

Original Research Article

THE EFFECTS OF LABORATORY PRACTICES ON HEAVY METAL CONTAMINATION OF WATER SOURCES IN TERTIARY INSTITUTIONS

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Abstract: Science, engineering, and health-related laboratories in tertiary institutions generate liquid waste that may contain toxic heavy metals, including lead, cadmium, chromium, manganese, and iron. Poor segregation, treatment, handling, and disposal of laboratory waste may contaminate drains and nearby water sources. This study investigated the effects of laboratory waste disposal, effluent handling, and safety compliance practices on heavy metal contamination of water sources in selected tertiary institutions. A quantitative cross-sectional design was used, combining questionnaire data with laboratory analysis of water samples. Using multistage sampling and Cochran's formula, 380 respondents were selected; however, 360 valid questionnaires were analysed. Ten water samples collected within or near laboratory complexes were analysed for lead, cadmium, chromium, manganese, and iron using Atomic Absorption Spectroscopy. Data were analysed using descriptive statistics, Pearson correlation, multiple regression, and ANOVA at the 0.05 significance level. Findings revealed a low overall level of laboratory waste-management practices (grand mean = 2.61), particularly in chemical waste segregation and effluent pre-treatment/neutralisation. Lead, cadmium, chromium, and iron exceeded the WHO/NSDWQ guideline limits, while manganese remained within the permissible limit. Waste disposal, effluent handling, and safety compliance significantly predicted heavy metal contamination, jointly explaining 54.6% of the variation in the contamination index ($R^2=0.546$, $p<0.05$). The study concludes that weak laboratory waste-management and effluent-control practices are significantly associated with elevated heavy metal contamination. It recommends improved waste segregation, effluent treatment facilities, routine water-quality monitoring, and regular safety training.

Keywords: Heavy Metals, Laboratory Practices, Tertiary Institutions, Waste Disposal, Water Contamination, Water Quality.

Introduction

Laboratories are central to teaching, learning, and research in tertiary institutions, particularly in departments such as Chemistry, Biochemistry, Microbiology, Medical Laboratory Science, and Applied Sciences. Routine laboratory activities, including qualitative and quantitative analysis, chemical synthesis, and sample digestion, generate substantial quantities of liquid and solid waste laden with heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), and iron (Fe). Furthermore, laboratory waste liquids are discarded at the end of most analyses and, in the absence of designated pre-treatment systems, are commonly discharged through washbasins and drains that ultimately connect to public sewers or nearby water bodies (Dhenkula et al., 2024). Because heavy metals do not biodegrade and tend to bioaccumulate in living tissue, their release into water sources poses serious and long-lasting risks to human health and the environment (Izah et al., 2016).

Evidence from Nigerian tertiary institutions illustrates the scale of this concern. Galadima et al. (2010) reported elevated concentrations of iron, chromium, and lead in wastewater from a university environment, indicating that institutional wastewater streams can contribute substantially to heavy metal pollution. Other Nigerian studies have also shown that poorly managed waste streams can elevate heavy metal concentrations in water, soils, and sediments (Oloruntoba et al., 2021; Kolawole et al., 2018). Beyond Nigeria, Kassim et al. (2022) linked wastewater effluent to heavy metal contamination in receiving water bodies, reinforcing concerns about institutional and laboratory effluent management.

The specific hazards of laboratory-generated waste have also attracted attention. Dhenkula et al. (2024) noted that laboratory waste liquids might be discharged through washbasins and drains unless institutions provide systems for collection and treatment. Treatment methods such as precipitation, adsorption, and membrane separation are only effective where waste is collected and managed at the point of generation. Similarly, Emmanuel et al. (2022) reported health risks associated with heavy metals in drinking-water sources, particularly where toxic metals occur above permissible limits. These findings suggest that weak laboratory waste disposal, poor effluent handling, and inadequate safety compliance may increase the likelihood that heavy metals reach water sources.

This study is anchored on the Source-Pathway-Receptor (SPR) Model and the Health Belief Model (HBM). The SPR Model conceptualises pollution as a chain in which a contaminant source, such as laboratory chemical waste, moves through a pathway, including drains, gutters, and effluent channels, before reaching a receptor such as a borehole, tap, stream, or other water source. Weak waste segregation and the absence of effluent pre-treatment may strengthen this pathway and increase contamination at the receptor point. The HBM complements this framework by explaining how perceptions of risk, benefits, barriers, and responsibility may influence compliance with safe chemical handling and disposal procedures.

Despite growing evidence of heavy metal contamination in water sources, comparatively little empirical attention has been directed at tertiary institution laboratories as a distinct and recurring source of heavy metal discharge. Existing studies have often focused on measuring metal concentrations without simultaneously examining the laboratory practices that may influence the movement of contaminants from laboratories to water sources. This study, therefore, investigates how laboratory waste disposal, effluent handling, and safety compliance practices affect heavy metal contamination of water sources within selected tertiary institutions.

Problem Statement

Existing literature on heavy metal contamination in Nigeria has largely focused on industrial effluents, mining sites, dumpsites, and urban wastewater as principal sources of pollution (Kolawole et al., 2018; Oloruntoba et al., 2021). Comparatively little empirical attention has been directed at tertiary institution laboratories as distinct and recurring sources of heavy metal discharge. Where institutional environments have been investigated, the focus has commonly been on metal concentrations in wastewater or nearby water sources rather than on the underlying laboratory practices, such as waste segregation, effluent pre-treatment, and compliance with safety procedures, that may determine the quantity of contaminants reaching water sources. Consequently, there is limited empirical evidence linking measurable laboratory practices to heavy metal contamination in tertiary institution water sources. This study addresses this gap by jointly assessing laboratory waste disposal, effluent handling, and safety compliance practices and testing their effects on heavy metal contamination.

Research Objectives

1. To identify laboratory practices and activities that contribute to heavy metal contamination of water sources.
2. To determine the concentration of selected heavy metals in water sources within the tertiary institutions.
3. To determine the effect of laboratory waste disposal practices on heavy metal contamination of water sources in tertiary institutions.
4. To determine the joint effect of laboratory waste disposal, effluent handling, and safety compliance practices on heavy metal contamination of water sources in tertiary institutions.

Research Questions

1. What is the level of laboratory practices in tertiary institutions?
2. What is the level of heavy metal concentration in water sources in tertiary institutions?
3. What is the effect of laboratory waste disposal practices on heavy metal contamination of water sources in tertiary institutions?

4. What is the joint effect of laboratory waste disposal, effluent handling, and safety compliance practices on heavy metal contamination of water sources in tertiary institutions?

Research Hypotheses

- H0₁: Laboratory waste disposal practices have no significant effect on heavy metal contamination of water sources in tertiary institutions.
- H0₂: Laboratory effluent handling practices have no significant effect on heavy metal contamination of water sources in tertiary institutions.
- H0₃: Safety compliance practices have no significant effect on heavy metal contamination of water sources in tertiary institutions.
- H0₄: Laboratory waste disposal, effluent handling, and safety compliance practices have no significant joint effect on heavy metal contamination of water sources in tertiary institutions.

Methodology

Research Design

This study adopted a quantitative research approach using a cross-sectional survey design complemented by laboratory analysis of water samples. The survey component was used to collect data on the current state of laboratory waste disposal, effluent handling, and safety compliance practices. The laboratory component provided objective measurements of selected heavy metal concentrations in water sources located within or close to the selected laboratory complexes.

Population of the Study

The target population comprised 480 laboratory technologists/technicians, 1,150 science-based lecturers, and 3,200 students in science and science-related departments, including Chemistry, Biochemistry, Microbiology, Medical Laboratory Science, and Applied Sciences, giving a total population of 4,830 respondents. The study population was drawn from selected public tertiary institutions comprising Universities, Polytechnics, and Colleges of Education within the North Central States of Nigeria. The three respondent groups were selected because they possess direct knowledge of laboratory operations, chemical handling, and waste disposal routines. In addition to the human population, ten water sampling points comprising boreholes and taps located within or close to laboratory complexes were purposively selected for heavy metal analysis.

Sample Size and Sampling Technique

A multistage sampling procedure was adopted. First, tertiary institutions with active science-based laboratories were purposively selected. Within each selected institution, respondents were stratified into laboratory technologists/technicians, lecturers, and students. Simple random sampling was used to select respondents proportionately from each stratum. Using Cochran's sample-size determination formula for large populations, a minimum sample of 380 respondents was considered statistically adequate.

Table 1: Population and Sample of Respondents

Category	Population	Sample Size
Laboratory Technologists/Technicians	480	68
Lecturers	1,150	108
Students	3,200	204
Total	4,830	380

Sources of Data

The study used both primary and secondary sources of data. Primary survey data were obtained from laboratory technologists/technicians, science-based lecturers, and students through structured questionnaires administered physically and electronically through Google Forms. Primary laboratory data were obtained through the collection and analysis of water samples from ten purposively selected sampling points located within or close to laboratory complexes. Secondary data were obtained from institutional laboratory logs and waste-disposal records where available, as well as relevant WHO and Nigerian Standard for Drinking Water Quality (NSDWQ) guideline documents.

Data Collection Procedure

Questionnaire data were collected by administering the Laboratory Practices and Water Contamination Assessment Questionnaire (LPWCAQ) to the sampled respondents. Respondents were informed of the purpose of the study and completed the instrument physically or electronically. Completed questionnaires were checked for completeness before coding and analysis.

Water Sample Collection Procedure

Water sampling was conducted separately from questionnaire administration. Ten sampling points consisting of boreholes and taps located within or close to laboratory complexes were purposively selected because they were considered potential receptor points for laboratory-related drainage and effluent pathways. Samples were collected in clean, properly labelled, pre-cleaned polyethylene bottles. To minimise contamination, the sample bottles were rinsed appropriately with the water to be collected, except where bottles had been pre-acid-washed for trace-metal preservation. Samples were labelled with the sampling point, date, and time of collection and transported to the laboratory for analysis under appropriate storage conditions.

Instrument for Data Collection and Water Sample Preparation

The main instrument for primary survey data collection was a structured questionnaire titled Laboratory Practices and Water Contamination Assessment Questionnaire (LPWCAQ). The questionnaire was divided into four sections: Section A: Demographic Information; Section B: Laboratory Waste Disposal Practices; Section C: Effluent Handling Practices; and Section D: Safety Compliance Practices. A 5-point Likert

scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree) was used for Sections B, C, and D.

For heavy metal determination, water samples were prepared using a standard acid-preservation and digestion procedure suitable for Atomic Absorption Spectroscopy (AAS). Each sample was mixed thoroughly, acidified with analytical-grade nitric acid to preserve dissolved metals and minimise adsorption of metals to the sample container, and digested under controlled heating conditions where necessary to release target metals into solution. After digestion and cooling, samples were filtered where particulate matter was present, transferred into clean volumetric containers, and made up to the required volume with deionised water. Calibration standards and appropriate blanks were prepared, after which the samples were analysed using AAS for lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), and iron (Fe). The measured concentrations were compared with relevant WHO and NSDWQ guideline limits.

The selected metals were chosen for four reasons. First, lead, cadmium, chromium, manganese, and iron are commonly encountered in laboratory chemicals, reagents, instruments, or laboratory-related waste streams. Second, several of these metals are persistent and may accumulate in environmental media. Third, lead, cadmium, and chromium are of major toxicological concern at elevated concentrations, while manganese and iron are important water-quality indicators that may increase through contamination or environmental mobilisation. Fourth, the selected metals are covered by recognised drinking-water quality guidelines, allowing measured concentrations to be evaluated against permissible limits.

Validity and Reliability Test

The LPWCAQ was subjected to face and content validity assessment and a reliability test using Cronbach's Alpha. The instrument was presented to three experts in Environmental Health, Analytical Chemistry, and Laboratory Management for content validation. Based on their ratings, a Content Validity Index (CVI) of 0.86 was obtained, indicating high content validity. In addition, a Cronbach's Alpha coefficient of 0.79 was obtained, indicating acceptable internal consistency because values of 0.70 and above are generally considered acceptable.

Method of Data Analysis

Data were coded and analysed using frequencies, percentages, means, and standard deviations to answer Research Questions 1 and 2. Simple regression was used to determine the effect of laboratory waste disposal practices on heavy metal contamination for Research Question 3. Multiple regression was used to determine the joint effect of laboratory waste disposal, effluent handling, and safety compliance practices on the heavy metal contamination index for Research Question 4. ANOVA was used to test the overall significance of the regression model. All hypotheses were tested at the 0.05 level of significance.

Results

A total of 380 questionnaires were distributed to the three respondent categories: laboratory technologists/technicians, science-based lecturers, and students. Thus, the figure of 380 represents the combined sample for all three categories, not a separate sample for any single group. Of the 380 questionnaires distributed, 360 were correctly completed and returned, representing a response rate of 94.7%, which was considered adequate for statistical analysis.

Analysis of Research Questions

Research Question 1: What is the level of laboratory practices in tertiary institutions?

Table 1: Mean Analysis of Laboratory Practices in Tertiary Institutions

Laboratory Practice Indicators	Mean	Std. Dev.	Decision
Segregation of chemical waste by hazard class	2.41	1.12	Low
Pre-treatment/neutralisation of effluent before discharge	2.28	1.09	Low
Use of designated waste collection containers	2.87	1.05	Moderate
Availability of laboratory waste disposal protocol	2.55	1.15	Low
Staff/student training on safe chemical disposal	2.94	1.08	Moderate
Grand Mean	2.61	1.10	Low

Table 1 indicates a generally low level of laboratory practices, with a grand mean of 2.61. Particular concern is pre-treatment/neutralisation of effluent before discharge, which recorded the lowest mean score (2.28). This finding indicates that effluent is frequently discharged without adequate treatment or neutralisation. Such a practice may allow dissolved metals and other hazardous constituents to enter drainage channels and eventually reach nearby water sources. Chemical waste segregation also recorded a low mean score (2.41), suggesting that hazardous and non-hazardous wastes may not be consistently separated. These two weaknesses are environmentally significant because poor segregation can complicate treatment, while the absence of pre-treatment increases the likelihood of direct contaminant discharge. The findings therefore point to the need for institutional effluent-treatment facilities, clear waste-segregation procedures, and stronger monitoring of laboratory discharge practices.

Research Question 2: What is the level of heavy metal concentration in water sources in tertiary institutions?

Table 2: Mean Heavy Metal Concentration of Water Sources within Tertiary Institutions

Heavy Metal	Mean Conc. (mg/L)	WHO/NSDWQ Limit (mg/L)	Decision
Lead (Pb)	0.052	0.010	Exceeded
Cadmium (Cd)	0.019	0.003	Exceeded
Chromium (Cr)	0.081	0.050	Exceeded
Manganese (Mn)	0.32	0.40	Within limit
Iron (Fe)	0.94	0.30	Exceeded

Table 2 shows that lead, cadmium, chromium, and iron exceeded their respective WHO/NSDWQ guideline limits, whereas manganese remained within the permissible limit. The result, therefore, indicates elevated concentrations of several selected heavy metals in water sources located within or close to laboratory complexes.

Research Question 3: What is the effect of laboratory waste disposal practices on heavy metal contamination of water sources in tertiary institutions?

Table 3: Regression Result Showing the Effect of Laboratory Waste Disposal Practices on Heavy Metal Contamination

Variable	B	Std. Error	β	t	Sig.	Decision
Constant	0.647	0.121	--	5.35	0.000	--
Waste Disposal Practices	0.512	0.052	0.512	9.85	0.000	Significant

Table 3 shows that laboratory waste disposal practices had a statistically significant effect on heavy metal contamination of water sources ($\beta = 0.512$, $t = 9.85$, $p < 0.05$). The positive coefficient indicates that, as measured deficiencies in waste disposal practices increase, the heavy metal contamination index also increases. Therefore, laboratory waste disposal practices significantly affect heavy metal contamination of water sources, and the null hypothesis H_{01} was rejected.

Research Question 4: What is the joint effect of laboratory waste disposal, effluent handling, and safety compliance practices on heavy metal contamination of water sources?

Table 4: Model Summary of the Joint Effect of Laboratory Practices on Heavy Metal Contamination Index

Model Statistic	Value
R	0.739
R-Squared	0.546
Adjusted R-Squared	0.542
Standard Error of Estimate	0.588
F-Statistic	142.86
Prob(F-Statistic)	0.000
Number of Observations	360

Table 4 shows that laboratory waste disposal, effluent handling, and safety compliance practices jointly explained 54.6% of the variation in the heavy metal contamination index ($R^2 = 0.546$). The remaining 45.4% may be attributable to other factors not included in the model. The result indicates a substantial joint relationship between laboratory practices and heavy metal contamination of water sources.

Table 5: ANOVA Result for the Joint Effect of Laboratory Practices on Heavy Metal Contamination Index

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	148.267	3	49.422	142.86	0.000
Residual	123.108	356	0.346		
Total	271.375	359			

The ANOVA result in Table 5 shows that the overall regression model was statistically significant ($F = 142.86$, $p < 0.05$). Therefore, laboratory waste disposal, effluent handling, and safety compliance practices jointly had a significant effect on heavy metal contamination of water sources in tertiary institutions. The null hypothesis H_{04} was rejected.

Discussion of Findings

The first finding showed that laboratory practices were generally low, with a grand mean of 2.61. The weakest areas were pre-treatment/neutralisation of effluent before discharge (mean = 2.28) and segregation of chemical waste by hazard class (mean = 2.41). This pattern highlighted the challenge of laboratory waste liquids being discharged through sinks and drains where institutions lack adequate collection and treatment systems. The finding, therefore, shows that inadequate infrastructure and weak procedural controls can create direct pathways through which laboratory-generated contaminants enter the environment. The low level of effluent pre-treatment is particularly important because untreated effluent may carry dissolved metals directly into drainage systems and eventually into receiving water sources.

In addition, the findings revealed that concentrations of lead, cadmium, chromium, and iron exceeded the relevant WHO/NSDWQ permissible limits, whereas manganese remained within the acceptable limit. This indicates elevated levels of some heavy metals in wastewater and water sources within the selected tertiary-institution environment. The presence of these metals suggests that laboratory-related activities, especially where waste is inadequately segregated, stored, treated, or discharged, may contribute to contamination of nearby water bodies. This raises concern because prolonged exposure to elevated concentrations of heavy metals may pose environmental and public health risks. In addition, findings showed that laboratory waste-disposal practices had a significant effect on heavy metal contamination ($\beta = 0.512$, $p < 0.05$). This implies that weaknesses in the collection, segregation, storage, treatment, and disposal of chemical waste are associated with increased levels of contamination. Where metal-containing laboratory waste is mixed with general waste, discharged into drains, or disposed of without adequate treatment, contaminants may migrate through wastewater channels, soil, drainage systems, and runoff into surrounding water sources. The finding, therefore, demonstrates the importance of controlling laboratory waste at the point of generation to reduce the release and movement of hazardous metals within the institutional environment.

Furthermore, the study showed that laboratory waste disposal, effluent handling, and safety-compliance practices jointly explained 54.6% of the variation in heavy metal contamination ($R^2=0.546$), and the overall model was statistically significant ($F=142.86$, $p<0.05$). This result indicates that heavy metal contamination is influenced by the combined effects of waste-management procedures, effluent-control practices, and compliance with laboratory safety requirements rather than by any single practice alone. In other words, poor waste segregation, inadequate effluent treatment, unsafe disposal methods, and non-compliance with safety procedures can interact to increase the likelihood that contaminants reach nearby water sources. The joint effect observed in this study supports the Source–Pathway–Receptor framework.

In this context, laboratory chemicals and metal-containing waste constitute the source; drains, wastewater channels, soil, and runoff serve as pathways; while nearby water sources constitute the receptors. Where waste is not properly controlled at the source and when the pathways are not adequately managed through containment, treatment, and monitoring, contaminants can reach and degrade water sources. The significant role of safety compliance further indicates that effective contamination control requires both appropriate institutional facilities and responsible practices by laboratory personnel and users.

Conclusion

The study concludes that laboratory practices are significantly associated with heavy metal contamination of water sources in the selected tertiary institutions. The findings showed that laboratory practices were generally low, particularly in the areas of chemical waste segregation and pre-treatment/neutralisation of effluent before discharge. Water analysis further showed that lead, cadmium, chromium, and iron exceeded the applicable WHO/NSDWQ guideline limits, while manganese remained within the permissible limit. In addition, laboratory waste disposal practices significantly affected the heavy metal contamination index, and laboratory waste disposal, effluent handling, and safety compliance practices jointly explained 54.6% of the variation in contamination. These findings indicate that weaknesses in laboratory waste management and effluent control constitute important pathways through which contaminants may reach nearby water sources. The study, therefore, concludes that improving source-level waste management, effluent treatment, and safety compliance is essential for reducing the risk of heavy metal contamination within tertiary institution environments.

Recommendations

1. Management of tertiary institutions should provide functional effluent pre-treatment and neutralisation facilities for laboratories that generate chemical and metal-containing wastewater before such effluent is discharged into drains or other disposal systems.
2. Laboratories should implement strict segregation of chemical waste by hazard class and provide clearly labelled, designated containers for hazardous and non-hazardous laboratory waste.

3. Institutional environmental health, laboratory management, and safety units should establish routine monitoring programmes for water sources located within or close to laboratory complexes, including periodic testing for heavy metals.
4. Regular training and refresher programmes on chemical handling, waste segregation, effluent management, and laboratory safety should be made mandatory for laboratory technologists/technicians, lecturers, researchers, and students who use science-based laboratories.
5. Tertiary institutions should develop, update, and enforce written laboratory waste-management protocols, with clear responsibilities, supervision, and sanctions for non-compliance.

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