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Environmental Chemical Exposure and Occupational Health Outcomes among Workers in Selected Occupational Settings in Enugu State, Nigeria: Implications for Occupational Nursing Practice

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Abstract : *Occupational exposure to environmental chemical contaminants is a major public health concern, especially in low- and middle-income countries with limited occupational safety systems. This study assessed environmental chemical exposures and associated occupational health outcomes among workers in healthcare facilities, laboratories, manufacturing industries, and agro-allied establishments in Enugu State, Nigeria, with emphasis on implications for occupational nursing practice. A cross-sectional analytical design was used. A total of 320 questionnaires were distributed, and 301 were completed and returned, giving a response rate of 94.1%. Data were obtained through environmental monitoring, biological sampling, structured questionnaires, and clinical assessments. Findings showed that mean concentrations of $PM_{2.5}$ (42.6 ± 8.7 µg/m³), PM_{10} (87.4 ± 14.3 µg/m³), VOCs (0.82 ± 0.11 ppm), lead (0.067 ± 0.014 mg/m³), cadmium (0.006 ± 0.002 mg/m³), and formaldehyde (0.12 ± 0.03 ppm) exceeded WHO/OSHA permissible limits. Biological monitoring revealed elevated blood lead (8.41 ± 2.37 µg/dL), cadmium (1.94 ± 0.51 µg/L), mercury (4.76 ± 1.12 µg/L), urinary pesticide metabolites (0.87 ± 0.24 mg/L), and malondialdehyde levels (6.34 ± 1.47 µmol/L), indicating significant internal exposure. The most common occupational health outcomes were fatigue (60.8%), persistent headaches (57.8%), respiratory symptoms (53.8%), and eye irritation (45.2%). Significant positive correlations were observed between exposure indicators and health outcomes, including $PM_{2.5}$ and respiratory symptoms (r = 0.612), blood lead and neurological symptoms (r = 0.693), and VOCs and fatigue (r = 0.511) (p < 0.01). Logistic regression analysis identified inadequate personal protective equipment use (OR = 4.12, 95% CI: 2.47–6.89), elevated blood lead levels (OR = 3.41, 95% CI: 2.11–5.48), prolonged exposure duration (OR = 2.84, 95% CI: 1.76–4.58), and high VOC exposure (OR = 2.63, 95% CI: 1.58–4.39) as significant predictors of occupational illness. The study concludes that workers are exposed to hazardous chemical levels associated with measurable biological uptake and adverse health outcomes. Strengthening environmental monitoring, occupational health surveillance, and nursing-led interventions is essential to reduce exposure risks and improve worker safety.*

Keywords: *Occupational exposure; Environmental chemicals; Biological monitoring; Occupational health; Nursing practice*

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1.0 Introduction

Occupational exposure to environmental chemicals remains a major global public health concern, affecting millions of workers across diverse industrial, agricultural, manufacturing, and healthcare settings. Workers are routinely exposed to hazardous substances such as heavy metals, pesticides, solvents, particulate matter, disinfectants, volatile organic compounds (VOCs), and other industrial chemicals through inhalation, dermal contact, ingestion, or

accidental injection (International Labour Organization [ILO], 2021). These exposures have been associated with a wide range of adverse health outcomes, including respiratory diseases, cardiovascular disorders, neurological impairments, cancers, reproductive abnormalities, and dermatological conditions (World Health Organization [WHO], 2021a). The increasing complexity of modern workplaces, coupled with the introduction of new chemical substances and technologies, has heightened concerns regarding occupational health risks and the need for effective preventive measures.

The burden of occupational diseases attributable to environmental chemical exposure remains substantial worldwide. According to the WHO and ILO Joint Estimates, approximately 1.9 million deaths annually are associated with work-related diseases and injuries, many of which are linked to exposure to hazardous chemicals and environmental pollutants (WHO, 2021b). Furthermore, the ILO (2021) reported that more than one billion workers globally are exposed to hazardous chemicals in occupational settings, resulting in significant morbidity, mortality, and economic losses. These statistics highlight the urgent need for improved workplace monitoring, risk assessment, and health protection strategies.

Chemical exposures are particularly important in healthcare environments where workers frequently encounter disinfectants, sterilizing agents, laboratory reagents, hazardous drugs, anesthetic gases, and cleaning chemicals. Exposure to these agents has been linked to respiratory disorders, skin diseases, and other chronic health conditions among healthcare professionals (Colas *et al*., 2022). Occupational nurses and other healthcare workers are especially vulnerable because of their routine interaction with chemical and biological hazards during patient care and facility maintenance activities.

Several recent studies have demonstrated the prevalence of occupational exposure among healthcare workers. Zhang *et al*. (2022) reported significant occupational exposure to blood and body fluids among registered nurses, indicating persistent workplace health risks despite existing safety measures. Similarly, Mengistu *et al*. (2022), through a systematic review and meta-analysis, found widespread occupational exposure among healthcare workers globally, emphasizing the need for strengthened preventive interventions and occupational health surveillance systems.

Occupational exposure is not limited to healthcare settings. Environmental and industrial exposures continue to affect workers across various sectors. Teixeira *et al*. (2021) identified occupational noise exposure as a major environmental hazard affecting workers worldwide, while Hulshof *et al*. (2021) reported widespread exposure to ergonomic risk factors that contribute to occupational illnesses and reduced worker productivity. Furthermore, Yuan *et al*. (2022) observed substantial exposure to chemical and biological hazards among dental nurses, demonstrating that workplace exposures remain prevalent even in highly regulated professional environments.

Advances in environmental chemistry have enhanced the understanding of the sources, transport pathways, transformation mechanisms, and toxicological effects of workplace contaminants. Environmental monitoring techniques and exposure assessment tools now provide more accurate characterization of occupational hazards and facilitate evidence-based interventions (Colas *et al*., 2022). These developments have strengthened the integration of environmental science with occupational health practice and have improved the capacity to identify and manage workplace risks.

Occupational nurses play a critical role in preventing and managing work-related

illnesses associated with environmental chemical exposures. Their responsibilities include workplace health surveillance, risk assessment, health promotion, worker education, emergency response, and policy implementation. Effective occupational nursing practice contributes significantly to early disease detection, exposure prevention, and the promotion of safer work environments (WHO, 2021a).

Although previous studies have documented the prevalence and health consequences of occupational exposures among workers (Hulshof *et al*., 2021; Mengistu *et al*., 2022; Yuan *et al*., 2022), most investigations have focused on specific occupational hazards or individual worker populations. Limited attention has been given to the integrated assessment of environmental chemical exposures and their occupational health outcomes from the perspective of occupational nursing practice. Furthermore, evidence from low- and middle-income countries remains inadequate despite the higher likelihood of weak occupational health systems, poor regulatory enforcement, and increased worker vulnerability. Consequently, there is a need for comprehensive studies that evaluate environmental chemical exposures, associated health outcomes, and the implications of these findings for occupational nursing interventions and workplace health policies.

This study aims to evaluate environmental chemical exposures and their associated occupational health outcomes while examining the implications of these findings for occupational nursing practice. Specifically, the study seeks to:

1. Identify major environmental chemical hazards encountered in occupational settings.
2. Assess the occupational health outcomes associated with these exposures.
3. Examine the relationships between exposure levels and health effects among workers.
4. Explore evidence-based occupational nursing interventions that can reduce exposure risks and improve worker health and safety.

This study is significant because it contributes to the growing body of knowledge on the relationship between environmental chemical exposures and occupational health outcomes. The findings will provide evidence that can support workplace health surveillance programs, environmental risk assessments, and occupational disease prevention strategies. The study will also strengthen occupational nursing practice by providing insights into effective exposure monitoring, worker education, and early intervention approaches.

Additionally, the findings may inform policymakers, occupational health practitioners, environmental scientists, and employers on strategies for improving workplace safety standards and reducing the burden of occupational diseases. By integrating environmental chemistry and occupational nursing perspectives, the study will contribute to the development of multidisciplinary approaches for protecting worker health and promoting sustainable occupational environments.

2.0 Materials and Methods

2.1 Study Design

This study adopted a cross-sectional analytical research design to evaluate environmental chemical exposures and their associated occupational health outcomes among workers in selected occupational settings in Enugu State, Nigeria. The design was considered appropriate because it allows simultaneous assessment of workplace chemical exposures and health outcomes among workers, thereby facilitating the identification of associations between environmental contaminants and occupational health conditions. The study

integrated environmental exposure assessment, biological monitoring, and occupational health evaluation to provide a comprehensive understanding of workplace-related chemical risks and their implications for occupational nursing practice.

2.2 Study Area

The study was conducted in Enugu State, South-East Nigeria. Enugu State lies between latitudes 5°56′N and 7°06′N and longitudes 6°53′E and 7°55′E, covering an area of approximately 7,161 km². The state is characterized by a tropical climate with distinct wet and dry seasons and supports a diverse range of economic activities, including manufacturing, healthcare delivery, mining, agriculture, transportation, and commerce. The study specifically focused on selected tertiary healthcare institutions, industrial establishments, diagnostic laboratories, and agro-allied industries located within Enugu metropolis and its surrounding areas.

The choice of Enugu State was informed by its history of industrial activities, the presence of healthcare facilities serving a large population, and the increasing concerns regarding occupational exposure to hazardous chemicals in workplaces. Workers in these settings are frequently exposed to chemical agents such as disinfectants, cleaning chemicals, solvents, laboratory reagents, pesticides, heavy metals, and airborne particulate matter, making the area suitable for investigating environmental chemical exposures and their health implications.

2.3 Study Population

The study population comprised workers employed in occupations characterized by regular exposure to chemical substances. Participants were recruited from tertiary hospitals, diagnostic laboratories, manufacturing industries, agro-allied industries, and selected mining-related enterprises within the study area. The target population included nurses, laboratory scientists, laboratory technicians, industrial workers, agricultural workers, and environmental health personnel who had been employed in their respective workplaces for at least one year prior to the study.

Workers who met the inclusion criteria and voluntarily consented to participate were enrolled in the study. Individuals with less than one year of occupational experience, temporary workers, and those unavailable during the study period were excluded to ensure that participants had sufficient exposure history for meaningful assessment.

2.4 Sample Size Determination and Sampling Procedure

The sample size for the study was determined using Cochran's formula for cross-sectional studies. The prevalence of occupational exposure reported in previous occupational health studies among healthcare and industrial workers was used to estimate the minimum sample size required for statistical validity. An additional 10% was incorporated to compensate for possible non-response and incomplete data.

A multistage sampling procedure was employed. In the first stage, healthcare facilities, laboratories, and industries were purposively selected based on the likelihood of occupational chemical exposure. In the second stage, workers were stratified according to occupational category. Thereafter, simple random sampling was used to select eligible participants from each stratum proportionate to the workforce size within each institution.

2.5 Data Collection

Data collection involved environmental monitoring, biological monitoring, questionnaire administration, and clinical health assessment. Environmental monitoring was conducted to determine the concentrations of chemical contaminants present within occupational settings. Air samples were collected using calibrated portable air samplers

positioned at strategic locations within work environments. The collected samples were analyzed for particulate matter ($PM_{2.5}$ and PM_{10}), volatile organic compounds, solvent vapours, and other airborne contaminants commonly encountered in occupational settings.

Surface swab samples and workplace water samples were also collected to evaluate the presence of chemical residues and heavy metals. Particular attention was given to contaminants such as lead, cadmium, chromium, mercury, and arsenic due to their known toxicological significance and prevalence in occupational environments.

To assess internal exposure levels, biological monitoring was performed using blood and urine samples collected from consenting participants. Blood samples were analyzed for heavy metal concentrations and selected biomarkers of oxidative stress, while urine samples were examined for metabolites of pesticides, organic solvents, and other chemical contaminants. Standard sample collection, preservation, transportation, and laboratory handling procedures were strictly followed to maintain sample integrity.

Occupational health data were obtained through the administration of structured questionnaires designed to collect information on demographic characteristics, occupational history, duration of employment, frequency of exposure, utilization of personal protective equipment, workplace safety practices, and self-reported health symptoms. In addition, participants underwent basic clinical examinations focusing on respiratory, dermatological, neurological, and cardiovascular indicators commonly associated with occupational chemical exposure.

2.6 Laboratory Analysis

Environmental and biological samples were analyzed at accredited environmental and analytical chemistry laboratories using internationally accepted analytical procedures. Heavy metal concentrations in environmental and biological samples were determined using Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma–Mass Spectrometry (ICP-MS). These techniques were selected because of their sensitivity, accuracy, and suitability for trace-level metal determination.

Organic pollutants, including pesticides and volatile organic compounds, were analyzed using Gas Chromatography–Mass Spectrometry (GC-MS). Calibration standards, certified reference materials, procedural blanks, duplicate analyses, and recovery studies were employed throughout the analytical process to ensure data quality and reliability.

2.7 Data Analysis

Data generated from questionnaires, environmental monitoring, biological analyses, and clinical assessments were entered into Microsoft Excel and subsequently analyzed using the Statistical Package for the Social Sciences (SPSS) version 26.0 and R Statistical Software.

Descriptive statistical tools including means, standard deviations, frequencies, percentages, minimum values, and maximum values were used to summarize the data. Measured concentrations of environmental contaminants were compared with permissible exposure limits established by the World Health Organization (WHO), the Occupational Safety and Health Administration (OSHA), and the National Institute for Occupational Safety and Health (NIOSH).

Pearson correlation analysis was employed to determine relationships between environmental chemical exposure levels and occupational health indicators. Independent sample t-tests and one-way analysis of variance (ANOVA) were used to compare exposure levels and health outcomes among different occupational groups. Furthermore, multiple linear regression and logistic regression

analyses were performed to identify significant predictors of adverse occupational health outcomes and estimate the influence of exposure variables on workers' health status. Statistical significance was established at a confidence level of 95%, corresponding to a p-value less than 0.05.

2.8 Ethical Considerations

Ethical approval for the study was obtained from the Health Research Ethics Committee of the University of Nigeria Teaching Hospital, Ituku-Ozalla, Enugu State. Permission was also obtained from the management of participating institutions before commencement of the study. All participants were adequately informed about the objectives, procedures, potential risks, and benefits of the research before providing written informed consent. Confidentiality of personal information was maintained throughout the study, and all data were anonymized prior to analysis. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki for research involving human participants.

3.0 Results and discussion

3.1 Results

A total of 320 questionnaires were distributed to workers across selected healthcare facilities, laboratories, agro-allied industries, and manufacturing industries in Enugu State, Nigeria. Of these, 301 were correctly completed and returned, giving a response rate of 94.1%.

3.1.1 Socio-Demographic Characteristics of Participants

The socio-demographic characteristics of the respondents are presented in Table 1. A total of 301 participants were included in the study. The results showed that males constituted the majority of the respondents, accounting for 178 (59.1%) of the study population, while females represented 123 (40.9%). This gender distribution suggests a relatively higher participation of males in occupations associated with environmental chemical exposure within the selected workplaces.

Regarding age distribution, the largest proportion of respondents belonged to the 30–39 years age group, comprising 114 (37.9%) participants, followed by those aged 40–49 years with 82 (27.2%) respondents. Participants aged 20–29 years accounted for 61 (20.3%), while those aged 50 years and above represented the smallest age category with 44 (14.6%) respondents (Table 1). The predominance of workers within the economically active age groups indicates that a substantial proportion of the workforce is exposed to occupational chemical hazards during their most productive years, potentially increasing the long-term health and economic consequences of workplace exposures.

Table 1. Socio-demographic Characteristics of Respondents (n = 301)

Variable	Category	Frequency	Percentage (%)
Gender	Male	178	59.1
	Female	123	40.9
Age (years)	20–29	61	20.3
	30–39	114	37.9
	40–49	82	27.2
	≥50	44	14.6
Occupation	Nurses	87	28.9
	Laboratory Personnel	56	18.6
	Industrial Workers	94	31.2

	Agricultural Workers	64	21.3
Work Experience	1–5 years	83	27.6
	6–10 years	104	34.6
	11–15 years	67	22.3
	>15 years	47	15.6

The occupational distribution revealed that industrial workers constituted the highest proportion of respondents, accounting for 94 (31.2%), followed by nurses with 87 (28.9%), agricultural workers with 64 (21.3%), and laboratory personnel with 56 (18.6%) (Table 1). The higher representation of industrial workers may reflect the extensive involvement of this occupational category in activities associated with the use, handling, and processing of chemicals. Similarly, the inclusion of healthcare and laboratory personnel highlights the potential for exposure to disinfectants, reagents, pharmaceuticals, and other hazardous substances commonly encountered in healthcare settings.

Analysis of work experience showed that 104 (34.6%) respondents had worked for 6–10 years, representing the largest category, while 83 (27.6%) had 1–5 years of occupational experience. Respondents with 11–15 years and more than 15 years of experience accounted for 67 (22.3%) and 47 (15.6%), respectively (Table 1). The findings indicate that most participants had accumulated several years of workplace exposure, suggesting a greater likelihood of chronic exposure to environmental contaminants. Prolonged occupational exposure has been associated with increased accumulation of toxic substances in biological systems and a higher risk of developing adverse health outcomes.

Overall, the demographic profile of the respondents demonstrates that the study population consisted predominantly of middle-aged, experienced workers employed in occupations characterized by varying degrees of chemical exposure. The substantial proportion of workers with more than five years of occupational experience provides a suitable basis for evaluating the potential relationships between environmental chemical exposure, biological markers of exposure, and occupational health outcomes examined in this study.

3.1.2 Environmental Chemical Exposure Levels

The mean concentrations of selected environmental contaminants measured across the occupational settings are presented in Table 2. The results revealed that all assessed contaminants exceeded their respective recommended guideline or occupational exposure limits, indicating the presence of potentially hazardous workplace conditions.

Among the particulate pollutants, the mean concentration of $PM_{2.5}$ was 42.6 ± 8.7 µg/m³, which exceeded the recommended limit of 25.0 µg/m³ by approximately 70.4% (Table 2). Similarly, PM_{10} recorded a mean concentration of 87.4 ± 14.3 µg/m³, exceeding the recommended limit of 50.0 µg/m³ by 74.8%. These findings suggest a substantial burden of airborne particulate matter within the occupational environments investigated. Elevated concentrations of particulate matter are of concern because prolonged inhalation has been associated with respiratory irritation, impaired lung function, chronic respiratory diseases, and increased cardiovascular risks among exposed workers

Table 2. Mean Concentrations of Environmental Contaminants in Occupational Settings

Contaminant	Mean Concentration	WHO/OSHA Limit	Compliance Status
$PM_{2.5}$ (µg/m³)	42.6 ± 8.7	25.0	Exceeded
PM_{10} (µg/m³)	87.4 ± 14.3	50.0	Exceeded
VOCs (ppm)	0.82 ± 0.11	0.50	Exceeded
Lead (mg/m³)	0.067 ± 0.014	0.050	Exceeded
Cadmium (mg/m³)	0.006 ± 0.002	0.005	Exceeded
Formaldehyde (ppm)	0.12 ± 0.03	0.10	Exceeded

The concentration of volatile organic compounds (VOCs) was found to be 0.82 ± 0.11 ppm, which exceeded the recommended limit of 0.50 ppm by approximately 64.0% (Table 2). This observation indicates the likely presence of chemical emissions originating from industrial processes, laboratory reagents, cleaning agents, solvents, and other workplace materials. Continuous exposure to VOCs may contribute to headaches, dizziness, mucosal irritation, neurological disturbances, and other adverse health effects, particularly in poorly ventilated work environments.

The results further showed elevated concentrations of heavy metals in workplace air. Lead concentration was 0.067 ± 0.014 mg/m³, exceeding the recommended limit of 0.050 mg/m³ by 34.0%, while cadmium concentration was 0.006 ± 0.002 mg/m³ compared with the recommended limit of 0.005 mg/m³, representing an exceedance of 20.0% (Table 2). The presence of these toxic metals in occupational environments is noteworthy because both lead and cadmium are recognized environmental pollutants with the potential to accumulate in biological systems following prolonged exposure. Chronic exposure to these metals has been associated with neurological, renal, hematological, and reproductive health effects.

Formaldehyde concentration was recorded at 0.12 ± 0.03 ppm, exceeding the recommended limit of 0.10 ppm by 20.0% (Table 2). The elevated level of formaldehyde may be attributable to its widespread use in healthcare facilities, laboratories, manufacturing processes, and preservation activities. Exposure to formaldehyde has been linked to respiratory irritation, eye discomfort, allergic reactions, and increased risks of chronic respiratory disorders among occupationally exposed populations.

Overall, the findings presented in Table 2 demonstrate widespread non-compliance with recommended exposure limits across the assessed contaminants. The simultaneous exceedance of particulate matter, volatile organic compounds, heavy metals, and formaldehyde suggests that workers in the selected occupational settings may be exposed to multiple chemical hazards concurrently. Such combined exposures could increase the likelihood of adverse health effects and underscore the need for effective workplace environmental monitoring, engineering controls, exposure reduction strategies, and strengthened occupational health surveillance programs.

3.1.3 Biological Monitoring Results

The results of biological monitoring conducted using blood and urine samples are presented in Table 3. The findings revealed that the mean concentrations of all measured biomarkers exceeded their respective reference values, indicating substantial internal exposure to hazardous chemicals among workers in the selected occupational settings.

Blood lead concentration was found to be 8.41 ± 2.37 µg/dL, which exceeded the recommended reference value of 5.00 µg/dL by approximately 68.2% (Table 3). This elevated level suggests significant occupational exposure to lead-containing materials and workplace contaminants. Lead is a cumulative toxicant that can accumulate in blood and

tissues over time, and prolonged exposure has been associated with neurological dysfunction, hematological abnormalities, cardiovascular disorders, and impaired cognitive performance.

Table 3. Biomarkers of Chemical Exposure among Workers

Parameter	Mean Value	Reference Value
Blood Lead (µg/dL)	8.41 ± 2.37	<5.00
Blood Cadmium (µg/L)	1.94 ± 0.51	<1.00
Blood Mercury (µg/L)	4.76 ± 1.12	<3.00
Urinary Pesticide Metabolites (mg/L)	0.87 ± 0.24	<0.50
Oxidative Stress Biomarker (MDA, µmol/L)	6.34 ± 1.47	<4.00

Similarly, the mean blood cadmium concentration was 1.94 ± 0.51 µg/L, almost double the accepted reference value of 1.00 µg/L (Table 3). Cadmium is a highly toxic heavy metal with a long biological half-life, and elevated blood concentrations may indicate continuous occupational exposure. Chronic cadmium accumulation has been linked to renal dysfunction, skeletal disorders, respiratory impairment, and increased oxidative stress.

The concentration of blood mercury was 4.76 ± 1.12 µg/L, exceeding the reference value of 3.00 µg/L by approximately 58.7% (Table 3). This finding suggests potential exposure to mercury-containing substances within workplace environments. Mercury is a recognized neurotoxicant, and prolonged exposure has been associated with neurological disturbances, tremors, memory impairment, and adverse effects on the kidneys and immune system.

Urinary pesticide metabolites recorded a mean concentration of 0.87 ± 0.24 mg/L, which was substantially higher than the reference value of 0.50 mg/L (Table 3). The elevated concentration of pesticide metabolites provides evidence of recent or ongoing exposure to agrochemicals and related compounds. This finding is particularly relevant among agricultural workers and other occupational groups that may encounter pesticides through handling, application, storage, or environmental contamination. Persistent exposure to pesticides has been associated with endocrine disruption, neurological disorders, reproductive toxicity, and increased risks of chronic diseases.

The level of malondialdehyde (MDA), an established biomarker of oxidative stress, was 6.34 ± 1.47 µmol/L, exceeding the reference value of 4.00 µmol/L by approximately 58.5% (Table 3). Elevated MDA levels indicate increased lipid peroxidation and oxidative damage within biological systems. This observation suggests that occupational exposure to chemical contaminants may be inducing oxidative stress among workers, potentially contributing to cellular injury and the development of chronic health conditions.

Overall, the biological monitoring results provide compelling evidence that environmental and occupational chemical exposures have translated into measurable internal body burdens among the workers studied. The concurrent elevation of heavy metals, pesticide metabolites, and oxidative stress biomarkers indicates that workers are experiencing multiple chemical exposures capable of affecting physiological processes and increasing susceptibility to adverse health outcomes. These findings underscore the importance of routine biomonitoring programs as part of occupational health surveillance, as they provide direct evidence of chemical absorption and facilitate the early detection of exposure-related health risks.

3.1.4 Occupational Health Outcomes

The prevalence of occupational health symptoms reported by the respondents is presented in Table 4, while their distribution is illustrated in Figure 1. The results revealed that fatigue was the most frequently reported health complaint, affecting 183 respondents (60.8%), followed closely by persistent headache, which was reported by 174 respondents (57.8%). Respiratory symptoms were also highly prevalent, occurring among 162 respondents (53.8%) (Table 4; Fig. 1).

Eye irritation and skin irritation were reported by 136 (45.2%) and 121 (40.2%) respondents, respectively (Table 4). These symptoms may reflect regular exposure to airborne pollutants, chemical vapours, dust particles, disinfectants, solvents, and other workplace contaminants capable of irritating the skin, eyes, and mucous membranes. The relatively high prevalence of these conditions suggests that workplace environmental quality may be contributing to discomfort and reduced well-being among workers.

Neurological symptoms were reported by 98 respondents (32.6%), while cardiovascular symptoms had the lowest prevalence, affecting 72 respondents (23.9%) (Table 4). Although less frequently reported than fatigue and respiratory complaints, the occurrence of neurological symptoms is noteworthy because it may be associated with exposure to neurotoxic substances such as heavy metals and organic solvents. Similarly, cardiovascular symptoms may be linked to prolonged exposure to particulate matter and other environmental pollutants that have been implicated in cardiovascular dysfunction.

Table 4. Prevalence of Occupational Health Symptoms among Respondents

Health Outcome	Frequency	Percentage (%)
Respiratory symptoms	162	53.8
Skin irritation	121	40.2
Persistent headache	174	57.8
Eye irritation	136	45.2
Fatigue	183	60.8
Neurological symptoms	98	32.6
Cardiovascular symptoms	72	23.9

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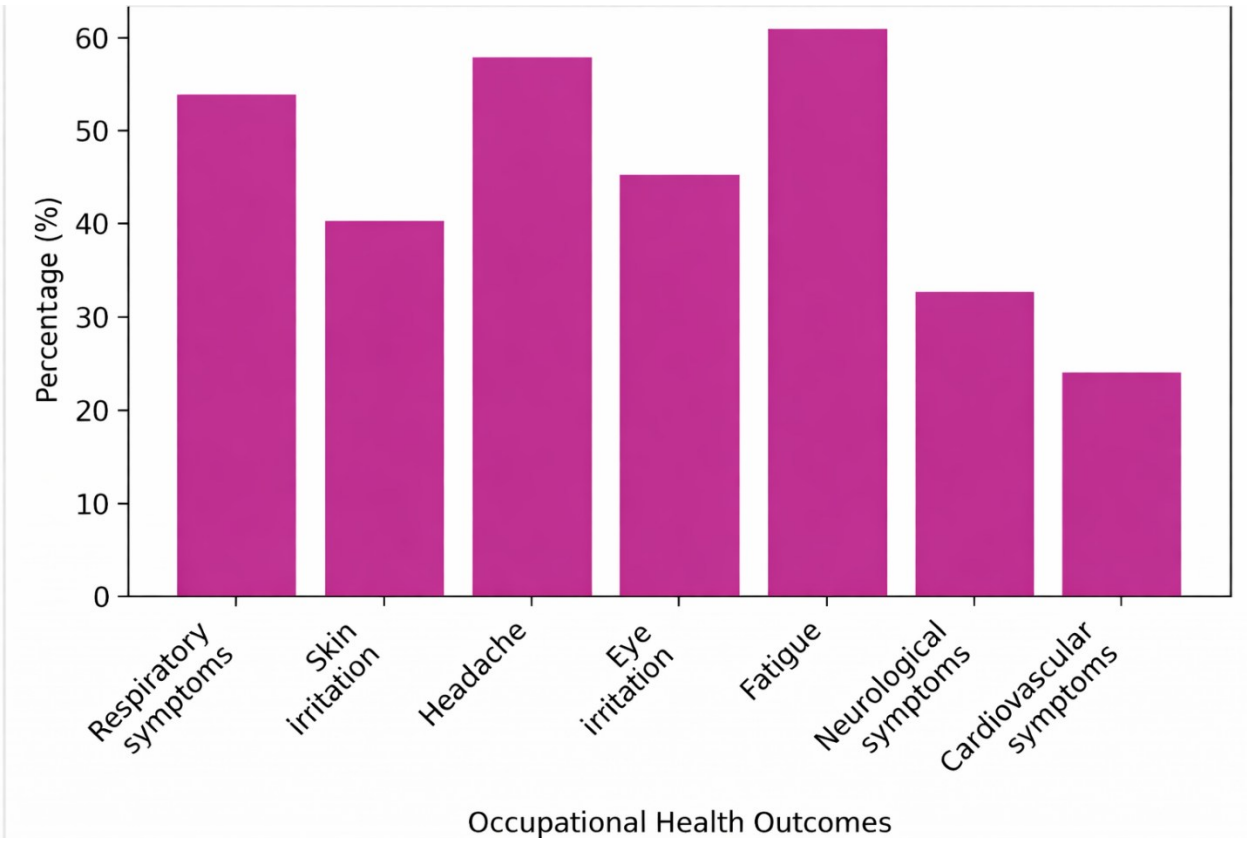

Fig. 1. Distribution of Occupational Health Outcomes among Workers

As shown in Fig. 1, fatigue and persistent headache constituted the dominant occupational health complaints among the study population, followed by respiratory symptoms. The graphical presentation highlights a clear pattern in which general systemic symptoms and respiratory disorders occurred more frequently than cardiovascular and neurological conditions. This pattern may reflect the immediate physiological responses of workers to continuous occupational exposure to chemical contaminants.

The high prevalence of fatigue among workers suggests that occupational exposures may be contributing to physical and mental stress, reduced productivity, and diminished quality of life. Fatigue is often regarded as a non-specific but important indicator of occupational strain and may result from chronic exposure to hazardous chemicals, poor workplace conditions, and cumulative physiological stress. Likewise, the high frequency of persistent headaches may indicate ongoing exposure to volatile organic compounds, particulate matter, formaldehyde, and other airborne contaminants commonly encountered in occupational settings.

The substantial prevalence of respiratory symptoms observed in this study further emphasizes the potential impact of workplace air pollution on worker health. Exposure to elevated levels of particulate matter and chemical vapours can irritate the respiratory tract, leading to coughing, wheezing, shortness of breath, and other respiratory complaints. The findings are consistent with the environmental monitoring results presented in Table 2, which showed that concentrations of particulate matter, volatile organic compounds, and

formaldehyde exceeded recommended exposure limits.

Overall, the results presented in Table 4 and Figure 1 indicate that occupational health symptoms are widespread among workers in the studied environments. The predominance of fatigue, headaches, respiratory complaints, and irritation-related symptoms suggests that workplace chemical exposures may be contributing significantly to the observed health burden. These findings underscore the importance of implementing effective occupational health surveillance, exposure reduction measures, and preventive interventions aimed at protecting worker health and improving workplace safety.

3.1.5 Association between Chemical Exposure and Occupational Health Outcomes

The relationships between selected chemical exposure indicators and occupational health outcomes are presented in Table 5. Correlation analysis revealed statistically significant positive associations between environmental and biological exposure indicators and the occurrence of respiratory symptoms, neurological symptoms, and fatigue among workers ($p < 0.01$). The positive correlation coefficients indicate that increasing levels of chemical exposure were associated with a higher prevalence and severity of adverse health outcomes.

Table 5. Correlation between Exposure Indicators and Health Outcomes

Variable	Respiratory Symptoms	Neurological Symptoms	Fatigue
$PM_{2.5}$	0.612**	0.441**	0.578**
VOCs	0.587**	0.492**	0.511**
Blood Lead	0.463**	0.693**	0.487**
Blood Cadmium	0.391**	0.645**	0.412**

Correlation significant at $p < 0.01$

Volatile organic compounds (VOCs) similarly demonstrated significant positive correlations with respiratory symptoms ($r = 0.587$, $p < 0.01$), neurological symptoms ($r = 0.492$, $p < 0.01$), and fatigue ($r = 0.511$, $p < 0.01$) (Table 5). The relatively strong associations observed between VOC exposure and adverse health outcomes may be attributable to the irritative and neurotoxic properties of many volatile chemical compounds commonly encountered in occupational environments. Workers exposed to elevated VOC concentrations may therefore be at increased risk of experiencing respiratory discomfort, headaches, dizziness, and general fatigue.

Among the biological exposure indicators, blood lead concentration showed a particularly strong positive correlation with neurological symptoms ($r = 0.693$, $p < 0.01$), representing the highest correlation coefficient observed in the study (Table 5). Blood lead levels were also positively associated with respiratory symptoms ($r = 0.463$, $p < 0.01$) and fatigue ($r = 0.487$, $p < 0.01$). The strong relationship between lead exposure and neurological manifestations supports existing evidence regarding the neurotoxic effects of lead and highlights the potential health consequences of chronic occupational exposure.

Similarly, blood cadmium concentration demonstrated significant positive correlations with neurological symptoms ($r = 0.645$, $p < 0.01$), respiratory symptoms ($r = 0.391$, $p < 0.01$), and fatigue ($r = 0.412$, $p < 0.01$) (Table 5). Although the associations involving cadmium were generally lower than those observed for lead, the findings nevertheless suggest that cadmium exposure may contribute substantially to adverse occupational health outcomes. The strong correlation between cadmium and neurological symptoms further emphasizes the potential toxicological effects

of heavy metal accumulation among exposed workers.

Overall, the results presented in Table 5 provide compelling evidence of significant relationships between workplace chemical exposures and worker health outcomes. The strongest associations were observed between blood lead and neurological symptoms, followed by blood cadmium and neurological symptoms, indicating that heavy metal exposure may be an important contributor to neurological health complaints among workers. The significant correlations involving particulate matter and VOCs further suggest that environmental contamination within workplaces may contribute to respiratory disorders and fatigue. Collectively, these findings support the premise that increased occupational exposure to chemical contaminants is associated with a greater burden of adverse health symptoms and underscore the need for effective exposure control measures, routine biomonitoring, and comprehensive occupational health surveillance programs.

3.1.6 Predictors of Adverse Occupational Health Outcomes

A multiple logistic regression analysis was performed to identify factors associated with the occurrence of adverse occupational health outcomes among workers. The results of the regression model are presented in Table 6. The analysis revealed that exposure duration, elevated blood lead levels, high volatile organic compound (VOC) exposure, and inadequate use of personal protective equipment (PPE) were significant predictors of occupational illness, whereas smoking status was not significantly associated with adverse health outcomes.

Table 6. Logistic Regression Analysis of Factors Associated with Occupational Illness

Variable	Odds Ratio (OR)	95% CI	p-value
Exposure duration (>10 years)	2.84	1.76–4.58	<0.001
Elevated blood lead level	3.41	2.11–5.48	<0.001
High VOC exposure	2.63	1.58–4.39	0.002
Inadequate PPE use	4.12	2.47–6.89	<0.001
Smoking status	1.21	0.81–1.96	0.286

As shown in Table 6, workers with occupational exposure durations exceeding 10 years were approximately 2.84 times more likely to experience adverse occupational health outcomes than those with shorter exposure periods (OR = 2.84, 95% CI: 1.76–4.58, $p < 0.001$). This finding suggests that prolonged workplace exposure increases the likelihood of developing exposure-related health conditions, possibly due to the cumulative effects of hazardous substances over time. The result further indicates that chronic occupational exposure may contribute substantially to the burden of workplace-related illnesses.

Elevated blood lead concentration emerged as a strong predictor of occupational illness, with affected workers being approximately 3.41 times more likely to report adverse health outcomes than those with lower blood lead levels (OR = 3.41, 95% CI: 2.11–5.48, $p < 0.001$) (Table 6). The relatively high odds ratio observed for blood lead concentration highlights the significant health risks associated with lead exposure and supports the biological monitoring findings presented in Table 3. This observation suggests that internal exposure to toxic metals may play a critical role in the development of occupational health problems.

Workers exposed to high concentrations of volatile organic compounds were also at significantly increased risk of occupational illness, with an odds ratio of 2.63 (95% CI: 1.58–4.39, p = 0.002) (Table 6). This finding indicates that exposure to elevated levels of airborne chemical contaminants contributes significantly to adverse health outcomes. VOCs are known to affect multiple organ systems, and their association with occupational illness in this study further underscores the importance of controlling workplace air quality.

Among all the variables examined, inadequate use of personal protective equipment emerged as the strongest predictor of occupational illness. Workers who reported inadequate PPE utilization were approximately 4.12 times more likely to experience adverse health outcomes than those who used PPE appropriately (OR = 4.12, 95% CI: 2.47–6.89, p < 0.001) (Table 6). The magnitude of this association highlights the critical protective role of PPE in minimizing occupational exposure to hazardous substances. This finding suggests that compliance with PPE guidelines remains an essential component of workplace health and safety programs.

In contrast, smoking status was not significantly associated with occupational illness in the present study (OR = 1.21, 95% CI: 0.81–1.96, p = 0.286) (Table 6). Although smokers exhibited slightly higher odds of experiencing adverse health outcomes, the confidence interval included unity and the p-value exceeded the level of statistical significance. This indicates that smoking did not independently predict occupational illness within the study population after accounting for other exposure-related factors.

Overall, the results presented in Table 6 demonstrate that both environmental and behavioural workplace factors contribute to the occurrence of adverse occupational health outcomes. Inadequate PPE use, elevated blood lead concentration, prolonged exposure duration, and high VOC exposure were identified as significant predictors of occupational illness, emphasizing the importance of exposure prevention, routine biomonitoring, workplace hazard control, and strict adherence to occupational safety practices. These findings further suggest that interventions aimed at reducing chemical exposure and improving compliance with protective measures may substantially decrease the burden of occupational disease among workers.

3.7 Implications for Occupational Nursing Practice

The findings indicate substantial occupational exposure to environmental contaminants among workers in Enugu State. Elevated environmental contaminant concentrations, increased biological markers of exposure, and the high prevalence of occupational health symptoms collectively demonstrate the need for strengthened occupational health surveillance. The results further suggest that occupational nurses should play a more proactive role in workplace exposure monitoring, risk communication, periodic health screening, and implementation of preventive interventions aimed at reducing chemical-related health risks among workers.

4.0 Conclusion

This study demonstrated that workers in selected occupational settings in Enugu State are exposed to significant levels of environmental chemical contaminants, including particulate matter, volatile organic compounds, lead, cadmium, and formaldehyde. Biological monitoring revealed elevated concentrations of heavy metals and exposure biomarkers among workers, indicating substantial internal chemical exposure. The study further established significant associations between environmental chemical exposures and adverse occupational health

outcomes, particularly respiratory disorders, fatigue, headaches, skin irritation, and neurological symptoms.

The findings emphasize the importance of integrating environmental chemistry and occupational nursing approaches in workplace health management. Effective occupational health surveillance, exposure monitoring, biomonitoring, and preventive nursing interventions are essential for reducing chemical-related health risks and promoting worker well-being.

Based on the findings of this study, it is recommended that employers establish comprehensive occupational health surveillance programs that incorporate routine environmental monitoring and biological assessment of workers. Regulatory agencies should strengthen the enforcement of occupational exposure limits and workplace safety standards, particularly in industries involving hazardous chemicals. Employers should also ensure the adequate provision and consistent use of personal protective equipment among workers.

Occupational nurses should be empowered through specialized training in environmental exposure assessment, toxicology, and workplace risk management. Regular health education programs should be implemented to improve workers' awareness of occupational hazards and preventive practices. Furthermore, future research should adopt longitudinal designs to investigate long-term health effects of chemical exposure and evaluate the effectiveness of occupational nursing interventions in reducing workplace-related illnesses.

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