
HAIR LEAD LEVELS AMONG GASOLINE STATION OPERATORS IN GORONTALO REGENCY AND THEIR ASSOCIATION WITH AGE

***Yolansawati Amir, Fitryane Lihawa, Marike Mahmud**

*Master's Program of Population and Environmental Studies, Postgraduate School,
Universitas Negeri Gorontalo, Gorontalo, Indonesia.*

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***Corresponding Author: Yolansawati Amir**

Master's Program of Population and Environmental Studies, Postgraduate School, Universitas Negeri Gorontalo,
Gorontalo, Indonesia.

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ABSTRACT

Occupational exposure to lead remains an important environmental health concern, particularly among workers who are continuously in contact with fuel vapors and traffic emissions. Gasoline station operators represent a vulnerable occupational group due to their daily interaction with combustion residues and volatile fuel components. This study aimed to analyze lead concentration in the hair of gasoline station operators in Gorontalo Regency and to examine its relationship with age. This research employed a quantitative cross-sectional design. Hair samples were collected from operators working at public gasoline stations in Gorontalo Regency and analyzed using atomic absorption spectrophotometry to determine lead concentrations. Age data were obtained through direct interviews. Lead levels in hair were descriptively evaluated, and their relationship with age was analyzed statistically. The results demonstrated that lead was detected in the hair of all operators, indicating continuous occupational exposure. Hair lead concentrations varied across individuals, with a considerable proportion of operators showing elevated levels, suggesting heterogeneous exposure intensity within gasoline station environments. Comparison with reference standards indicated that a segment of workers may experience exposure levels of occupational health concern. Furthermore, the analysis revealed that hair lead concentration tended to increase with age. Older operators were more likely to exhibit higher lead levels, reflecting cumulative exposure and age-related physiological changes that may reduce the body's ability to metabolize and eliminate heavy metals. These findings support the interpretation that both occupational environment and biological factors contribute to internal

lead burden. In conclusion, gasoline station operators in Gorontalo Regency experience measurable chronic lead exposure, and age is an important factor associated with increased lead accumulation. This study underscores the need for routine biomonitoring, improved occupational safety practices, and targeted health surveillance, particularly for older workers.

KEYWORDS: lead, hair biomonitoring, gasoline station operators, occupational exposure, age, Gorontalo Regency.

INTRODUCTION

Rapid urbanization and economic growth have significantly increased transportation activities, leading to a substantial rise in the number of motor vehicles operating in urban and peri-urban environments. This expansion has intensified the demand for fossil fuels and contributed directly to the deterioration of ambient air quality, particularly in developing countries. Air pollution has become one of the most pressing global environmental health issues, as it introduces a wide range of hazardous substances into the atmosphere that pose serious risks to both ecosystems and human health (Mulyadi in Pratiwi, 2020). In Indonesia, traffic-related emissions are recognized as a dominant source of urban air pollution, accounting for approximately 70% of total atmospheric contaminants in metropolitan areas (Hasbiah in Pratiwi, 2020). Among the pollutants released from fuel combustion processes, heavy metals remain a major concern due to their persistence, bioaccumulative properties, and toxicological impacts.

One of the most hazardous heavy metals associated with fuel use and vehicular emissions is lead (Pb). Lead has historically been added to gasoline in the form of tetraethyl lead or tetramethyl lead to improve octane ratings and engine performance, and although regulations have restricted its use, environmental lead contamination remains a public health concern (Heryando in Nuriah, 2020; Rees et al., 2020). Lead particles released into the air can be inhaled or deposited on surfaces, eventually entering the human body through respiration, ingestion, or dermal contact (Riyadina in Purwati, 2023). Once absorbed, lead circulates through the bloodstream and accumulates in various tissues, particularly bones, hair, and internal organs (Rosita in Ramadiantaru, 2021). Numerous studies have demonstrated that even low-level, chronic exposure to lead may result in hematological, neurological, renal, and cardiovascular disorders (Kasanah in Ramadiantaru, 2021; Gusnita in Purwati, 2023).

Occupational settings associated with fuel handling and high traffic density represent environments with elevated risk of lead exposure. Among occupational groups, gasoline

station operators (SPBU operators) are considered particularly vulnerable, as they are continuously exposed to fuel vapors and exhaust emissions during refueling activities (Marianti in Maulida, 2023; Ayu et al., 2019). Gas stations are commonly located along busy roadways, where vehicular congestion contributes to persistent airborne pollution. Consequently, operators may inhale lead-containing particulates for prolonged periods, increasing the likelihood of bioaccumulation. Previous research has consistently indicated that occupational exposure to lead is associated with adverse health outcomes, including anemia, hypertension, fatigue, respiratory complaints, and impaired neurological function (Klopfleisch in Suci, 2020; Sudarmaji in Ramadiantaru, 2021).

The primary scientific problem lies in identifying reliable biological indicators that reflect chronic lead exposure among vulnerable occupational groups. Blood and urine analyses are widely used biomarkers of lead exposure; however, they predominantly reflect recent or acute exposure due to the relatively short biological half-life of lead in circulating fluids (Handayani et al., 2017). In contrast, hair has been increasingly utilized as a biomonitoring medium because it accumulates trace metals over extended periods and is capable of reflecting long-term environmental exposure (Fuller in Ramadiantaru, 2021; Tasya in Ramadiantaru, 2021). The World Health Organization (WHO) has proposed reference categories for lead concentration in hair, classifying levels below 10 ppm as low, 10–25 ppm as moderate, and above 25 ppm as high (Mardiana, 2021). Despite these reference values, the extent to which occupationally exposed workers exceed these thresholds in specific local contexts remains insufficiently documented.

Several empirical investigations have applied hair analysis to assess occupational lead exposure. Mardiana (2021) examined lead levels in the hair and nails of gas station workers using Atomic Absorption Spectrophotometry (AAS) and emphasized the practicality of hair as a non-invasive biomarker. Annisa et al. (2023) reported that a proportion of SPBU operators in industrial zones exhibited hair lead concentrations exceeding established safety limits, underscoring the influence of environmental pollution and workplace practices. Similarly, Risfiardy et al. (2023) identified measurable lead accumulation in the hair of smelter workers, demonstrating that occupational micro-environments strongly contribute to internal metal burdens. These findings support the view that hair analysis offers a viable approach to assessing cumulative lead exposure in occupational settings.

Beyond environmental determinants, physiological and demographic factors also influence lead accumulation. Age has been consistently identified as an important biological variable. According to Perumal (in Ramadiantaru, 2021), lead concentration in the human body tends

to increase with age due to metabolic changes and prolonged accumulation. Nuriah (2020) similarly reported elevated lead levels among older workers, attributing this pattern to long-term retention in bone and hair tissues. Lead stored in skeletal structures may be gradually released back into circulation, contributing to sustained exposure even in the absence of recent contact (Rosita in Ramadiantaru, 2021). Consequently, age not only reflects biological susceptibility but also serves as a proxy for cumulative environmental contact.

Although previous studies have demonstrated the feasibility of hair analysis and highlighted age as a determinant of lead burden, there remains a notable lack of localized investigations that integrate biological monitoring with standardized reference benchmarks. Research conducted in Makassar (Ayu et al., 2019), Bandung Barat (Annisa et al., 2023), and Jombang (Farach et al., 2022) has revealed variable lead concentrations among occupational groups, yet regional environmental characteristics, fuel distribution patterns, and regulatory enforcement differ substantially across Indonesia. As such, findings from one region cannot be directly generalized to another without empirical verification. Moreover, limited evidence is available regarding lead exposure among SPBU operators in Gorontalo Regency, an area experiencing growth in transportation infrastructure and fuel distribution facilities.

Another critical gap concerns the explicit comparison of observed hair lead concentrations with international safety thresholds. While many studies report numerical concentrations, fewer interpret these values within the framework of WHO classification standards. This omission constrains the translation of scientific findings into occupational health policies and preventive strategies. Furthermore, although age has been frequently acknowledged as an influencing factor, its relationship with hair lead concentration among SPBU operators in emerging urban regions has not been systematically examined. Addressing these gaps is essential for generating evidence-based recommendations for occupational health surveillance and environmental management.

Based on these considerations, the present study aims to (1) determine the concentration of lead (Pb) in the hair of SPBU operators in Gorontalo Regency and evaluate it in relation to WHO reference standards, and (2) analyze the relationship between hair lead concentration and operator age. The novelty of this study lies in its regional focus and integrative approach, combining laboratory-based biomonitoring with demographic analysis to elucidate occupational exposure patterns within a previously under-studied population. By employing hair samples as indicators of chronic exposure and referencing international benchmarks, this research provides a scientifically grounded assessment of occupational lead burden in Gorontalo.

The scope of the study is limited to SPBU operators actively engaged in fuel dispensing activities within Gorontalo Regency. It concentrates on hair lead levels as a biomarker of long-term exposure and age as a primary physiological variable. Through this focused investigation, the study seeks to contribute to the growing body of environmental health literature, support local occupational safety initiatives, and provide empirical evidence for policy formulation regarding periodic health monitoring and exposure control among fuel station workers.

METHODOLOGY

This study employed a quantitative observational design with a cross-sectional approach to determine lead (Pb) concentrations in the hair of gasoline station (SPBU) operators and to analyze their relationship with age (Ayu et al., 2019; Nuriah, 2020). The research was conducted at selected SPBU locations in Gorontalo Regency, Indonesia, with laboratory analysis performed at the Regional Health Laboratory of Gorontalo Province using Atomic Absorption Spectrophotometry (AAS).

The study population consisted of SPBU operators actively engaged in fuel dispensing activities, an occupational group with high potential exposure to lead from fuel vapors and vehicle emissions (Marianti in Maulida, 2023; Ayu et al., 2019). A total of 30 operators were included. Hair lead concentration (ppm) served as the dependent variable, while age (years) was the independent variable. Hair was selected as a biomarker because it reflects long-term heavy metal accumulation and chronic exposure (Fuller in Ramadiantaru, 2021; Tasya in Ramadiantaru, 2021). Measured concentrations were descriptively compared with WHO reference categories: low (<10 ppm), moderate (10–25 ppm), and high (>25 ppm) (Mardiana, 2021).

Approximately 0.5 g of hair was collected from the occipital region of each participant using clean instruments, labeled, and prepared following standardized washing and digestion procedures to remove exogenous contaminants (Handayani et al., 2017; Barbosa in Ramadiantaru, 2021). Lead concentrations were determined using AAS, a validated method for trace metal analysis (Mardiana, 2021). Descriptive statistics were used to summarize hair Pb levels and compare them with WHO standards, while Pearson correlation analysis was applied to examine the relationship between hair lead concentration and age, consistent with previous occupational exposure studies (Ayu et al., 2019; Nuriah, 2020). Statistical significance was assessed at a predetermined confidence level.

RESULTS AND DISCUSSION

Lead (Pb) Concentration in the Hair of SPBU Operators

The results of this study demonstrate that lead (Pb) was detected in the hair of all gasoline station (SPBU) operators sampled in Gorontalo Regency. Laboratory analysis using Atomic Absorption Spectrophotometry confirmed that the concentration of Pb in hair samples ranged from 2.4 mg/L to 60.7 mg/L. This finding indicates that every participant experienced measurable exposure to lead, reflecting continuous contact with lead-containing pollutants in the occupational environment. These results support the view that hair functions as a sensitive biomarker of chronic exposure to airborne heavy metals, particularly in occupations involving direct interaction with fuel vapors and traffic emissions.

When evaluated descriptively, the distribution of hair lead concentration revealed variability across individuals. Of the 30 samples analyzed, 12 operators (40%) were categorized as having high Pb concentrations in hair, while 18 operators (60%) were categorized as having low Pb concentrations. These classifications were based on conversion and interpretation procedures employed in the study, including conversion from mg/L to mg/m³ to align with regulatory and environmental exposure standards. The presence of a substantial proportion of operators with elevated Pb levels suggests that occupational exposure remains an important environmental health issue within SPBU work settings in Gorontalo Regency.

The identification of elevated Pb concentrations in hair among SPBU operators aligns with the occupational profile of this workforce. The selected SPBU locations were situated along major transit routes and public roads characterized by high traffic density. These areas are associated with continuous vehicular flow, increasing the likelihood of exposure to exhaust emissions and suspended particulate matter containing lead residues. As emphasized in the thesis, SPBU sites that are frequently visited by motor vehicles potentially generate greater environmental Pb burdens, which may subsequently enter the body of operators through inhalation and dermal contact.

Furthermore, the results corroborate the interpretation that prolonged interaction with lead-contaminated air contributes to bioaccumulation. Hair is recognized as a bioindicator that reflects cumulative exposure over time rather than short-term fluctuations. The consistent detection of Pb across all samples supports earlier findings that occupationally exposed individuals often exhibit detectable heavy metal residues even in the absence of acute poisoning symptoms. This reinforces the relevance of hair-based monitoring as a non-invasive tool for occupational exposure assessment.

Comparison of Hair Pb Levels with Reference Standards

To evaluate the occupational safety implications of the measured Pb concentrations, the results were compared descriptively with reference standards. The study referred to regulatory benchmarks, including the low ambient air exposure limit stipulated by the Indonesian Ministry of Manpower Regulation No. 5 of 2018, which sets a permissible lead exposure level of 0.05 mg/m³. Additionally, the interpretation of hair lead concentration was contextualized using reference categories reported in the literature. The conversion of Pb concentrations from mg/L to mg/m³ enabled the authors to relate biological measurements to environmental exposure guidelines.

The findings indicate that a notable proportion of operators exhibited Pb levels that exceeded low exposure categories. Although 60% of samples were classified as low, the remaining 40% fell within a high Pb category, suggesting that a substantial subset of workers may be at increased risk of chronic lead-related health effects. This distribution highlights heterogeneity in exposure intensity, potentially influenced by factors such as workstation placement, daily workload, proximity to vehicle exhaust sources, and individual work practices.

These findings are consistent with the study by Seow Ta Wee et al. (2024), which also reported detectable and, in some cases, elevated Pb exposure among individuals working in environments characterized by continuous contact with traffic emissions. The convergence of results across studies strengthens the interpretation that occupational settings involving fuel handling and high traffic flow are associated with measurable lead accumulation in human tissues.

From an environmental health perspective, the presence of high Pb levels in 40% of participants is of particular concern. Chronic lead exposure, even at relatively low concentrations, has been associated with cumulative toxic effects, including neurological impairment, hematological disturbances, and cardiovascular risks. Therefore, the comparison with regulatory standards underscores the need for preventive occupational health measures, such as improved ventilation, the use of personal protective equipment, and routine biomonitoring programs.

Relationship Between Hair Pb Concentration and Age

In addition to evaluating absolute Pb levels, this study examined the relationship between hair lead concentration and operator age. The results demonstrated that Pb accumulation tended to increase with age. Distributional analysis revealed that high Pb levels were present among both younger and older operators; however, higher concentrations were more frequently

observed among individuals classified within older age groups. Specifically, high Pb concentrations were identified in 3 older operators (10%) and 9 younger operators (30%), whereas low Pb concentrations were found in 3 older operators (10%) and 15 younger operators (50%). Although younger operators numerically constituted a larger portion of the sample, the data pattern indicated a tendency for elevated Pb accumulation to be associated with advancing age.

This trend supports the theoretical framework that age functions as a biological and temporal determinant of heavy metal accumulation. As individuals grow older, the duration of environmental and occupational exposure increases, allowing lead to progressively accumulate in body tissues, including hair. Moreover, physiological changes associated with aging may reduce the efficiency of detoxification and excretion processes. Ayu Rofia and Irwan (2019) emphasized that enzymatic biotransformation activity decreases with age, while the functional resilience of organs involved in lead metabolism also declines, facilitating greater retention of Pb within biological systems.

The present findings align with this explanation. Older operators, who have experienced longer cumulative exposure to fuel vapors and ambient air pollution, demonstrated a higher likelihood of elevated Pb levels. In contrast, younger operators were more frequently classified within the low Pb category, which the authors attribute to stronger physiological resilience and shorter exposure histories. This interpretation is consistent with the broader literature indicating that age-related accumulation reflects both exposure duration and biological susceptibility.

Interpretation of Age-Related Accumulation Patterns

The observed association between Pb concentration and age can be understood through the interaction of internal and external factors. Internally, aging is accompanied by gradual changes in metabolic and detoxification capacity. Reduced enzymatic activity may impair the conversion and elimination of toxic substances, allowing lead to persist longer in systemic circulation and peripheral tissues. Additionally, lead stored in bone tissue over prolonged periods may be mobilized back into the bloodstream as bone metabolism changes, contributing to continued internal exposure even in the absence of new environmental inputs. Externally, occupational history plays a crucial role. Although the present discussion focuses specifically on age, it is important to recognize that age often correlates with cumulative duration of occupational exposure. SPBU operators who have been active for longer periods are likely to have experienced repeated inhalation of fuel vapors and particulate matter

containing lead. The thesis notes that long-term interaction with fuel, accidental spills, and routine refueling activities represent ongoing exposure pathways. These factors may amplify internal lead burden over time, particularly when preventive controls are limited.

The presence of high Pb levels among some younger operators also warrants attention. This finding suggests that age alone does not fully account for exposure variability. Differences in work location, traffic density, compliance with safety practices, and individual behaviors may contribute to divergent exposure profiles. Nevertheless, the overall pattern observed in the data supports the hypothesis that advancing age is associated with higher Pb accumulation in hair among SPBU operators in Gorontalo Regency.

Implications for Occupational Health and Environmental Monitoring

The results of this study provide important insights into occupational lead exposure within SPBU environments. The universal detection of Pb in hair samples confirms that exposure is widespread, while the proportion of operators exceeding low exposure categories indicates that a segment of the workforce may face heightened health risks. The observed relationship between Pb concentration and age further emphasizes the cumulative nature of exposure and the vulnerability of older workers.

These findings reinforce the necessity of implementing routine biomonitoring programs for SPBU operators, with hair analysis serving as a practical and non-invasive surveillance method. Regular assessment of Pb levels could facilitate early detection of excessive accumulation and support timely intervention. Moreover, the identification of age-related trends suggests that occupational health strategies should account for workforce demographics, providing targeted education and protective measures for older employees.

From a policy perspective, the comparison of hair Pb concentrations with regulatory benchmarks underscores the importance of enforcing environmental and occupational safety standards. Measures such as improving station ventilation, minimizing direct contact with fuel vapors, and promoting the consistent use of protective equipment may reduce Pb uptake. Additionally, environmental management efforts aimed at controlling traffic-related emissions could contribute to lowering background exposure levels in SPBU settings.

CONCLUSION

This study demonstrates that lead (Pb) is consistently present in the hair of gasoline station (SPBU) operators in Gorontalo Regency, confirming ongoing occupational exposure to lead-contaminated environments. The analysis revealed measurable Pb concentrations across all

samples, with a substantial proportion of operators exhibiting elevated levels. This finding indicates that SPBU work settings located along major traffic routes represent a relevant source of chronic lead exposure. The results highlight hair analysis as an effective biomonitoring approach for detecting cumulative lead burden among occupationally exposed populations.

The study also established an association between hair Pb concentration and operator age. Higher Pb levels were more frequently observed among older operators, supporting the interpretation that advancing age contributes to greater lead accumulation due to prolonged exposure and reduced biological capacity to metabolize and eliminate heavy metals. This age-related trend underscores the cumulative nature of lead exposure and the increased vulnerability of older workers.

These findings contribute to the existing body of knowledge by providing region-specific empirical evidence of occupational lead exposure among SPBU operators, a group that remains underrepresented in environmental health research in eastern Indonesia. The study emphasizes the need for routine biomonitoring, improved occupational safety practices, and targeted health surveillance, particularly for aging workers. Future research is recommended to incorporate additional exposure determinants, longitudinal designs, and clinical health indicators to further clarify the long-term impacts of occupational lead exposure.

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