking workers, and this is due to the synergistic exposure role of heavy metals found in petroleum derivatives and cigarette smoke. The duration of occupational exposure played a critical role in the gradual increase of blood heavy metal concentrations. Workers with longer employment periods exhibited higher levels of Pb, Cu, and Zn, indicating a cumulative effect over time. Chronic exposure to petroleum products and the heavy metals they contain resulted in significant alterations in hematological parameters, emphasizing the occupational health risks associated with prolonged exposure in such environments.

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