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The Relationship between Urinary Exposure to PAHs (1-Hydroxyphenanthrene) and Inflammatory Biomarkers in Female Waste Workers

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Keywords

Polycyclic Aromatic Hydrocarbons; urinary OHPHE1; white blood cell count; inflammation; waste workers

Abstract

Exposure to polycyclic aromatic hydrocarbons (PAHs) from open waste burning and contaminated dust at temporary waste collection sites (TPS) may trigger systemic inflammation, particularly among female workers routinely exposed. This study assessed the association between urinary 1-hydroxyphenanthrene (OHPHE1), a biomarker of PAHs exposure, and white blood cell (WBC) count, an indicator of systemic inflammation. An analytical cross-sectional study was conducted among 35 female waste-sorting workers at TPS. Urinary PAHs metabolites (OHPHE1, OHPHE2, OHNAP) were measured in urine, and WBC counts were obtained from blood examinations. Spearman correlation showed a significant positive association between urinary OHPHE1 and WBC count. OHPHE2 showed a positive trend that did not reach statistical significance, whereas OHNAP showed no association. These results suggest that PAHs exposure, particularly as reflected by OHPHE1, may contribute to systemic inflammation among female TPS workers. Reducing open burning, improving personal protective equipment use, and implementing routine biomonitoring-based health surveillance are recommended.

INTRODUCTION

Air pollution in the vicinity of waste disposal sites has become a serious concern for environmental health, particularly due to the practice of open burning of waste, which produces hazardous pollutants. Polycyclic aromatic hydrocarbons (PAHs) are organic compounds formed from the incomplete combustion of organic materials such as waste, plastics, and fossil fuels (Hong et al., 2023; Sombiri et al., 2024). Workers at waste recycling sites are exposed to particulate matter and PM2.5-associated PAHs (Kwarteng et al., 2022). This issue is particularly specific and crucial for waste pickers, especially women, who work in landfill areas without adequate protection. Waste pickers in low- and middle-income countries work on dumps and landfills and are exposed to a wide range of health hazards (Gutberlet & Uddin, 2018). Chronic exposure to smoke and dust containing lipophilic compounds increases the risk of toxin accumulation in the body, which is much higher than in the general population (Farina et al., 2025). This risk is compounded by the persistent nature of PAHs and their ability to cause serious health effects such as respiratory tract cancer and other systemic disorders (Farina et al., 2025).

The vulnerability of female workers in the informal TPS sector is of particular concern due to a combination of occupational exposure and biological factors. Female waste pickers are often at the forefront of exposure to combustion fumes, and this vulnerability is exacerbated by limited personal protective equipment and socioeconomic factors (Farina et al., 2025). Occupational PAH exposure has also been linked to reproductive and fertility implications (Montano et al., 2025). When PAHs from the environment are inhaled or enter the body, these compounds are metabolized

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relevant biomonitoring approach for assessing occupational exposure among female workers in high-risk waste collection environments.into hydroxyl forms and excreted in urine (Farina et al., 2025). One specific metabolite that is stable and capable of reflecting environmental PAH exposure, particularly from phenanthrene, is 1-hydroxyphenanthrene (1-OHPHE) (Farina et al., 2025). Therefore, the detection of 1-OHPHE in urine is a highly relevant biomonitoring method for measuring the magnitude of internal exposure received by female workers in such high-risk environments.

Biologically, the entry of PAHs into the body does not simply result in chemical residues, but triggers a complex immune response. Exposure to PAHs is known to activate aryl hydrocarbon receptors (AhR), which play a role in altering immune responses and the expression of inflammatory genes (Farina et al., 2025). Chronic PAH exposure also alters metabolic profiles in humans (Wang et al., 2015). This process triggers oxidative stress, which then stimulates the release of proinflammatory cytokines and increases the production of white blood cells (WBCs) as an indicator of systemic inflammation (Lim & Kim, 2024). Such inflammation is considered the bridge between exposure to pollutants and the emergence of various chronic diseases (Farina et al., 2025; Lim & Kim, 2024). The relationship between exposure sources at TPS, metabolism into 1-OHPHE, and the emergence of an inflammatory response in the form of an increase in leukocytes is illustrated in the conceptual framework in Figure 1.

Although the toxicity pathway of PAHs has been extensively studied, studies on the direct relationship between specific 1-hydroxyphenanthrene (1-OHPHE) metabolites in urine and leukocyte inflammatory biomarkers still show limited and inconsistent results (Farina et al., 2025). Most previous studies have focused on the general population, children, or formal industrial workers, so specific data on female workers in the waste management sector is still very rare. However, understanding this correlation is very important to prove the real impact of waste incineration pollution on the immune systems of the most vulnerable workers. The uncertainty regarding the strength of the correlation between internal PAH doses and inflammatory responses in this group of informal workers needs to be addressed through empirical research.

Based on the urgency of this issue, this study aims to analyze urinary 1-hydroxyphenanthrene (1-OHPHE) levels as an exposure marker, identify inflammatory biomarker profiles through



Source: Author's Own Illustration, 2026

Figure 1

PAH Exposure Pathways and Inflammatory Response

leukocyte counts, and examine the relationship between the two in female waste pickers at TPS. This study is expected to fill the gap in local data on the health impacts of work in the informal sector. In addition, the results of this study can provide a strong scientific basis for stakeholders in designing more effective occupational health interventions and safer waste management policies for female workers.

RESEARCH METHOD

The study used an observational analytical design with a cross-sectional approach, in which PAH exposure and inflammatory response measurements were taken at the same time. This approach was chosen because it is efficient and commonly used to examine the initial relationship between exposure biomarkers and inflammatory parameters. In this study, urinary OHPHE1 served as the independent variable, while WBC count served as the dependent variable. The cross-sectional design was considered practical and appropriate for describing the initial relationship between PAH exposure and systemic inflammation.

The research subjects were female waste pickers who were exposed to combustion smoke and dust at the TPS location every day. Through a strict sampling technique (purposive), 35 respondents who met the inclusion and exclusion criteria were selected. The main criteria included female workers of productive or fertile age (±15–49 years), given that this age group still has an active hormonal cycle that can biologically affect the sensitivity of hematological responses to exposure to chemicals such as PAHs. PAHs have also been shown to affect pregnancy, the placenta, and placental trophoblasts, which adds to the concern for women of reproductive age (Dai et al., 2023). This sample size was considered adequate for a preliminary study with a cross-sectional design to detect correlations between the variables studied.

Ethical aspects were a top priority in conducting this study. The research was declared ethically sound by the Universitas Muhammadiyah Lamongan Health Research Ethics Committee with the issuance of Ethical Clearance letter number 133/EC/KEPK–S3/04/2025. All research procedures were carried out in accordance with the principles of respect for persons, beneficence, and justice. Before collecting urine and blood specimens, all respondents were given detailed explanations about the purpose and medical procedures to be performed and were asked to voluntarily sign an informed consent form. The confidentiality of respondent data was fully guaranteed through a numerical coding system, and biological samples were handled in accordance with biosafety standards for mutual safety.

The data analysis began with a normality test using the Shapiro–Wilk method to examine the distribution of 1-OHPHE levels and WBC counts. The test results showed that the data were not normally distributed, so the correlation analysis was continued using the Spearman nonparametric test. This test aims to assess the strength and direction of the relationship between exposure variables and health effects. In addition, simple linear regression analysis was also applied to model quantitative relationships, allowing researchers to predict the magnitude of changes in leukocyte counts as urinary 1-OHPHE levels increase. Interpretation of the results was based on a predetermined level of statistical significance ($p < 0.05$).

To strengthen the interpretation of field findings, this study also integrated literature review methods. The empirical data obtained were compared and discussed alongside relevant journal articles that examined the relationship between urinary PAH metabolites and hematological biomarkers in various populations. The combination of rigorous quantitative statistical analysis and in-depth literature review is expected to provide a comprehensive understanding of the mechanism of the impact of TPS

environmental exposure on the health profile of female workers, particularly in relation to the risk of inflammation.

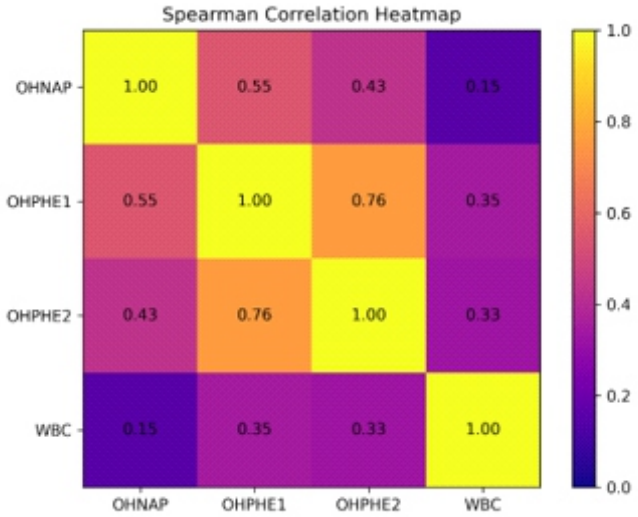
RESULTS AND DISCUSSION

The analysis of the relationship between exposure biomarkers and inflammatory response in this study is visualized through a correlation matrix in Figure 2. Visually, the heatmap illustrates the pattern of relationships between variables, where brighter or more intense colors indicate stronger correlations. There is a consistent positive correlation among exposure biomarkers (OHNAP, OHPHE1, and OHPHE2), especially between the two phenanthrene metabolites (OHPHE1 and OHPHE2), which have a fairly high correlation. This is reasonable considering that both originate from the same parent compound. However, the main focus of this visualization is on the last column, namely the relationship between PAH metabolites and white blood cell (WBC) count. Here, OHPHE1 shows the most prominent color intensity indicating a positive correlation compared to other metabolites, providing an initial signal that this metabolite variant has the strongest biological relevance to the inflammatory response in the study subjects.

The Spearman correlation test results confirmed the relationship pattern previously illustrated in the heat map. A significant positive correlation was found between urinary 1-hydroxyphenanthrene (OHPHE1) levels and leukocyte counts in female workers at the TPS (r_s = 0.346; p = 0.042). This value indicates that an increase in OHPHE1 levels, as an indicator of internal exposure to Polycyclic Aromatic Hydrocarbons (PAHs), is associated with an increase in leukocyte count as a systemic inflammatory response. Biologically, this finding indicates that exposure to PAHs from waste incineration activities has the potential to trigger immune system activation through inflammatory mechanisms.

Another phenanthrene metabolite, OHPHE2, showed a similar positive correlation (r_s = 0.326), but did not reach statistical significance (p = 0.056). Although the association was borderline significant, the consistent relationships observed for both phenanthrene metabolites support a potential link between PAH exposure and inflammatory responses. The difference in significance levels may be influenced by individual metabolic variations, limited sample size, or differences in biomarker sensitivity in reflecting cumulative exposure.

Naphthalene metabolites (OHNAP) showed no significant



Source: Processed Primary Data, 2026

Figure 1
PAH Exposure Pathways and Inflammatory Response

correlation with leukocyte count (r_s = 0.152; p = 0.382). This difference can be explained by the toxicokinetic characteristics of naphthalene, which is more volatile and tends to reflect short-term or fluctuating exposure, such as vehicle exhaust or transient environmental sources (Zhu et al., 2021). Phenanthrene, as a compound with a more complex aromatic ring structure, binds more easily to fine dust particles and is more persistent in combustion environments. These properties allow for more stable and cumulative exposure, making its metabolites, particularly OHPHE1, more representative indicators of chronic exposure burden at TPS (Wu et al., 2022).

These findings are consistent with previous international studies reporting associations between urinary PAH metabolites and inflammatory biomarkers. The Flemish Environment and Health Study (FLEHS-4) showed that urinary hydroxylated PAH metabolites were associated with biomarkers of chronic endocrine stress, oxidative stress, and inflammation in adolescents (Verheyen et al., 2021). Arachidonic acid metabolism and inflammatory biomarkers have likewise been associated with PAH exposure (Lin et al., 2022), and co-exposure to PAHs and phthalates was associated with blood cell-based inflammatory biomarkers in children (Zhao et al., 2022). In addition, a meta-analysis of firefighters showed that increased OH-PAH levels after exposure correlated with oxidative stress and the risk of systemic disorders (Hwang et al., 2022). The consistency of these findings suggests that PAHs have a relatively uniform pathophysiological mechanism in triggering inflammatory responses through oxidative stress and immune activation pathways. Urinary PAH metabolites have also been associated with serum C-reactive protein (Everett et al., 2010). Analyses of NHANES 2001–2006 data likewise reported that urinary PAH biomarkers were positively associated with serum C-reactive protein and total WBC count, with the association more evident in men (Alshaarawy et al., 2013). However, the evidence is not entirely uniform: an analysis of NHANES 2001–2004 data found no clear association between urinary PAH metabolites and white blood cell count among nonsmokers after controlling for tobacco exposure (Clark III et al., 2012). This underlines the importance of accounting for smoking and other confounders when interpreting biomarker associations, which was not possible in the present preliminary study.

Research on other worker populations also supports the clinical relevance of this relationship. Navarro et al. (2019) reported that hydroxyl PAH metabolites are associated with respiratory and cardiovascular dysfunction in individuals exposed to diesel emissions. A large-scale study by Liu et al. (2021) also concluded that PAH exposure contributes to low-grade chronic inflammation that plays a role in the pathogenesis of cardiometabolic diseases. Thus, the increase in leukocyte count in female workers at TPS can be understood as an early indicator of an inflammatory response due to chronic toxin exposure that has the potential to develop into long-term health disorders.

The implications of these findings are highly relevant for informal sector workers in TPS, who are generally not covered by formal occupational health systems (Yang et al., 2018) Informal waste pickers also commonly work under unsafe conditions and are often unaware of the health risks they face (Uddin et al., 2021). Chronic exposure without adequate personal protective equipment (PPE) increases the risk of toxin accumulation in the body. Therefore, the implementation of simple biomonitoring through periodic OHPHE1 urine tests and leukocyte counts can be considered as an efficient and relatively affordable occupational health surveillance strategy (Louro et al., 2022). This approach allows for the early detection of biological changes before they develop into more severe clinical conditions.

The results of this study emphasize the importance of improving waste

management governance, particularly controlling open burning practices, which are a major source of PAH emissions. The literature shows that modernizing waste management systems and reducing open burning contribute significantly to reducing air pollution and health risks for workers (Gómez-Sanabria et al., 2022; Yang et al., 2018). Therefore, health interventions should not be limited to medical approaches, but also require environmental policy support and social protection for informal workers.

CONCLUSION

Based on the overall research results, it can be concluded that exposure to Polycyclic Aromatic Hydrocarbons (PAHs), as reflected in urinary OHPHE1 levels, has a significant positive correlation with leukocyte count as an indicator of systemic inflammation in workers in the waste processing environment. These findings indicate that increased exposure to PAHs has the potential to trigger an inflammatory response in the body, although not all PAH metabolites show a statistically significant relationship. The results of this study emphasize the importance of using biological biomarkers in assessing the impact of environmental exposure on health and the need for PAH exposure prevention and control efforts to protect worker health, especially in high-risk work groups.

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REFERENCES

Alshaarawy, O., Zhu, M., Ducatman, A., Conway, B., & Andrew, M. E. (2013). Polycyclic aromatic hydrocarbon biomarkers and serum markers of inflammation. A positive association that is more evident in men. *Environmental Research*, *126*, 98–104.https://doi.org/10.1016/j.envres.2013.07.006

Clark III, J. D., Serdar, B., Lee, D. J., Arheart, K., Wilkinson, J. D., & Fleming, L. E. (2012). Exposure to Polycyclic Aromatic Hydrocarbons and Serum Inflammatory Markers of Cardiovascular Disease. *Environmental Research*, *22*(117), 132–137.https://doi.org/10.1016/j.envres.2012.04.012

Dai, Y., Xu, X., Huo, X., & Faas, M. M. (2023). Effects of polycyclic aromatic hydrocarbons (PAHs) on pregnancy, placenta, and placental trophoblasts. *Ecotoxicology and Environmental Safety*, *262*, 1–14. https://pubmed.ncbi.nlm.nih.gov/37536008/

Everett, C. J., King, D. E., Player, M. S., Matheson, E. M., Post, R. E., & 3rd, A. G. M. (2010). Association of urinary polycyclic aromatic hydrocarbons and serum C-reactive protein. *Environmental Research*, *110*(1), 79–82. https://doi.org/10.1016/j.envres.2009.09.010

Farina, E., Iamiceli, A. L., Orengia, M., Gandini, M., Crosetto, L., Abate, V., Filippis, S. P. De, Luca, S. De, Iacovella, N., Felip, E. De, & Bena, A. (2025). Biomonitoring of Hydroxylated Polycyclic Aromatic Hydrocarbon Metabolites in Workers at a Waste-to-Energy Incinerator, Turin, Italy. *International Journal of Environmental Research and Public Health*, *22*(1), 77. https://pubmed.ncbi.nlm.nih.gov/39857530/

Gómez-Sanabria, A., Kiesewetter, G., Klimont, Z., Schoepp, W., & Haberl, H. (2022). Potential for future reductions of global GHG and air pollutants from circular waste management systems. *Nature Communications*, *13*(106). https://www.nature.com/articles/s41467-021-27624-7

Gutberlet, J., & Uddin, S. M. N. (2018). Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries. *International Journal of Occupational and Environmental Health*, *23*(4), 299–310. https://doi.org/10.1080/10773525.2018.1484996

Hong, D. H., Jung, J., Jo, J. H., Kim, D. H., & Ryu, J. Y. (2023). Occupational exposure to polycyclic aromatic hydrocarbons in Korean adults: evaluation of urinary 1-hydroxypyrene, 2-naphthol, 1-hydroxyphenanthrene, and 2-hydroxyfluorene using Second Korean National Environmental Health Survey data. *Annals of Occupational and Environmental Medicine*, *35*(1), 1–15. https://pubmed.ncbi.nlm.nih.gov/37063599/

Hwang, J., Xu, C., Grunsted, P., Agnew, R. J., Malone, T. R., Clifton, S., Thompson, K., & Xu, X. (2022). Urinary Metabolites of Polycyclic Aromatic Hydrocarbons in Firefighters: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, *19*(14), 1–14. https://pubmed.ncbi.nlm.nih.gov/35886320/

Kwarteng, L., Devasurendra, A. M., Laskaris, Z., Arko-Mensah, J., Nti, A. A. A., Takyi, S., Acquah, A. A., Dwomoh, D., Basu, N., Robins, T., Fobil, J. N., & Batterman, S. (2022). Occupational exposures to particulate matter and PM2.5-associated polycyclic aromatic hydrocarbons at the Agbogbloshie waste recycling site in Ghana. *Environmental International*, *158*.https://www.sciencedirect.com/science/article/pii/S0160412021005961

Lim, E. Y., & Kim, G.-D. (2024). Particulate Matter-Induced Emerging Health Effects Associated with Oxidative Stress and Inflammation. *Antioxidants*, *13*(10). https://pubmed.ncbi.nlm.nih.gov/39456509/

Lin, Y., Lu, X., Qiu, X., Yin, F., Faull, K. F., Tseng, C.-H., Zhang, J. J., Fiehn, O., Zhu, T., Araujo, J. A., & Zhu, Y. (2022). Arachidonic acid metabolism and inflammatory biomarkers associated with exposure to polycyclic aromatic hydrocarbons. *Environmental Research*, *221*. https://doi.org/10.1016/j.envres.2022.113498

Liu, C., Wu, M., Fu, M., Wang, H., & Nie, J. (2021). Dose-response relationships between polycyclic aromatic hydrocarbon exposure and blood cell counts among coke oven workers: A sex-stratified analysis. *BMJ Open*, *11*(12).https://doi.org/10.1136/bmjopen-2020-046843

Louro, H., Gomes, B. C., Saber, A. T., Iamiceli, A. L., Göen, T., Jones, K., Katsonouri, A., Neophytou, C. M., Vogel, U., Ventura, C., Oberemm, A., Duca, R. C., Fernandez, M. F., Olea, N., Santonen, T., Viegas, S., & Silva, M. J. (2022). The Use of Human Biomonitoring to Assess Occupational Exposure to PAHs in Europe: A Comprehensive Review. *Toxics*, *10*(8), 1–30. https://doi.org/10.3390/toxics10080480

Montano, L., Baldini, G. M., Piscopo, M., Liguori, G., Lombardi, R., Ricciardi, M., Esposito, G., Pinto, G., Fontanarosa, C., Spinelli, M., Palmieri, I., Sofia, D., Brogna, C., Carati, C., Esposito, M., Gallo, P., Amoresano, A., & Motta, O. (2025). Polycyclic Aromatic Hydrocarbons (PAHs) in the Environment:

Occupational Exposure, Health Risks and Fertility Implications. *Toxics*, *13*(3).https://doi.org/10.3390/toxics13030151

Navarro, K. M., Mann, J. K., Hammond, S. K., McKone, T. E., & Balmes, J. R. (2019). Predictors of Urinary Polycyclic Aromatic Hydrocarbon Concentrations: NHANES 2001–2006. *Exposure and Health*, *11*, 237–247.https://link.springer.com/article/10.1007/s12403-018-00292-7

Sombiri, S., Balhara, N., Attri, D., Kharb, I., & Giri, A. (2024). An overview on occurrence of polycyclic aromatic hydrocarbons in food chain with special emphasis on human health ailments. *Discover Environment*, *2*(87). https://link.springer.com/article/10.1007/s44274-024-00121-6

Uddin, M. M., Zakeel, M. C. M., Zavahir, J. S., Marikar, F. M. M. T., & Jahan, I. (2021). Heavy Metal Accumulation in Rice and Aquatic Plants Used as Human Food: A General Review. *Toxics 2021, Vol. 9, Page 360*, *9*(12), 360. https://doi.org/10.3390/TOXICS9120360

Verheyen, V. J., Remy, S., Bijnens, E. M., Colles, A., Govarts, E., Martin, L. R., Koppen, G., Bruckers, L., Nielsen, F., Vos, S., Morrens, B., Coertjens, D., Decker, A. De, Franken, C., Hond, E. Den, Nelen, V., Covaci, A., Loots, I., Henauw, S. De, … Schoeters, G. (2021). Long-term residential exposure to air pollution is associated with hair cortisol concentration and differential leucocyte count in Flemish adolescent boys. *Environmental Research*, *201*, 1–15. https://doi.org/10.1016/j.envres.2021.111595

Wang, Z., Zheng, Y., Zhao, B., Zhang, Y., Liu, Z., Xu, J., Chen, Y., Yang, Z., Wang, F., Wang, H., He, J., Zhang, R., & Abliz, Z. (2015). Human Metabolic Responses to Chronic Environmental Polycyclic Aromatic Hydrocarbon Exposure by a Metabolomic Approach. *Journal of Proteome Research*, *14*(6), 2583–2593. https://doi.org/10.1021/acs.jproteome.5b00134

Wu, X., Cao, X., Lintelmann, J., Peters, A., Koenig, W., Zimmermann, R., Schneider, A., Wolf, K., & KORA-Study group. (2022). Assessment of the association of exposure to polycyclic aromatic hydrocarbons, oxidative stress, and inflammation: A cross-sectional study in Augsburg, Germany. *International Journal of Hygiene and Environmental Health*, *244*.https://doi.org/10.1016/j.ijheh.2022.113993

Yang, H., Ma, M., Thompson, J. R., & Flower, R. J. (2018). Waste management, informal recycling, environmental pollution and public health. *Journal of Epidemiology & Community Health*, *72*(3). https://doi.org/10.1136/jech-2016-208597

Zhao, L., Liu, M., Liu, L., Guo, W., Yang, H., Chen, S., Yu, J., Li, M., Fang, Q., Lai, X., Yang, L., & Zhang, X. (2022). The association of co-exposure to polycyclic aromatic hydrocarbon and phthalates with blood cell-based inflammatory biomarkers in children: A panel study. *Environmental Pollution*. https://www.sciencedirect.com/science/article/abs/pii/S0269749122006935

Zhu, H., Martinez-Moral, M.-P., & Kannan, K. (2021). Variability in urinary biomarkers of human exposure to polycyclic aromatic hydrocarbons and its association with oxidative stress. *Environmental International*, *156*. https://doi.org/10.1016/j.envint.2021.106720