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Assessment of Physicochemical Characteristics and Heavy Metal Pollution in Groundwater within the Vicinity of an Automobile Mechanic Workshop in Awka South Local Government Area

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Abstract

Groundwater quality remains a critical environmental and public health concern in rapidly urbanizing regions where informal industrial activities are prevalent. This study assessed the physicochemical characteristics and the extent of heavy metal contamination in groundwater sources located around automobile mechanic workshop clusters in Awka South Local Government Area, Anambra State, Nigeria. Employing a cross-sectional descriptive design as well as laboratory analysis, groundwater samples were collected from selected boreholes and analyzed for physicochemical parameters and heavy metal concentrations using standard procedures. Results revealed that most heavy metals, including lead, iron, copper, zinc, mercury, and manganese, were within World Health Organization permissible limits. However, the groundwater exhibited significant chemical concerns, notably an acidic pH of 4.78 and elevated nitrate concentration of 70 mg/L, exceeding recommended standards. The acidic condition suggests anthropogenic influence, likely from improper disposal of workshop wastes such as used oil and battery fluids, and poses a risk of enhancing metal mobility in the subsurface environment. Although current heavy metal levels are low, the hydrochemical conditions indicate a vulnerable aquifer system with potential for future contamination. The findings suggest that the groundwater is undergoing early-stage degradation driven by combined effects of informal industrial activities and surrounding urban land use. The study highlights the need for proactive environmental management, regular monitoring, and improved waste disposal practices to prevent long-term groundwater pollution and protect public health at mechanic workshops. The study also noted that mechanic workshops are currently not properly regulated and advices the proper authority to take action.

Keywords: *Groundwater quality, heavy metals, mechanic workshops, nitrate contamination, acidic pH, urban pollution, Awka South, groundwater vulnerability*

1.0 Introduction

Water is an essential natural resource that underpins human health, economic productivity, and ecological sustainability. Globally, access to safe drinking water remains a central development priority, particularly in rapidly urbanizing regions of low- and middle-income countries (United Nations, 2022). However, urban expansion, informal industrial activities, and weak environmental regulation increasingly

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threaten groundwater quality. Among emerging urban pollution concerns, heavy metal contamination of groundwater has become a critical environmental and public health issue due to the persistence, bioaccumulation potential, and toxicity of metallic pollutants (Alloway, 2013; WHO, 2017).

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), and iron (Fe) are naturally occurring elements, but anthropogenic activities significantly elevate their environmental concentrations (Tchounwou et al., 2012). Unlike many organic pollutants, heavy metals are non-biodegradable and can accumulate in soils, sediments, and groundwater systems over extended periods (Wuana & Okieimen, 2011). Chronic exposure to contaminated water is associated with severe health consequences, including neurological disorders, kidney dysfunction, carcinogenic effects, developmental abnormalities in children, and cardiovascular complications (WHO, 2017; Tchounwou et al., 2012). As a result, monitoring heavy metal concentrations in drinking water sources is central to environmental health protection.

Groundwater serves as a primary source of domestic water supply in many Nigerian cities, particularly where centralized municipal systems are inadequate or unreliable. Shallow wells and boreholes are widely utilized for drinking, cooking, and other household purposes. However, groundwater quality is highly susceptible to contamination from surface and near-surface anthropogenic activities, especially in areas lacking proper waste management and environmental safeguards (Edet & Offiong, 2002). In urban environments characterized by informal industrial clusters, subsurface contamination pathways may facilitate the migration of pollutants from soil to aquifers.

Mechanic workshop clusters represent a significant yet under-regulated source of heavy metal pollution in many Nigerian cities. These clusters typically involve automobile repair, engine servicing, battery replacement, welding, spray painting, and metal fabrication. Such activities generate waste products including used engine oil, spent lubricants, brake fluids, battery acids, metal scraps, and paint residues, many of which contain elevated concentrations of heavy metals (Nwachukwu et al., 2010; Ipeaiyeda & Dawodu, 2008). Improper disposal practices, such as direct discharge onto bare soil, open dumping, and unlined waste pits facilitate the leaching of metallic contaminants into underlying soils and groundwater systems.

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Empirical studies across Nigeria have documented elevated heavy metal concentrations in soils and surface waters surrounding mechanic workshops and auto-repair clusters. Nwachukwu et al. (2010) reported significant levels of lead, cadmium, and chromium in soils adjacent to automobile workshops, while Ipeaiyeda and Dawodu (2008) identified contamination of surface water bodies linked to automobile-related waste discharge. Similarly, Aderemi et al. (2011) observed increased concentrations of heavy metals in groundwater sources located near industrial and commercial clusters. These findings collectively highlight mechanic workshops as potential point sources of metallic pollution in urban environments.

Heavy metals enter groundwater systems primarily through leaching processes. Rainfall infiltration facilitates the downward movement of dissolved contaminants through soil profiles into aquifers (Alloway, 2013). The extent of migration depends on soil composition, permeability, pH, redox conditions, and depth to groundwater. Shallow aquifers, in particular, are highly vulnerable to contamination due to limited protective geological barriers (Edet & Offiong, 2002). In densely built urban areas, where shallow wells are common and protective casing may be inadequate, the risk of contamination increases significantly. The vulnerability of shallow wells contrasts with deeper boreholes, which typically draw water from more confined aquifers. However, even boreholes are not immune to contamination where casing integrity is compromised or where contaminant plumes extend to deeper strata. Beyond environmental chemistry, heavy metal contamination represents a profound public health challenge. Lead exposure, even at low concentrations, is associated with cognitive impairment and neurodevelopmental delays in children (WHO, 2017). Cadmium accumulation can result in kidney damage and skeletal disorders, while hexavalent chromium is recognized as a carcinogen (Tchounwou et al., 2012). The persistence and cumulative nature of these metals mean that prolonged ingestion of contaminated groundwater may result in chronic health effects that are often difficult to diagnose and manage. Consequently, the World Health Organization has established guideline values for permissible concentrations of heavy metals in drinking water to safeguard public health (WHO, 2017).

In many Nigerian urban centers, rapid expansion has led to the spatial clustering of mechanic workshops within residential neighborhoods. Weak enforcement of environmental regulations and absence of engineered waste disposal systems

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exacerbate the potential for soil and groundwater contamination. Urban planning frameworks often fail to enforce adequate buffer distances between informal industrial activities and residential water sources, thereby increasing exposure risks.

Within this broader national context, Awka, the capital city of Anambra State, has experienced sustained urban growth accompanied by proliferation of informal commercial and industrial clusters. Awka South Local Government Area hosts several mechanic workshop concentrations that support transportation and economic activity within the city. These clusters are frequently situated in close proximity to residential dwellings, where households rely on shallow wells and boreholes for domestic water supply. The spatial coexistence of mechanic workshops and groundwater abstraction points raises concerns regarding potential heavy metal infiltration into drinking water sources.

Despite growing recognition of groundwater contamination risks in Nigerian cities, localized assessment of heavy metal concentrations in wells and boreholes surrounding mechanic workshop clusters in Awka South LGA remains limited. Existing studies in southeastern Nigeria have primarily focused on general water quality parameters or industrial effluent impacts without systematically examining contamination gradients around informal automobile repair hubs. Moreover, a policy-relevant gap is evident, as localized evidence linking groundwater contamination to informal industrial activities remains inadequate to guide environmental regulation, zoning enforcement, and public health intervention.

Addressing these gaps requires systematic assessment of heavy metal concentrations in groundwater sources located around mechanic workshop clusters. By generating empirical data on contamination levels and potential health risks, the study provides evidence base necessary for environmental monitoring, groundwater protection, and sustainable urban planning in Awka South LGA.

In this context, the present study undertakes a comprehensive assessment of heavy metal contamination in boreholes surrounding mechanic workshop clusters in Awka South LGA. The research seeks to determine the extent to which informal automobile repair activities contribute to groundwater pollution and whether observed concentrations exceed internationally accepted safety thresholds.

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2.0 Materials and Methods

2.1 Study Area

The study was conducted in Awka South Local Government Area (LGA), Anambra State, Nigeria. Awka lies within the tropical rainforest belt and experiences two distinct seasons: the wet season and dry season. The area is characterized by rapid urbanization and the presence of multiple mechanic workshop clusters located within residential neighborhoods. Groundwater in the area is primarily accessed through shallow wells and boreholes, which serve as major sources of domestic water supply.

2.2 Research Design

A cross-sectional descriptive design as well as laboratory analysis was adopted in this research to assess heavy metal concentrations in groundwater obtained from boreholes located around mechanic workshop clusters. The study focused on determining the levels of selected heavy metals and evaluating their compliance with established drinking water standards.

2.3 Sample Collection

Groundwater samples were collected from selected boreholes situated around mechanic workshop clusters. Seven (7) water samples were collected in pre-cleaned, acid-washed polyethylene bottles following standard procedures. Prior to sample collection, boreholes were allowed to run for 3–5 minutes to obtain representative groundwater samples.

Each sample bottle was rinsed three times with the sample water before final collection. The collected samples were immediately acidified with concentrated nitric acid (HNO_3) to pH < 2 to prevent metal precipitation and adsorption to container walls.

3.4 Data Analysis

Descriptive statistics were used to summarize the concentrations of heavy metals in the sampled boreholes. The mean values of each metal were computed and presented in tables. The measured concentrations were compared with World Health Organization (WHO, 2017) guideline values for drinking water to determine the level of compliance and potential health implications.

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3.0 Results

The results of physicochemical and heavy metal analysis of groundwater samples collected around mechanic workshop clusters in Awka South LGA are presented in Table 1.

Table 1: Physicochemical and Heavy Metal Analysis of Groundwater

Parameter	Measured Mean Value	Guideline (WHO typical limits)
pH	4.78	6.5 – 8.5 (recommended for drinking water by WHO)
Electrical Conductivity (EC)	470 µS/cm	Fresh groundwater commonly 100 – 1000 µS/cm
Total Dissolved Solids (TDS)	221 ppm (mg/L)	<300 mg/L (excellent); <500 mg/L acceptable
Oxidation Reduction Potential (ORP)	+349 mV	Natural groundwater often 100 – 400 mV
Salinity (Salt)	210 ppm	Freshwater generally <500 ppm
Salt Percentage	0.02%	Freshwater usually <0.05%
Salt Specific Gravity (S.G)	1.000	Pure water ≈ 1.000
Carbonate	0 mg/L	Not strictly regulated
Total Hardness	5 mg/L	<60 mg/L = soft water
Zinc	0 mg/L	3 mg/L (taste threshold)
Free Chlorine	0 mg/L	0.2–0.5 mg/L for treated water
Iron	0.1 mg/L	0.3 mg/L
QAC & QUAT	0	Not usually present in groundwater
Copper	0 mg/L	2 mg/L
Lead	2 µg/L (likely)	10 µg/L
Mercury	0	6 µg/L
Nitrate	70 mg/L	50 mg/L
Nitrite	0 mg/L	3 mg/L
Total Chlorine	0 mg/L	Usually present only in treated water
Manganese	0 mg/L	0.4 mg/L
Sulphate	250 mg/L	250 mg/L
Fluoride	0 mg/L	1.5 mg/L

3.1 Physicochemical Characteristics

The pH of the sampled groundwater was 4.78, which is significantly below the World Health Organization (WHO) recommended range of 6.5–8.5, indicating that the water is acidic. Acidic groundwater conditions can enhance the mobility and solubility of heavy metals, thereby increasing contamination risks (Jolaosho et al., 2024). This low pH may be attributed to infiltration of acidic wastes such as used engine oil, battery

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fluids, and other workshop-related discharges.

Electrical Conductivity (EC) was measured at 470 µS/cm, which falls within the typical range for freshwater (100–1000 µS/cm). Similarly, Total Dissolved Solids (TDS) recorded a value of 221 mg/L, indicating good water quality, as it is below the WHO acceptable limit of 500 mg/L. These values suggest moderate mineralization and low dissolved ionic content in the groundwater.

The Oxidation Reduction Potential (ORP) value of +349 mV indicates an oxidizing environment, which is typical of well-aerated groundwater systems. Salinity (210 ppm), salt percentage (0.02%), and specific gravity (1.000) further confirm that the water is fresh and low in dissolved salts, consistent with unpolluted groundwater systems.

Total hardness was recorded as 5 mg/L, classifying the water as very soft (<60 mg/L). While soft water is not harmful, it may enhance corrosivity, especially under acidic conditions, potentially leading to metal leaching from pipes and aquifer materials (Oyeku & Eludoyin, 2010).

Carbonate concentration was 0 mg/L, indicating minimal buffering capacity, which may partly explain the observed acidic pH.

3.2 Heavy Metal Concentrations

The concentrations of heavy metals analyzed in the groundwater samples were generally low and within WHO permissible limits, with a few notable exceptions.

- Iron (Fe) was detected at 0.1 mg/L, which is below the WHO guideline value of 0.3 mg/L, indicating no immediate concern.
- Lead (Pb) was recorded at approximately 2 µg/L, which is within the WHO limit of 10 µg/L but still noteworthy due to its toxicity even at low concentrations.
- Copper (Cu), Zinc (Zn), Mercury (Hg), and Manganese (Mn) were not detected (0 mg/L) in the samples, suggesting minimal contamination from these metals.

The generally low concentrations of heavy metals may indicate limited vertical migration of contaminants or effective natural attenuation processes within the subsurface (Ogbuene et al., 2025). However, the acidic nature of the water raises concern for potential future mobilization of metals.

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3.3 Nutrient and Anion Concentrations

Nitrate concentration was found to be 70 mg/L, which exceeds the WHO guideline value of 50 mg/L, indicating significant contamination. Elevated nitrate levels are often associated with anthropogenic activities such as waste disposal, sewage infiltration, and organic matter decomposition. In the context of mechanic workshops, nitrate contamination may also arise indirectly from surrounding residential and commercial activities.

High nitrate levels pose serious health risks, particularly methemoglobinemia (blue baby syndrome) in infants (WHO, 2017). This makes the groundwater unsuitable for drinking without treatment. Nitrite concentration was 0 mg/L, indicating no immediate concern, as it falls well below the WHO limit of 3 mg/L.

Sulphate concentration was measured at 250 mg/L, which is at the upper limit of WHO permissible levels. While not exceeding the guideline, this value suggests possible influence from anthropogenic sources and warrants monitoring.

Fluoride was not detected, indicating no risk of fluorosis, while chloride-related parameters (free chlorine and total chlorine) were absent, confirming that the water is untreated groundwater.

3.4 Overall Water Quality Assessment

Overall, the groundwater in the study area exhibits mixed quality characteristics. While most heavy metals are within safe limits and salinity indicators suggest freshwater conditions, two critical concerns emerge:

1. Strong acidity (low pH)
2. Elevated nitrate concentration

These findings suggest that although heavy metal contamination is currently low, the groundwater is chemically vulnerable and potentially at risk of future contamination due to ongoing anthropogenic activities. The acidic condition, in particular, may enhance the leaching of metals into groundwater over time.

4.0 Discussion

4.1 Hydrochemical Condition of the Groundwater System

The groundwater in the study area is characterized by low mineralization (TDS = 221 mg/L; EC = 470 µS/cm) and very low hardness (5 mg/L), indicating limited dissolution of aquifer minerals and suggesting a relatively young or weakly mineralized groundwater system. Similar hydrochemical signatures have been

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reported in south-eastern Nigeria, where sandy and unconsolidated formations allow rapid infiltration with minimal water–rock interaction (Okorie et al., 2024).

However, despite this apparent geochemical simplicity, the groundwater exhibits marked acidity (pH = 4.78). This is a critical deviation from natural groundwater systems, which are typically neutral to slightly acidic. The absence of carbonate buffering (0 mg/L) further explains the inability of the aquifer to neutralize acidic inputs. According to Oyeku and Eludoyin (2010), groundwater systems lacking carbonate minerals are particularly vulnerable to pH fluctuations and external contamination.

The acidic condition suggests external anthropogenic influence rather than purely geogenic control. Mechanic workshop activities—especially disposal of battery acids, petroleum products, and metal residues—are plausible contributors. Acidic leachates generated from these wastes can infiltrate soils and alter groundwater chemistry over time.

4.2 Low Concentration of Heavy metal but High-Risk Potential

Interestingly, the concentrations of heavy metals (Pb, Fe, Cu, Zn, Mn, Hg) were within WHO permissible limits, with several metals not detected. At face value, this suggests minimal contamination. However, such a conclusion would be incomplete without considering geochemical context.

The acidic groundwater environment significantly increases the mobility of heavy metals, even when current concentrations are low. Under low pH conditions, metals adsorbed onto soil particles can desorb and migrate into groundwater (Alloway, 2013). This implies that:

- The system may be in an early contamination phase
- Heavy metals may still be retained in the soil matrix
- Future mobilization is highly likely if acidic conditions persist

This aligns with findings by Ogbuene et al. (2025), who noted that groundwater systems near pollution sources may initially show low metal concentrations before gradual accumulation occurs due to continued leaching.

Lead (Pb), although within safe limits (2 µg/L), remains particularly important. Even low-level exposure has no safe threshold for neurological effects, especially in children (WHO, 2017). Its presence, even at low concentration, suggests incipient

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contamination linked to anthropogenic activities, likely from automobile batteries and metal components.

4.3 Nitrate as a Primary Indicator of Anthropogenic Contamination

The most significant chemical anomaly observed is the elevated nitrate concentration (70 mg/L), exceeding the WHO guideline of 50 mg/L. Unlike heavy metals, nitrate is highly mobile in groundwater and does not readily adsorb to soil particles, making it a sensitive and early indicator of contamination.

The elevated nitrate level suggests active infiltration of surface-derived pollutants, which may include:

- Organic waste decomposition
- Sewage leakage
- Runoff from residential and commercial activities
- Workshop-associated waste mixtures

Although mechanic workshops are not traditionally primary nitrate sources, their co-location within residential zones creates a mixed contamination environment, where multiple anthropogenic inputs converge.

This finding is consistent with Olawale (2020), who observed that nitrate often exceeds permissible limits in urban groundwater even when heavy metals remain low, indicating different transport behaviors and contamination timelines.

From a health perspective, elevated nitrate poses a serious risk, particularly methemoglobinemia in infants, and is therefore a more immediate public health concern than the currently low heavy metal concentrations.

4.4 Role of Acidity in Contaminant Mobility and Aquifer Vulnerability

One of the most critical insights from this study is the interaction between acidity and contamination risk. The combination of Low pH (4.78), Low buffering capacity (0 carbonate), Soft water (5 mg/L hardness) creates a hydrochemical environment that is highly aggressive and chemically unstable**.**

Such conditions enhance corrosion of pipes and borehole casings, introducing secondary metal contamination, promote leaching of metals from soils and geological formations and increase bioavailability and toxicity of dissolved metals. Jolaosho et al. (2024) emphasize that groundwater systems with low buffering capacity are particularly susceptible to rapid chemical changes following anthropogenic inputs. Therefore, even if contamination is currently low, the system is highly vulnerable to future deterioration**.**

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4.5 Sulphate and Emerging Anthropogenic Influence

Sulphate concentration (250 mg/L) lies exactly at the WHO permissible limit, suggesting increasing anthropogenic influence. Elevated sulphate in groundwater is often linked to:

- Industrial waste
- Petroleum-related activities
- Oxidation of sulphide minerals

Given the proximity to mechanic workshops, sulphate may originate from lubricants, fuels, and metal processing residues. While not yet exceeding safe limits, this parameter indicates progressive chemical alteration of groundwater quality.

4.6 Integrated Interpretation: Early-Stage Contamination System

When all parameters are considered together, a clear pattern emerges:

Table 2: Integrated Interpretation

Indicator Type	Observation	Interpretation
Heavy metals	Low	No advanced contamination yet
pH	Very low	Strong chemical disturbance
Nitrate	High	Active anthropogenic pollution
Hardness & Carbonate	Very low	Poor buffering capacity
Sulphate	At limit	Emerging contamination

This combination suggests that the groundwater system is not yet heavily contaminated with metals but is undergoing active chemical stress, placing it in an early-stage contamination phase. This is particularly important from an environmental management perspective. Intervention at this stage can prevent long-term heavy metal accumulation.

4.7 Implications for Public Health and Environmental Management

From a public health standpoint, the findings raise two major concerns. First, the elevated nitrate levels indicate that the water is unsafe for drinking, particularly for infants and other vulnerable populations who are more susceptible to nitrate-related health conditions. Second, the presence of acidic conditions suggests a longer-term risk, as such an environment can enhance the mobility and solubility of heavy metals, creating a pathway for progressive contamination that may not yet be fully evident.

From an environmental perspective, the results underscore the need for improved

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waste management practices within mechanic workshops, as improper disposal of oils, metals, and other contaminants can contribute significantly to groundwater pollution. There is also a clear need for stricter regulation of workshop siting, including the establishment of buffer zones between such activities and nearby water sources. In addition, routine groundwater monitoring programs should be implemented to track changes in water quality over time and detect early signs of contamination.

Overall, the study reinforces the understanding that groundwater contamination is often a gradual process. Early chemical indicators, such as low pH and elevated nitrate levels, serve as important warning signals that precede more severe forms of pollution, including heavy metal accumulation.

5.0 Conclusion

This study assessed the physicochemical characteristics and heavy metal concentrations of groundwater sources around mechanic workshop clusters in Awka South LGA. The findings reveal that while most heavy metals including lead, copper, zinc, mercury, and manganese were within World Health Organization (WHO) permissible limits, the groundwater exhibited significant chemical imbalance and emerging contamination indicators.

The most critical findings include:

- Acidic pH (4.78), which falls far below the WHO recommended range, indicating chemically unstable groundwater conditions
- Elevated nitrate concentration (70 mg/L), exceeding the WHO guideline value of 50 mg/L and posing immediate public health risks
- Low total hardness and absence of carbonate buffering, suggesting high vulnerability of the aquifer to contamination
- Sulphate concentration at the permissible limit, indicating increasing anthropogenic influence

Although heavy metal concentrations are currently low, the acidic nature of the groundwater enhances the mobility and potential future accumulation of toxic metals. This suggests that the study area is not yet heavily contaminated but is undergoing early-stage groundwater degradation driven by anthropogenic activities, including those associated with mechanic workshops and surrounding urban land use.

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Overall, the groundwater in the study area is not entirely suitable for direct consumption without treatment, particularly due to nitrate contamination and acidity. The results highlight the need for proactive intervention to prevent progression to more severe heavy metal pollution.

6.0 Recommendations

Based on the findings of this study, several recommendations are proposed to safeguard public health and improve groundwater quality in the study area. Groundwater from the area should be treated before consumption, particularly to reduce nitrate levels and correct acidity. Suitable treatment methods include pH adjustment using neutralizing agents, as well as filtration and ion exchange systems for nitrate removal, since boiling alone is ineffective for addressing nitrate contamination.

There is also a need for stricter regulation of mechanic workshop activities. This should involve proper collection and disposal of used oils, battery fluids, and metal wastes, as well as the prohibition of direct discharge of such wastes onto bare soil. Establishing designated waste handling and management systems is essential to minimize contaminant infiltration into the subsurface, as noted by Adelekan and Abegunde (2011). In addition, urban planning authorities should enforce minimum safe distances between mechanic workshops and groundwater sources such as boreholes. The establishment of buffer zones will help reduce direct contamination pathways and limit the migration of pollutants into aquifers.

Beyond the study area, there is a broader need for improved environmental governance of mechanic workshops across Nigeria. Currently, mechanic workshop operations are largely underregulated in many parts of the country, despite their potential to generate significant environmental pollutants. This regulatory gap represents a weak link in environmental monitoring and compliance systems, creating pathways through which contaminants can enter soil, surface water, and groundwater resources with limited oversight. Government agencies and relevant environmental authorities should therefore develop and enforce comprehensive environmental management guidelines for mechanic workshops, including licensing requirements, routine inspections, waste management standards, and environmental monitoring programs. Addressing this gap will strengthen environmental governance and reduce the risk of pollution from informal and semi-formal workshop activities.

Routine groundwater monitoring programs should also be implemented to track heavy metal concentrations, nitrate levels, and key physicochemical parameters such as pH. Continuous monitoring is important for detecting gradual contamination trends, especially given the observed vulnerability of the groundwater system. Alongside this, there is a need for increased public awareness and community education. Residents should be informed about the risks associated with consuming untreated groundwater, as well as safe water handling and storage practices. They should also be educated on the environmental consequences of improper waste disposal, as public awareness plays a crucial role in reducing both exposure risks and pollution sources.

Finally, further research is recommended to deepen understanding of groundwater contamination in the area. Future studies should include seasonal analysis to capture temporal variations in water quality, conduct health risk assessment modeling using indices such as the Hazard Quotient (HQ) and Hazard Index (HI), and investigate soil and sediment contamination to better understand pollutant pathways and the overall dynamics of contamination.

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