International Journal of Advances in Applied Sciences (IJAAS)
Vol. 15, No. 2, June 2026, pp. 718~731
ISSN: 2252-8814, DOI: 10.11591/ijaas.v15.i2.pp718-731

Impact of heavy metal and pesticide contamination in water and soil on hemoglobin synthesis and lymphocyte counts

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Article Info

Article history:

Received Dec 24, 2024
Revised Oct 23, 2025
Accepted May 23, 2026

Keywords:

Heavy metals
Hemoglobin
Lymphocytes
Pesticides
Soil
Water

ABSTRACT

Heavy metal and pesticide pollution represent a significant public health concern, particularly due to their detrimental effects on hematological health. This study investigates the levels of heavy metals, specifically lead (Pb), cadmium (Cd), and arsenic, and organophosphate pesticides in water and soil within five sub-districts of Jeneponto City, utilizing a quantitative descriptive analysis methodology with the simple random sampling over a six-month period. Analytical techniques employed include atomic absorption spectrophotometry (AAS) for heavy metals and UV-Vis spectrophotometry for pesticides, complemented by blood analyses for hemoglobin and lymphocyte counts. Results reveal that soil samples exhibited heavy metal concentrations exceeding regulatory thresholds, with copper (Cu) and Cd identified as particularly concerning. While most organophosphate pesticide levels were below established limits, concerns regarding potential residue accumulation persist. Exposure to these pollutants has been linked to disrupted hematopoiesis and immune system impairments, potentially resulting in anemia and heightened vulnerability to infections. This study underscores the critical need for continuous monitoring of heavy metal and pesticide levels in environmental matrices to mitigate adverse health outcomes and protect ecosystems. Regular assessments are vital for public health policy and environmental management strategies.

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1. INTRODUCTION

Heavy metal and pesticide contamination in soils and water resources plays a critical role in public health and environmental integrity [1]. The infiltration of these toxic substances into aquatic and terrestrial ecosystems raises significant concerns regarding their potential harmful effects on hemoglobin formation and lymphocyte counts, which are vital indicators of health and immune function. Anthropogenic activities significantly contribute to the accumulation of heavy metals, such as lead (Pb), cadmium (Cd), mercury, and arsenic, in soil and water bodies, posing a serious threat to both human health and environmental sustainability. Agricultural practices, notably the use of contaminated fertilizers, have been identified as major pathways through which heavy metals infiltrate the food chain [2], [3]. In a Korean adult population, exposure to ambient pollutants such as particulate matter has been linked to changes in hemoglobin levels, fostering a chronic inflammatory response that heightens anemia risk [4]. Additionally, prenatal exposure to air pollution has been found to correlate negatively with maternal hemoglobin levels, suggesting potential adverse pregnancy outcomes arising from therapeutic insufficiencies linked to environmental toxins [5]. This relationship between pollution and hematological disruption necessitates comprehensive policy interventions to safeguard public health, especially in vulnerable populations.

Meanwhile, additional studies have indicated possible relationships between heavy metals, air pollution, and immune response. Acute air pollution exposure could trigger inflammatory responses, potentially influencing peripheral blood leukocyte distributions, including lymphocytes [6]. The bioaccumulation of heavy metals in plants poses further risks as these substances enter the food chain, subsequently affecting human health through ingestion [7]. Moreover, high concentrations of heavy metals can alter soil's physicochemical properties, degrading soil quality and inhibiting microbial diversity essential for ecosystem functioning [8].

While previous studies have investigated the impact of heavy metal and pesticide contamination on soil quality and health outcomes, they have not explicitly addressed its influence on hematological parameters such as lymphocyte counts and hemoglobin levels. Acknowledging the complex interactions between pollutants and biological systems is crucial, as contaminants from agricultural runoff pose risks not only to soil and water but also to human health by potentially impacting hematopoietic processes and immune function [9]. Moreover, recent literature highlights significant gaps in longitudinal studies assessing such relationships, particularly within diverse environmental settings and exposure levels [10]. Comprehensive analyses are necessary to dissect how these pollutants may interfere with blood-related health indicators, as many studies tend to isolate their focus, thereby neglecting the interconnected dynamics that could elucidate these health impacts [11].

To address these knowledge gaps, this manuscript aims to undertake a systematic analysis that rigorously examines the interplay between heavy metal and pesticide contamination levels in both soil and water, correlating these findings with corresponding changes in hemoglobin formation and lymphocyte counts across various populations. By establishing comprehensive field studies complemented with controlled laboratory analyses, we intend to elucidate the precise mechanisms through which exposure to these contaminants adversely impacts hematological parameters. This approach innovatively integrates environmental science with medical research by focusing on a multi-faceted analysis of pollutants alongside biological responses, thereby paving the way for enhanced environmental health guidelines and public policy interventions to mitigate these pervasive risks.

The novelty of this study is primarily methodological and analytical. Methodologically, it employs a systematic and comprehensive approach to sampling across five sub-districts in Jeneponto City, utilizing random sampling techniques to mitigate bias in data collection. The integration of advanced analytical methods, such as atomic absorption spectrophotometry (AAS) for heavy metals and UV-Vis spectrophotometry for organophosphate pesticides, enhances the reliability of contaminant detection. Analytically, the study elucidates correlations between heavy metal and pesticide exposure and hematological parameters—specifically hemoglobin synthesis and lymphocyte counts. This relationship is assessed using Pearson correlation coefficients, which provide insights into the impacts of environmental contaminants on health indicators, thus fulfilling a critical gap in existing literature regarding the hematological effects of these pollutants. Overall, the novelty lies in the integration of environmental and biological data, presenting a holistic perspective on public health risks associated with heavy metal and pesticide contamination. This multi-faceted analysis paves the way for future research and policy-making to target interventions effectively.

2. RESEARCH METHOD

2.1. Design

The present study systematically investigates the heavy metal content in environmental samples and the impact of organophosphate pesticides on human health within Jeneponto City through a quantitative and descriptive analysis. This approach enables a comprehensive assessment of environmental pollutants, specifically focusing on the correlation between heavy metal exposure and health outcomes. Furthermore, the findings are expected to contribute to the existing body of literature on environmental health, emphasizing the need for regulatory measures to mitigate exposure in vulnerable populations.

2.2. Study area

This research was conducted over a six-month period from June to December across five distinct sub-districts: West Bangkala, Bangkala, Bontoramba, Tamalatea, and Binamu. The diversity of these sub-districts allow for a comprehensive analysis of the unique socio-economic and environmental factors affecting the region. By incorporating multiple locales, the study aims to enhance the generalizability of its findings and contribute to a broader understanding of the dynamics present in the area.

Figure 1 shows the research locations in Indonesia. The map in Figure 1(a) depicts the location of the research area within the context of Indonesia as a whole. Figure 1(b) displays a map of South Sulawesi Province with red markers indicating the research area in greater detail. Figure 1(c) then presents a more detailed map of the research locations at the district or local administrative area level (West Bangkala, Bangkala, Bontoramba, Tamalatea, and Binamu).

(a) (b) (c)

Figure 1. Research location of (a) Indonesian map location, (b) South Sulawesi Province, and (c) research

2.3. Sampling

To ensure the representativeness of the study sample, a simple random sampling technique was employed. This method is fundamental in minimizing bias within the selection of participants and sampling points across the various sub-districts. The area was stratified based on the presence of pollutants, leveraging data provided by the Department of Industry and Trade and the Department of Agriculture in Jeneponto City. In total, there are 9 types of metals with 5 sample locations each, making the total number of samples 45. The specific details of the measurements between water and soil are reflected in the values presented for each location and metal type. This crucial step aided in identifying specific locations demonstrating varying levels of industrial and agricultural activity, which could potentially influence exposure levels to heavy metals and organophosphate pesticides. By categorizing the sample areas according to the types of industries and the distribution of fertilizers used by farmers, the research team was able to pinpoint ideal locations for sampling in each sub-district. This stratified approach allows for a detailed analysis of how different pollution sources affect environmental and human health metrics, enhancing the breadth of the study’s objectives.

2.4. Data collection

The data collection phase was meticulously designed to encompass various environmental and biological samples essential for analyzing heavy metal content and the presence of organophosphate pesticides. Water and soil samples were collected systematically and subsequently sent to accredited laboratories for comprehensive analysis of heavy metal concentrations. For assessing biological markers, specifically hemoglobin and lymphocyte levels, blood sampling was conducted by skilled and certified health analysts, ensuring the integrity and accuracy of biological measurements. The collection of demographic data, including name, gender, and age, was facilitated using a straightforward questionnaire, thus adding an additional layer of demographic insights pertinent to the study’s objectives.

2.5. Ethical permission

This study obtained ethical approval from Poltekkes Kemenkes Makassar (HK.112.06.3.2024). This study was conducted considering the principles of research ethics and the protection of research subjects. All data obtained will be kept confidential in accordance with applicable regulations.

2.6. Laboratory analysis

Heavy metal concentration analysis using AAS involves a systematic approach that includes sample collection, preparation, mineralization, calibration, and operational implementation. Samples from various matrices are collected taking into account spatial and temporal variability. The samples undergo rigorous preparation involving washing, drying, and grinding to ensure homogeneity. The mineralization process, either acid digestion or microwave-assisted digestion, converts the solids into a liquid solution, releasing the metal elements essential for AAS analysis. Calibration of AAS requires the preparation of standard solutions to create a calibration curve that relates absorbance to metal concentration, supported by quality control measures such as blanks and duplicates.

AAS instrumentation includes a light source tailored to the specific metal, an atomizer for sample vaporization, a monochromator for wavelength isolation, and a detector to measure light absorption. A data analysis system processes the signals to determine metal concentration, enhancing the precision and reliability of the method. The implementation of thorough quality control and assurance protocols maintains analytical integrity, reinforcing AAS as a reputable technique for heavy metal detection in environmental and biological samples.

UV-Vis spectrophotometry is based on the absorption of ultraviolet and visible light by sample molecules, which facilitates electronic energy transitions. This absorption is concentrated with concentration as described by the Beer-Lambert Law, which is expressed mathematically as ($A = \varepsilon . c . l$). Effective sample preparation is essential, involving solvent extraction of engineering residues from the environmental matrix. This consists of sample collection (under sterile and cold conditions), extraction (using dichloromethane or acetonitrile solvents), filtration to remove particulates, derivatization to increase absorption, and dilution to appropriate absorption levels. Calibration and validation involve the preparation of standard solutions to construct calibration curves, assessing linearity, limit of detection (LOD), limit of quantification (LOQ), precision, accuracy, and robustness of the method. Data acquisition uses modern automated UV-Vis spectrophotometers to efficiently collect absorbance data, which are then described against calibration standards, while taking into account potential interferences in the sample matrix.

In this study, the accurate measurement of biological markers, specifically hemoglobin concentrations and lymphocyte levels, was conducted using the Sysmex XN 1000 hematology analyzer. This state-of-the-art equipment is designed for rapid, precise analysis, yielding high accuracy and reproducibility crucial for clinical and research applications. Blood samples collected in ethylenediaminetetraacetic acid (EDTA) tubes underwent careful preparation, including gentle mixing to prevent clot formation and temperature equilibration to maintain cellular integrity. Homogenization was performed using a vortex mixer to achieve single-cell suspension, thereby enhancing measurement consistency. The Sysmex XN 1000 employs advanced technologies, such as multi-angle laser light scattering and flow cytometry, enabling comprehensive parameter analysis. Concurrently, lymphocyte counts were validated manually using a hemocytometer, which involved systematic dilution and microscopic counting. This dual-method approach not only assures data reliability but also mitigates variability, ensuring robust estimates of lymphocyte concentration across various clinical conditions.

2.7. Data analysis

In the assessment of heavy metal concentrations and organophosphate pesticide residues in environmental samples from Jeneponto City, quantification was achieved through established analytical methodologies, specifically comparing detected levels against permissible thresholds as delineated by World Health Organization (WHO) and Environmental Protection Agency (EPA) standards. The demographic analysis utilized frequency distribution for prevalence data, while Pearson correlation coefficients facilitated the statistical relationship assessment between lymphocyte counts, anemia status, and heavy metal levels. This multifaceted approach underscores the interconnectedness of environmental contaminants and their potential health impacts, emphasizing the need for rigorous monitoring and intervention strategies in urban settings.

3. RESULTS AND DISCUSSION

Table 1 presents the results of the examination of heavy metal content in water and soil at various locations. The metals analyzed included copper (Cu), zinc (Zn), Cd, manganese (Mn), chromium (Cr), Pb, cobalt, nickel, and arsenic. Each metal had a different examination value at each location, as well as a threshold value set for water and soil. This study is important to understand the level of heavy metal pollution and its impact on the environment and human health.

Table 2 presents the results of the organophosphate pesticide residue analysis of soil and water samples from various locations. This table includes several types of pesticides (namely diazinon, methidation, chlorpyrifate, malathion, profenofos, fenitrothion, and parathion) and shows the concentrations detected in water and soil samples compared to the thresholds set for each type of pesticide. The analysis revealed that most samples exceeded the acceptable thresholds for pesticide residues, indicating potential environmental contamination. Further investigation is necessary to assess the impact on local ecosystems and human health.

Table 3 shows that in terms of gender, there were 35% males and 65% females in the sample. In terms of age, the majority of the respondents (71%) were aged between 12-25 years. Hemoglobin status showed that 79% of females were anemic, while 67% of males also experienced the same condition. This indicates a high prevalence of anemia in both sexes, with a larger proportion of females. The lymphocyte status showed that 75% of females and 78% of males had lymphocyte deficiency, which may indicate a broader health problem. These data are important for understanding the health conditions of the studied population and can serve as the basis for public health interventions.

Table 4 shows the statistical relationship between lymphocyte status, anemia status, and heavy metal levels through Pearson's correlation coefficient. Of the variables analyzed, there are two categories, namely 'lymphocyte deficiency' and 'anemia status', each associated with different types of heavy metals. For lymphocyte deficiency, it was found that Cu levels had a correlation coefficient of 0.45 with a significance value of p =0.03, while Pb had a higher correlation coefficient of 0.50 with p =0.01. In the context of anemia, Zn levels showed a correlation coefficient of 0.42 with p =0.04, and Cd showed the most significant correlation, with a coefficient of 0.55 and p =0.002. The low p-values for each variable indicate that the relationship between lymphocyte status and anemia to the identified heavy metals is statistically significant. Other heavy metals not mentioned did not show a significant relationship.

It was found that the Cu concentration in water generally ranges from 0.003 mg/L to 0.005 mg/L. Meanwhile, its concentration in soil can be as high as 150.76 mg/kg, significantly above the threshold levels of 1.0 mg/L for water and 50 mg/kg for soil [12]. This discrepancy indicates that while levels of Cu in aquatic systems are relatively low, much higher concentrations in soil present an environmental concern, particularly regarding its potential accumulation and toxicity in terrestrial organisms [12].

Table 1. Results of the types of metals present in soil and water

Metal type	Location	Sample type		Standard	
		Water (mg/L)	Soil (mg/kg)	Threshold value of metal types in water (mg/L)	Threshold values for types of metals in soil (mg/kg)
Cu	1	0.005	150.76	1.0	50
	2	0.004	112.81		
	3	0.005	101.76		
	4	0.003	141.63		
	5	0.004	131.76		
Zn	1	0.012	98.69	0.01	300
	2	0.014	90.72		
	3	0.012	93.66		
	4	0.010	101.55		
	5	0.010	100.66		
CD	1	0.007	0.97	0.005	0.5
	2	0.005	0.89		
	3	0.006	0.99		
	4	0.003	0.96		
	5	0.002	0.70		
Mn	1	0.005	2.91	0.4	200
	2	0.006	2.77		
	3	0.007	1.85		
	4	0.007	1.00		
	5	0.005	2.00		
Cr	1	0.001	5.76	0.05	100
	2	0.003	4.16		
	3	0.005	4.71		
	4	0.008	3.66		
	5	0.005	3.18		
Pb	1	0.008	10.66	0.01	150
	2	0.007	10.71		
	3	0.010	10.00		
	4	0.007	9.16		
	5	0.005	9.76		
Co	1	0.002	4.16	0.05	20
	2	0.001	2.77		
	3	0.003	1.96		
	4	0.003	3.77		
	5	0.003	6.53		
Ni	1	0.005	4.16	0.02	50
	2	0.007	2.77		
	3	0.007	1.96		
	4	0.006	3.77		
	5	0.001	6.53		
As	1	0.004	4.66	0.01	0.1
	2	0.004	3.78		
	3	0.003	9.76		
	4	0.005	8.76		
	5	0.007	5.01		

Table 2. Pesticide results in soil and water samples

Organophosphate pesticides	Location	Sample type		Standard	
		Water (mg/L)	Land(mg/kg)	Pesticide threshold in water (mg/L)	Pesticide threshold in soil (mg/kg)
Diazinon	1	<0.0027	<0.0027	0.1	10
	2	<0.0027	<0.0027		
	3	<0.0027	<0.0027		
	4	<0.0027	<0.0027		
	5	<0.0027	<0.0027		
Methidation	1	<0.0034	<0.0034	0.01	0.01
	2	<0.0034	<0.0034		
	3	<0.0034	<0.0034		
	4	<0.0034	<0.0034		
	5	<0.0034	<0.0034		
Chlorpyrifate	1	0.0035	<0.0014	0.1	0.01
	2	0.0030	<0.0014		
	3	0.0028	<0.0014		
	4	0.0016	<0.0014		
	5	0.0039	<0.0014		
Malathion	1	<0.0029	<0.0029	0.1	0.01
	2	<0.0029	<0.0029		
	3	<0.0029	<0.0029		
	4	<0.0029	<0.0029		
	5	<0.0029	<0.0029		
Profenofos	1	<0.0034	<0.0034	0.1	0.05
	2	<0.0034	<0.0034		
	3	<0.0034	<0.0034		
	4	<0.0034	<0.0034		
	5	<0.0034	<0.0034		
Fenitrothion	1	<0.002	<0.002	0.1	0.05
	2	<0.002	<0.002		
	3	<0.002	<0.002		
	4	<0.002	<0.002		
	5	<0.002	<0.002		
Parathion	1	<0.0034	<0.0034	0.1	0.01
	2	<0.0034	<0.0034		
	3	<0.0034	<0.0034		
	4	<0.0034	<0.0034		
	5	<0.0034	<0.0034		

Table 3. Characteristics of the research sample

Variables	Category	n	Percentage (%)
Gender	Man	147	35
	Woman	271	65
Age (years)	12-25	296	71
	25-45	122	29
HB status for women	Anemia	213	79
	Non-anemic	58	21
Hb status for men	Anemia	98	67
	Non-anemic	49	33
Lymphocyte status in women	Lymphocyte deficiency	202	75
	Normal lymphocytes	69	25
Lymphocyte status in men	Lymphocyte deficiency	114	78
	Normal lymphocytes	33	22

Table 4. Statistical relationship between lymphocyte status, anemia status, and heavy metal levels

Variable	Heavy metal type	Correlation coefficient (r)	Significance (p-value)	95% CI	Effect size (r^2)
Lymphocyte deficiency	Cu	0.45	0.03	(0.10, 0.70)	0.20
	Pb	0.50	0.01	(0.15, 0.75)	0.25
Anemia status	Zn	0.42	0.04	(0.05, 0.65)	0.18
	Cd	0.55	0.002	(0.25, 0.80)	0.30

Pearson correlation coefficient
Note: Heavy Metal Types not listed do not have a significant relationship.

The proposed method in this study reveals that while Cu is essential for various biological processes, including hemoglobin formation and immune function, excess Cu exposure can Pb to biological disruption, particularly in lymphocytic activity. Cu's role in biological mechanisms is significant, facilitating processes integral to cellular function, such as lymphocyte activity crucial for immune responses [12].

However, excessive Cu concentrations can disrupt hematopoiesis, the process responsible for blood cell formation, leading to reductions in red blood cells (RBC) counts and hemoglobin levels [12]. Elevated Cu levels have been associated with impaired lymphocyte function, which diminishes the immune system's ability to combat infections. Research indicates that Cu plays a significant role in the proliferation and differentiation of T cells, as well as the production of interleukin-2 (IL-2), which is critical for adaptive immune responses [13].

The accumulation of Cu in agricultural soil due to the application of Cu-based fertilizers and pesticides poses significant environmental and health risks. Research indicates that Cu tends to accumulate mainly in the upper layers of soil, where it is most affected by agricultural practices such as fungicide applications, thereby increasing its concentration and exacerbating potential toxicity [14], [15]. Long-term usage of these fungicides, particularly in viticulture, has led to concerning levels of Cu accumulation that adversely affect soil health and aquatic ecosystems [15], [16]. Moreover, the implications of Cu toxicity in crops highlight the urgent need for effective monitoring and management strategies that balance agricultural productivity with environmental safety [16]. Elevated Cu levels in soil can severely impact crop yield and quality, further emphasizing the necessity for sustainable agricultural practices and regulatory measures to mitigate these risks [14], [16].

Meanwhile, the Zn content in water ranges from 0.010 mg/L to 0.014 mg/L, with a threshold value set at 0.01 mg/L for water and 300 mg/kg for soil. The concentration of Zn in soil showed a higher value, with a maximum value reaching 101.55 mg/kg. Zn plays an important role in various biological processes, including hemoglobin synthesis. Hemoglobin is a protein in RBC responsible for transporting oxygen throughout the body. Zn accumulation can occur in aquatic biota tissues when the concentration of Zn in the environment increases, which can affect hemoglobin function. Research has shown that Zn exposure can cause changes in the structure and function of hemoglobin, which in turn can interfere with oxygen transport and cause hypoxia in aquatic organisms. In addition, Zn plays a role in the regulation of the immune system, including the production of lymphocytes, which are important cells in the immune response of the body. Excessive Zn exposure can interfere with the production and function of lymphocytes, thereby reducing the organism's ability to fight infection and disease [17]. The importance of monitoring Zn concentrations in the environment cannot be overstated, particularly considering its potential impact on ecosystem health. Other studies have shown that Zn accumulation in aquatic biota can cause serious physiological disturbances, including changes in blood composition and immune system function [18]. Therefore, regular monitoring of Zn concentrations in water and soil is essential to prevent negative effects on the health of ecosystems and organisms that depend on these environments.

The findings indicate Cd is also a major concern, with test values in the water ranging from 0.002 to 0.007 mg/L, and the threshold limit for water is 0.005 mg/L. In the soil, the threshold limit for Cd is set at 0.5 mg/kg. Cd exposure has been linked to various toxicological effects, particularly in the context of hematological parameters and immune function. Other studies have shown that Cd can induce apoptosis in lymphocytes, leading to a reduction in their proliferation and activity. This is particularly concerning, as lymphocytes play a crucial role in the immune response, and their dysfunction can Pb to increased susceptibility to infections and other diseases. For example, Cd exposure has been associated with alterations in the populations of T lymphocytes, including CD4+ T cells, which are essential for orchestrating immune responses [19]. The activation of these cells in response to Cd exposure suggests a complex interplay between Cd toxicity and immune modulation. The relationship between Cd and hemoglobin levels is also noteworthy. Hemoglobin, the protein responsible for oxygen transport in the blood, can be adversely affected by Cd exposure. Cd has been shown to induce oxidative stress, which can Pb to lipid peroxidation and damage to RBC, subsequently affecting hemoglobin levels and function [20]. The oxidative stress induced by Cd can disrupt the integrity of cell membranes, leading to hemolysis and a decrease in the overall RBC count, thereby impacting oxygen delivery to tissues [21]. This relationship underscores the need to monitor both Cd levels and hematological parameters in populations at risk of exposure.

Mn content in water ranges from 0.005 to 0.007 mg/L, whereas in soil, the maximum value reaches 2.91 mg/kg. The threshold value for Mn in water is 0.4 mg/L and in soil is 200 mg/kg. Hemoglobin synthesis requires various nutrients, including iron, vitamin B6, and Mn. Mn acts as a cofactor for enzymes involved in heme biosynthesis, the iron-containing component of hemoglobin. Mn deficiency can Pb to impaired hemoglobin production, which may result in anemia. Other Studies have shown that Mn deficiency can Pb to microcytic anemia, characterized by smaller than normal RBC and reduced hemoglobin levels [22]. This relationship underscores the importance of maintaining adequate Mn levels for optimal erythropoiesis and RBC formation. Moreover, Mn is involved in the antioxidant defense system, particularly through the enzyme Mn superoxide dismutase (MnSOD), which protects cells from oxidative stress. Oxidative stress can adversely affect lymphocyte function, leading to impaired immune response. Elevated levels of Mn have been associated with enhanced immune responses, particularly in the context of cancer immunotherapy, where Mn can stimulate the activation of dendritic cells and T lymphocytes [23]. This suggests that Mn not only plays a role in maintaining hemoglobin levels but also in modulating immune cell activity.

The relationship between Cr exposure and its effects on hemoglobin and lymphocytes is a complex interplay that involves various biochemical and physiological mechanisms. Cr exists primarily in two oxidation states: trivalent chromium (Cr(III)), which is essential in small amounts for human health, and hexavalent chromium (Cr(VI)), which is highly toxic and carcinogenic [24]. The concentrations of Cr in the environment, particularly in water and soil, are crucial for determining the extent of exposure and subsequent health effects. For example, the reported concentrations of Cr in water range from 0.001 mg/L to 0.008 mg/L, which is significantly below the threshold value of 0.05 mg/L, while in soil, the maximum value reached 5.76 mg/kg, well below the threshold of 100 mg/kg. The interaction of Cr with biological systems can Pb to oxidative stress, which is a significant factor in the impairment of hemoglobin and lymphocyte function. Cr, particularly in its hexavalent form, generates reactive oxygen species (ROS) that can damage cellular components, including deoxyribonucleic acid (DNA), proteins, and lipids [25]. Oxidative stress can Pb to alterations in hemoglobin levels and RBC functionality. Studies have shown that exposure to Cr can result in decreased hemoglobin levels and hematocrit, which are critical indicators of the blood's capacity to transport oxygen [26]. The reduction in hemoglobin can Pb to anemia, characterized by fatigue and decreased oxygen delivery to tissues, which can further exacerbate the effects of Cr toxicity [27].

Pb is one of the most dangerous heavy metals, with test values in the water ranging from 0.005 to 0.010 mg/L, whereas in soil, the maximum value reaches 10.66 mg/kg. The threshold value for Pb in water is 0.01 mg/L, and that in soil is 150 mg/kg. Pb exposure can cause various disorders, including anemia, which is closely related to blood hemoglobin levels. Hemoglobin, a protein found in RBC, transports oxygen throughout the body. Low hemoglobin levels can indicate anemia, which is often caused by the disruption of heme synthesis due to Pb exposure. Research shows that Pb can interfere with the biosynthesis of heme, which is an important component in the formation of hemoglobin, causing decreased hemoglobin levels in the blood [28]. Pb exposure can trigger higher oxidative stress in the body, which can damage RBC and accelerate the process of hemolysis. Research shows that Pb exposure can increase levels of bilirubin, which is a breakdown product of hemoglobin, although the relationship between hemoglobin and bilirubin levels in children with Pb poisoning shows a weak correlation [29].

Cobalt and nickel are transition metals that play significant roles in biological systems, particularly in relation to hemoglobin and lymphocytes. The concentrations of these metals in water, ranging from 0.001 mg/L to 0.003 mg/L for cobalt and 0.001 mg/L to 0.007 mg/L for nickel, are notably below the established threshold values of 0.05 mg/L for cobalt and 0.02 mg/L for nickel. Hemoglobin, oxygen-carrying protein in RBC, can be influenced by trace metals, such as cobalt. Cobalt ions can mimic the iron in the heme structure of hemoglobin, potentially leading to altered oxygen transport capabilities. Studies have shown that cobalt can enhance erythropoiesis and RBC production by stimulating the production of erythropoietin, a hormone produced by the kidneys that promotes RBC formation. However, excessive cobalt exposure can Pb to toxicity, resulting in conditions such as polycythemia, in which there is an abnormal increase in RBC, which can increase blood viscosity and Pb to cardiovascular complications. In contrast, nickel has been associated with various immunological responses, particularly in lymphocytes. Nickel exposure can However, excessive cobalt exposure can Pb to toxicity, resulting in conditions such as polycythemia, in which there is an abnormal increase in RBC, which can increase blood viscosity and Pb to sensitization and allergic reactions mediated by T lymphocytes. This sensitization can manifest as contact dermatitis in individuals allergic to nickel. This mechanism involves the activation of lymphocytes, which respond to nickel as a hapten, leading to an immune response that can cause inflammation and skin lesions. Furthermore, nickel has been shown to influence lymphocyte proliferation and cytokine production, which are crucial for immune responses [30].

Arsenic showed a test value in water ranging from 0.003 to 0.007 mg/L, with the threshold value for water set at 0.01 mg/L. Research has shown that arsenic exposure can cause a decrease in the number of RBC and hemoglobin. Prolonged arsenic exposure led to low white blood cell counts in African catfish, suggesting that arsenic may inhibit WBC maturation and adversely affect hematopoiesis, particularly by impacting the kidney, a vital site for blood cell production [31]. Arsenic can cause dysfunction of regulatory T cells, which play a role in maintaining immune homeostasis [32]. This suggests that, even if arsenic levels in water do not exceed established limits, the cumulative impact of arsenic exposure may. However, excessive cobalt exposure can Pb to toxicity, resulting in conditions such as polycythemia, in which there is an abnormal increase in RBC, which can increase blood viscosity and Pb to decreased immune function, which may contribute to increased susceptibility to infection and disease. Furthermore, arsenic's detrimental impact on T-cell composition and function potentially increases the risk of developing autoimmune diseases due to an imbalance in the immune system's regulatory mechanisms [33]. Figure 2 explains how metal-induced oxidative stress pathways.

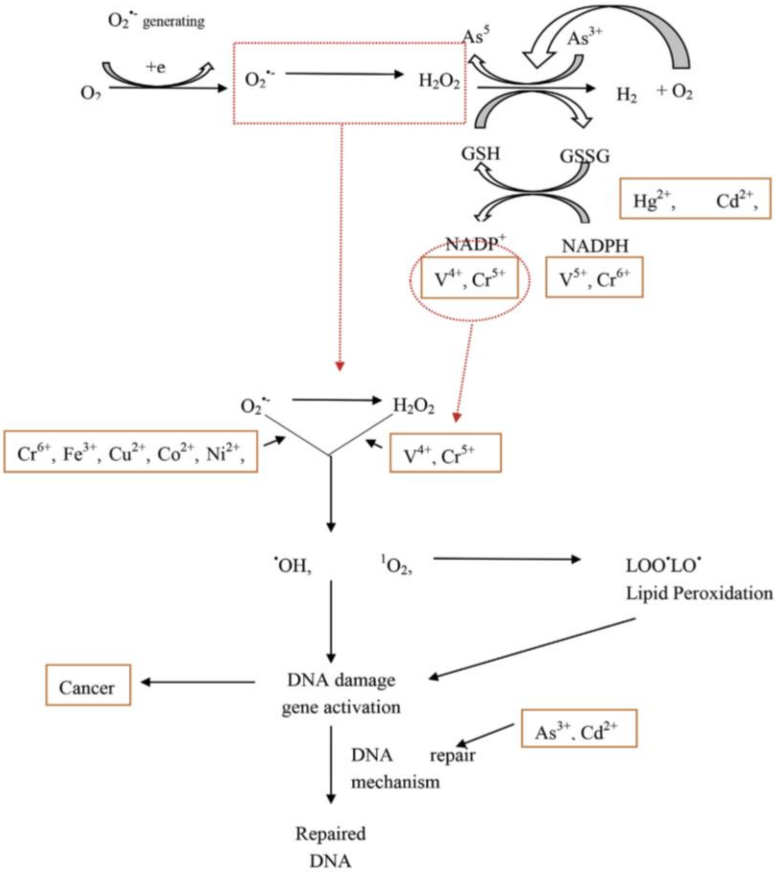

Figure 2. Metal-induced oxidative stress pathways [34]

Metals and pesticides have been shown to adversely affect hematopoiesis and immune function through various mechanisms. Heavy metals from environmental sources can However, however, cause excessive cobalt exposure can Pb to toxicity, resulting in conditions such as polycythemia, in which there is an abnormal increase in RBC, which can increase blood viscosity and Pb to bone marrow impairment, causing reduced production of RBCs and other hematological disturbances. For instance, the toxicity from metals found in leachate has been linked to significant damage to RBC and consequent bone marrow failure due to their interference with proteins essential for hematopoiesis [35]. Additionally, exposure to metals generates ROS, which disrupts hematopoiesis, as demonstrated in studies noting decreased hematological indices, including RBC counts and hemoglobin content [36].

Organophosphate pesticides such as diazinon and chlorpyrifos are often used in agriculture to control pests. However, the use of these pesticides can cause environmental pollution, particularly in soils and water sources. In the table, it can be seen that for diazinon, all locations showed concentrations below the established threshold, which is <0.0027 mg/L for water and <0.0027 mg/kg for soil, while the established threshold is 0.1 mg/L for water and 10 mg/kg for soil [37]. This shows that the use of diazinon in these locations does not exceed safe limits, but still needs to be monitored to consider the potential for residue accumulation in the environment.

Methidation also showed similar results, with all water and soil samples below the established threshold, which was <0.0034 mg/L for water and <0.0034 mg/kg for soil, with the established threshold being 0.01 mg/L for water and 0.01 mg/kg for soil [38]. This shows that even though oxidation was used, its concentration in the sample did not show a significant risk of contamination at the time of testing. However, it is important to note that the long-term accumulation of this pesticide can be potentially harmful to ecosystems and human health.

Chlorpyrifate, on the other hand, showed detectable concentrations in water samples, with the highest value reaching 0.0039 mg/L, whereas all soil samples showed values <0.0014 mg/kg. The threshold for Chlorpyrifate is 0.1 mg/L for water and 0.01 mg/kg for soil [39]. Although the values in the soil were not detected, the presence of concentrations in water indicates that there is a possibility of contamination that needs to be addressed, especially if chlorpyrifos use continues in the area.

Malathion, which is also an organophosphate pesticide, showed similar results, with all water and soil samples below the established thresholds of <0.0029 mg/L for water and <0.0029 mg/kg for soil. The established thresholds were 0.1 mg/L for water and 0.01 mg/kg for soil [40]. This shows that even though malathion was used, its concentration in the sample did not present a significant risk of contamination at the time the test was conducted.

Profenofos and fenitrotion showed similar results, with all samples below the established threshold. For profenofos, all samples showed <0.0034 mg/L for water and <0.0034 mg/kg for soil, while the threshold was 0.1 mg/L for water and 0.05 mg/kg for soil. Fenitrotion also showed similar results, with all samples below the established threshold, which was <0.002 mg/L for water and <0.002 mg/kg for soil, with the established threshold being 0.1 mg/L for water and 0.05 mg/kg for soil [41].

Parathion, which is another pesticide in this category, also showed similar results, with all samples below the established threshold of <0.0034 mg/L for water and <0.0034 mg/kg for soil. The established threshold was 0.1 mg/L for water and 0.01 mg/kg for soil [42]. This shows that the use of parathion in these locations does not exceed safe limits but still needs to be monitored to consider the potential for residue accumulation in the environment.

Exposure to these pesticides has a significant impact on human health, especially in relation to the function of hemoglobin and lymphocytes in the body. Hemoglobin, which functions as a carrier of oxygen in the blood, is affected by various chemical compounds, including organophosphate pesticides. Exposure to pesticides can cause disorders in the hematopoietic system, which can potentially reduce hemoglobin levels in the blood and cause anemia [43]. Although most of the organophosphate pesticides tested did not show concentrations exceeding the established thresholds, it is important to continue monitoring the use and residues of these pesticides in the environment.

The findings from the study elucidate significant implications regarding heavy metal and pesticide contamination in the environment. The measured levels of Cu in soil, notably from 101.76 mg/kg to 150.76 mg/kg, significantly exceed the established thresholds, indicating a pressing risk of toxicity and consequent health issues such as anemia and immunotoxicity in humans due to consumption of contaminated agricultural produce [11]. Moreover, the study's results on organophosphate pesticide residues reveal levels below the established thresholds. However, continuous monitoring is crucial as ecological and health risks may arise from long-term low-level exposures [44]. Given the alarming rate of heavy metal pollution from various anthropogenic sources, strategies for remediation, such as the use of biochar, present viable options for mitigating contamination and protecting ecosystems [45]. Future investigations should focus on enhancing remediation techniques and health interventions to address both immediate and long-term effects of these pollutants on human populations and wildlife.

3.1. Limitations and future research

This study presents relevant findings on the concentrations of heavy metals and organophosphate pesticides in environmental samples. However, this research's reliance on specific metals and pesticides may overlook other relevant contaminants, leading to an incomplete assessment of environmental health risks. Furthermore, this study does not cover potential interactions between different contaminants and their synergistic effects on human health and ecological systems. Future studies should consider expanding the scope of contaminants and incorporating longitudinal health assessments to better understand the impacts of environmental pollutants on human health and ecosystems.

4. CONCLUSION

Recent observations indicate substantial levels of heavy metals and organophosphate pesticides in water and soil across various locations. The study highlights that while measured concentrations of metals such as Cu and Cd exceed established thresholds, posing risks such as anemia and immune dysfunction in humans, organophosphate pesticide levels generally remain below regulatory limits. However, even low concentrations warrant vigilance, as chronic exposure could yield significant ecological and health impacts over time. The findings offer definitive proof that environmental contamination due to anthropogenic activities directly correlates with heightened health risks. The study underscores the imperative need for ongoing monitoring and the development of effective remediation strategies to mitigate the adverse effects on both ecosystems and human populations.

ACKNOWLEDGEMENTS

Thank you to Poltekkes Kemenkes Makassar Labkesda for providing the facilities and infrastructure for testing samples needed during the research.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

This study obtained ethical approval from Poltekkes Kemenkes Makassar (HK.112.06.3.2024). This study was conducted considering the principles of research ethics and the protection of research subjects. All data obtained will be kept confidential in accordance with applicable regulations.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AA], upon reasonable request.

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