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Assessment of Heavy Metal Contamination and Human Exposure Risk in Drinking Water Sources of Gaidau Community, Sokoto, Northwestern Nigeria

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ABSTRACT: The term 'heavy metals' refers to a class of elements characterized by high density and significant toxicity, even at minimal concentrations. The contamination of water resources with these metals has become a pronounced environmental problem of critical importance. Heavy metals are introduced into aquatic systems from a multitude of sources, which encompass industrial effluent, runoff from agricultural lands, substandard waste management practices, and natural geological phenomena. Upon entering a water supply, these metallic elements can demonstrate remarkable persistence over extended durations, thereby presenting substantial hazards to both human populations and the broader ecosystem. Certain demographic groups, specifically children and expectant mothers, exhibit heightened vulnerability to the effects of these metals and face an elevated risk of developmental complications. The presence of heavy metals such as lead, mercury, cadmium, and arsenic in water supplies is linked to severe health conditions, including but not limited

to neurological impairment, renal failure, and various forms of cancer.

In the Gaidau Community, located in Sokoto, Nigeria, residents are confronted with considerable health threats stemming from the contamination of their water sources by heavy metals. This investigation was designed to quantify the concentration levels and ascertain the human exposure risk associated with specific heavy metals—namely cadmium (Cd), copper (Cu), nickel (Ni), iron (Fe), and zinc (Zn)—within the drinking water of the Gaidau Community. The community has undergone swift modernization, a process that has amplified concerns regarding the potential for metallic contamination of its local water bodies. Although initial observations suggested the presence of potentially hazardous concentrations of heavy metals, the precise degree of exposure among the local populace has not been systematically recorded, which complicates the formulation of effective remediation plans. This research endeavors to conduct a methodical evaluation of heavy metal levels in Gaidau's water supply. It utilizes sophisticated monitoring approaches, including wastewater-based epidemiology (WBE), to quantify population-wide exposure and establish a robust scientific foundation for future public health initiatives.

A descriptive cross-sectional study framework was adopted to evaluate the existing contamination levels in a variety of water sources, including boreholes, local wells, and streams, within the Gaidau Community. Water specimens were procured from these designated sources and subjected to analysis via Atomic Absorption Spectrophotometry (AAS) at the Chemistry Department of Ahmadu Bello University, Zaria. The analytical results consistently demonstrated that streams contained the most elevated concentrations of the targeted heavy metals, followed in descending order by wells and then boreholes. Specifically, cadmium concentrations in stream water (mg/L) surpassed the levels found in well water (mg/L) and borehole water (mg/L). Copper concentrations reached their peak in streams (mg/L), while nickel levels in streams (mg/L) were markedly higher than those recorded in wells (mg/L) and boreholes (mg/L). Iron concentrations were also substantially higher in streams (mg/L) when compared to wells (mg/L) and boreholes (mg/L). A similar distribution was observed for zinc, with its highest concentration (mg/L) also found in stream water. This investigation highlights a significant degree of heavy metal contamination across the water sources available to the Gaidau Community, with streams being the most affected, thereby posing substantial health risks to the inhabitants. The outcomes of this study strongly indicate the necessity for focused public health interventions aimed at curtailing exposure to heavy metals and alleviating the associated health dangers.

Keywords: *Metallic Contaminants, Potable Water Safety, Community Health Assessment, Gaidau, Nigeria, Environmental Toxicology, Groundwater Sources, Surface Water Pollution, Human Health Hazards, Risk Analysis.*

Background of the Study

Heavy metals are classified as a distinct group of elements notable for their considerable densities and their capacity to exert toxic or poisonous effects even when present in low concentrations. Prominent heavy metals that raise health alarms include lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As). These elements present formidable health threats to humans, fauna, and flora, largely due to their resistance to biodegradation and their propensity for accumulation within both the environment and biological tissues.

The contamination of water by heavy metals stands as a paramount environmental dilemma. These metals find their way into water systems through a variety of pathways, such as discharges from industrial facilities, runoff from agricultural lands, improper disposal of waste materials, and natural geological erosion. Following their introduction into the water supply, these metals can endure for extended periods, presenting prolonged and significant risks to human health and the integrity of the ecosystem. Water laden with these contaminants can trigger the bioaccumulation of metals in aquatic life, which subsequently permeates the food chain. This process ultimately affects not only the local wildlife but also human populations that rely on these contaminated organisms for sustenance.

On a global scale, the issue of heavy metal contamination in water supplies has become a matter of urgent attention. Nations across the world are grappling with the challenges of managing and mitigating the adverse effects of heavy metals on their water resources. For example, in certain areas of China and India, industrial pollution has resulted in severe contamination of water bodies, precipitating extensive health issues and significant environmental decay. Within Africa, including Nigeria, the problems have been intensified by swift urbanization and industrial growth, leaving numerous communities without reliable access to clean and safe drinking water.

At the national level in Nigeria, this challenge is exacerbated by deficient infrastructure, suboptimal waste management protocols, and the absence of robust regulatory enforcement. This convergence of factors culminates in substantial health risks for the populace, especially within vulnerable communities such as Gaidau in Sokoto State. Demographics like children and pregnant women are disproportionately susceptible to the toxic effects of these metals and face a heightened probability of experiencing developmental problems.

In recent years, wastewater-based epidemiology (WBE) has been recognized as an effective instrument for evaluating the public health consequences of environmental pollutants, heavy metals included. WBE functions by analyzing specific biomarkers found in wastewater, which can serve as indicators of a population's overall health status. This innovative methodology has been successfully applied to monitor the transmission of infectious diseases, gauge patterns of drug consumption, and assess exposures to environmental hazards.

The Gaidau community faces considerable hurdles, most notably in securing access to uncontaminated water and adequate sanitation infrastructure, which are contributing factors to a range of health problems. The community is deeply rooted in Hausa and Fulani traditions, with Islam forming the core of its cultural identity. Traditional leadership structures continue to be pivotal in matters of governance and the mediation of disputes. Furthermore, the community contends with developmental deficits, including insufficient infrastructure, restricted access to healthcare and educational facilities, and a strong dependency on subsistence farming.

Despite these obstacles, Gaidau possesses considerable opportunities for advancement. Key areas identified for development include the modernization of agricultural techniques, the enhancement of educational and vocational training programs, and the reinforcement of the local healthcare system. Promoting vigorous community involvement in development initiatives is crucial for ensuring their long-term viability and for tailoring solutions that meet local needs effectively. Through the implementation of well-targeted interventions and the cultivation of strong community engagement, Gaidau has a significant capacity to achieve sustainable development and elevate the quality of life for its inhabitants.

Statement of the Problem

The Gaidau community in Sokoto, Nigeria, has undergone a period of rapid modernization, which has concurrently introduced pressing concerns about the contamination of local water sources with heavy metals and the subsequent repercussions for public health. Toxic elements like lead, mercury, cadmium, and arsenic may infiltrate the water supply via pathways such as industrial operations, agricultural surface runoff, and the improper handling of waste. These substances are known to present grave health hazards, which can manifest as neurological impairment, kidney dysfunction, and carcinogenesis. At present, there is a significant lack of documented evidence regarding the extent of heavy metal exposure among the residents of Gaidau, a situation that impedes the creation and execution of effective strategies for mitigation.

Anecdotal observations have pointed to potentially dangerous concentrations of heavy metals in the community's water, which appear to coincide with a higher frequency of health conditions like developmental disorders in children and chronic illnesses among adults. The primary impetus for this investigation is to fill this critical void in knowledge by undertaking a systematic evaluation of the heavy metal content in Gaidau's water supply. Through the application of modern monitoring methods, inclusive of wastewater-based epidemiology (WBE), this research aims to quantify the population's level of exposure to these dangerous substances. Gaining a clear understanding of the magnitude and origins of this heavy metal contamination will furnish a scientific rationale for public health actions, thereby facilitating the creation of proficient risk management and prevention frameworks. This research is vital for protecting the health and welfare of Gaidau's residents, as it will equip local authorities and relevant stakeholders with the essential data needed to enact policies that reduce heavy metal exposure and buffer the associated health risks.

Justification of the Study

This research was specifically situated in the Gaidau Community because of the substantial threat of heavy metal contamination within its local water sources. The community has seen accelerated modernization and a rise in industrial-related activities, which are well-known potential sources of heavy metals such as lead, cadmium, mercury, and arsenic. These contaminants are associated with severe health consequences, including neurological damage and the development of chronic diseases. Notwithstanding these clear risks, a notable scarcity of research on the water quality in Gaidau exists, making the formulation of effective mitigation plans exceptionally difficult.

The urgency of this study is underscored by the pressing need to safeguard public health amidst escalating interventional activities and the threat of heavy metal poisoning within the Gaidau Community. The findings from this work are expected to make a significant contribution to the crafting of targeted mitigation strategies, ultimately enhancing the overall health and safety of the community members. Moreover, the methodological approach and the results of this study have the potential to act as a valuable template for analogous investigations in other regions confronting similar challenges with metal-based pollution.

Water, frequently referred to as the "elixir of life," is fundamentally essential for the existence of all forms of life. In an ideal state, water should be devoid of hazardous pollutants, colorless, odorless, and tasteless, which would confirm its safety for consumption, agricultural applications, and the preservation of ecosystems. Regrettably, for a large portion of the global population, this ideal remains unattainable due to widespread pollution, especially from heavy metals. The Sokoto state metropolis is not immune to this issue; various studies have indicated that none of its water sources fully comply with the World Health Organization's (WHO) criteria for safe drinking water.

The presence of these metallic contaminants introduces significant risks to human health, the productivity of agriculture, and the delicate balance of the local ecology. This issue is of escalating concern in the Gaidau Community of Sokoto, Nigeria, where there is a marked deficiency of research on water quality, particularly concerning contamination by heavy metals. This gap in current knowledge presents a major obstacle to understanding the true extent of the pollution and to deploying effective measures for remediation. Although broader studies on water contamination in Nigeria exist, localized investigations are indispensable for tackling the distinct environmental and health challenges specific to the Gaidau Community. Data generated at the local level are crucial for the development of precisely targeted interventions and policies.

This study will produce foundational baseline data on the concentrations of heavy metals in the water sources of the Gaidau Community, which is vital for continuous monitoring efforts and for future comparative analyses. The results will establish a benchmark for subsequent research, aiding in the tracking of fluctuations in water quality over time and in assessing the efficacy of any implemented remedial actions. Furthermore, this research will play a role in educating the community about the origins and hazards of heavy metal contamination, thereby empowering residents to adopt preventive habits and to advocate for improved water quality. Pinpointing specific zones of contamination will facilitate focused health interventions, which can lead to a reduction in the occurrence of waterborne illnesses and cases of heavy metal poisoning. This study also aligns with and supports global health agendas and the Sustainable Development Goals (SDGs), most notably SDG 6, which advocates for the universal availability and sustainable management of water and sanitation.

Aim and Objectives

Aim

The principal aim of this research is to conduct a thorough investigation into Heavy Metal Contamination and the associated Human Exposure Risk within the Drinking Water Sources of the Gaidau Community, Sokoto, Nigeria.

Objectives

1. To quantify the concentration levels of specific heavy metals, namely copper (Cu), nickel (Ni), zinc (Zn), iron (Fe), and cadmium (Cd), present in the drinking water sources of the Gaidau Community.

2. To ascertain the levels of exposure to these identified heavy metals among the local population.

Research Questions

1. What are the precise concentrations of the heavy metals (Fe, Ni, Zn, Cd, Cu) in the drinking water utilized by the Gaidau community?
2. How do the measured levels of heavy metal contamination within the Gaidau community's water sources stand in comparison to the standards stipulated by the WHO?

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Water is an irreplaceable resource for the continuation of life on Earth, offering vitality and acting as a fundamental source of existence. Regrettably, a substantial segment of the global population experiences a deficit in access to fresh and potable drinking water. According to a report by the World Water Council, an estimated 1.2 billion individuals lack access to safe drinking water, and approximately 4 billion people reside in regions characterized by water scarcity. It is further projected that by the year 2050, roughly 6 billion people will be confronting conditions of severe water scarcity. This alarming statistical outlook is a direct consequence of escalating industrialization, urbanization, and fundamental natural requirements, all of which exert immense pressure on the global water situation.

The swift pace of urbanization, industrial expansion, and human population growth has culminated in significant environmental pollution, including the release of untreated waste and the contamination of both soil and water resources. The primary contributors to freshwater contamination include the discharge of untreated wastewater, the dumping of industrial effluent, and runoff from agricultural activities. Water pollution constitutes a major health threat, especially in developing nations, where it is estimated to be responsible for around 80% of all illnesses and fatalities. The introduction of toxic pollutants into wastewater not only harms aquatic ecosystems but also renders water sources unsuitable for human consumption. A wide array of harmful substances, such as pharmaceuticals, pesticides, surfactants, acids, detergents, dyes, and toxic metals, have infiltrated water resources, creating ecological hazards for humans, plants, and animals.

Heavy metals (HMs) have been identified as one of the most significant sources of water pollution globally. In recent times, the increasing demand for clean and safe drinking water has made it imperative to explore new solutions and technologies that can facilitate the effective purification of water for reuse. Heavy metals are a collection of elements that possess relatively high densities and exhibit toxicity even at low concentrations. They have been defined as a group of metals and metalloids with densities exceeding mg/L. Common examples of HMs include mercury (Hg), lead (Pb), and cadmium (Cd), among others. These metals are notorious contaminants of aquatic systems, soil, and the atmosphere, and they can be harmful even in minute quantities.

Heavy metals can be of natural origin or can result from human activities. The introduction of excessive amounts of HMs into the pedosphere is known to diminish both the productivity and quality of soil. Furthermore, contact with HMs, even at trace levels, can present a variety of health risks to humans. For instance, exposure to both acute and chronic levels of mercury (Hg) and lead (Pb) can result in conditions such as kidney failure and diarrhea. One such group of pollutants is heavy metals, which are defined by their high density and their toxicity even at low concentrations. While heavy metals do enter aquatic ecosystems from both natural and anthropogenic sources, natural phenomena like the leaching and weathering of rocks, soil erosion, or volcanic eruptions contribute a relatively small amount. In stark contrast, anthropogenic emissions of heavy metals into the environment saw a significant increase during the nineteenth and twentieth centuries, in tandem with the intensified exploitation and distribution of metal ores.

Exposure to heavy metals can alter the metabolome structure, diminish reproductive success, elevate mortality rates, produce teratogenic effects, and impede growth. It can also lead to acute toxicity, immunosuppression, and the generation of oxidative stress. Consequently, heavy metals like cadmium, lead, and mercury, as well as their compounds, are listed among the 45 priority substances and substance groups that pose a grave threat to surface waters, as detailed in Annex X of Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013. This directive amended Directives 2000/60/EC and 2008/105/EC concerning priority substances in the domain of water policy.

2.2 Conceptual Review

Heavy metals are categorized as metallic elements that possess a high density and are toxic at low concentration levels. This group commonly includes lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), and arsenic (As). These metals can be traced back to numerous sources, including industrial activities, where factories discharge effluents rich in heavy metals into adjacent water bodies; agricultural practices; urban rainwater, which carries contaminants from streets into water systems; and mining operations. Natural processes, such as the geological deposition of minerals, alongside human activities, substantially amplify the release of these toxic metals into the environment, leading to hazardous concentrations in the air, soil, food crops, and aquatic ecosystems. Human exposure to heavy metals typically occurs through the consumption of contaminated food and water, as well as by inhaling contaminated air and dust particles.

Industrialization has undeniably been a major contributor to the high levels of heavy metal contamination found in soil and, consequently, in water. A considerable body of research has been conducted in various parts of Nigeria, which provides strong indications of the potential for water contamination in Sokoto state. It has been established that the lack of safe drinking water is a persistent issue in Sokoto; however, much of the existing research has focused predominantly on bacteriological contamination. It is only more recently that a greater number of studies have begun to investigate heavy metal contamination, which itself has long-lasting effects on the human body.

A study by Ohiagu et al. (2021) identified heavy metal contamination from chromium, manganese, nickel, arsenic, selenium, lead, and bromine, with concentrations exceeding the WHO (2019) permissible limits. The samples for this particular research were sourced from tap water, well water, and sachet water, and none of them complied with the safety recommendations set forth by the WHO. In their research conducted at Sokoto State University and the nearby village of Bodinga, Nasiru and his associates discovered that heavy metal contamination levels for Mn and Cr were above the WHO-stipulated threshold, whereas Na and K levels were low. Lead was found to be below the detection limit, which, on the whole, suggests that the water in that locality is relatively safe for consumption. This contrasts with a study by Sarkingobir (2023), which identified unsafe water for Alimajiri children in Sokoto East. That study reported significant contamination with Cd, Cr, Pb, Fe, and Ni, all at levels above the WHO recommendations, which is likely to have long-term health consequences for these children.

In comparison, an analysis of heavy metal indices in Edo state's Ikpoba river and its surrounding water sources showed regional variations. The NW, NE, SW, and SS regions all demonstrated the highest mean concentration of iron (Fe) relative to other heavy metals, indicating a significant regional pattern. Conversely, the SE region exhibited a different trend, with zinc (Zn) having the highest mean concentration among the heavy metals analyzed. This regional variance underscores the heterogeneity of heavy metal contamination across different geographic areas of the country. On a larger scale, a national-level analysis of the data offered deeper insights into the overarching state of heavy metal contamination in water sources. The findings showed that zinc and iron were the most prevalent heavy metals, with mean concentrations of 1.10 mg/l and 2.31 mg/l, respectively. These figures were substantially higher than those for other heavy metals, pointing to a widespread presence of Zn and Fe in the nation's water supply. In contrast, cadmium (Cd) registered the lowest mean concentration, implying a comparatively lower level of Cd contamination. This granular analysis emphasizes the necessity of both regional and national water quality monitoring to effectively address the fluctuating levels of heavy metal contamination and to deploy targeted mitigation efforts.

The concentrations of certain contaminants, such as Cr, Mn, and Zn, have been observed to be higher during the rainy season, whereas Cd, Cu, Fe, and Pb tend to show higher concentrations during the dry season. The mobilization of heavy metals from the soil into water bodies during periods of rainfall may be responsible for this seasonal increase. However, a study on heavy metal contamination in the River Benue indicated high levels of Fe, while Cd was, on average, the lowest. This pattern is consistent with other studies conducted in different geopolitical zones, with the exception of a study in Jos.

Groundwater and surface water in Nigeria are especially susceptible to contamination, owing to a mix of environmental and anthropogenic influences. A key factor is the shallow depth of the water table relative to the soil surface, which curtails the natural filtration distance for potential pollutants. Furthermore, the geological layers situated above the water table are characterized by high permeability, which permits contaminants to infiltrate with ease and reach the groundwater. The problem is further aggravated by the multitude of superficial pollution sources in the region, including agricultural runoff, industrial discharges, and the inadequate disposal of waste. The combined impact of these factors renders both groundwater and surface water highly prone to contamination, thus posing considerable risks to public health and the environment. This situation highlights the urgent requirement for comprehensive water management strategies and effective pollution control measures to preserve these essential water resources.

Mining stands as a primary source of environmental pollution in Southern Africa, with South Africa being the world's largest gold producer and Zambia possessing vast deposits of Cu and Co. In a study conducted in South Africa by Okonkwo et al. (2021), the pollution of Thohoyandou rivers with Pb, Cd, Cu, and Zn was linked to a sewage treatment plant, waste dumping, and the application of fertilizers and pesticides containing Pb and Cd on nearby farms. Similarly, Hg contamination in the groundwater across Lusaka City in Zambia was traced back to urban waste.

2.2.1 Toxicological and Health Impact Framework

Heavy metals are implicated in the development of numerous diseases, such as diabetes, Alzheimer's disease, and various cancers. While individual metals exhibit specific toxicological profiles, there are general signs associated with poisoning from copper, lead, aluminum, zinc, mercury, cadmium, and arsenic. These include gastrointestinal (GI) dysfunctions, diarrhea, stomatitis, shivering, and hemoglobinuria, which leads to a rust-red depression and pneumonia when volatile vapors are inhaled.

Exposure to heavy metals has a profound impact on biological and ecological systems, influencing multiple facets of health and development. These metals are known to disrupt the metabolome's structure—the complete set of metabolites in an organism—resulting in metabolic imbalances. Furthermore, such exposure is correlated with diminished reproductive success and elevated mortality rates. The teratogenic effects of these metals, which cause developmental abnormalities, have also been well-documented. Heavy metals can also inhibit the normal growth processes in living organisms, significantly disrupting population dynamics and ecological equilibrium.

Beyond these effects, heavy metals are recognized for causing acute toxicity, which poses immediate and severe health threats. They also weaken the immune system, leading to immunosuppression, and stimulate the production of oxidative stress, a condition where an imbalance between free radicals and antioxidants damages cells and tissues. Due to these severe repercussions, heavy metals like cadmium, lead, and mercury, along with their chemical compounds, are classified as high-risk substances. They are included among the 45 priority substances identified as significant threats to surface water quality under Annex X of Directive 2013/39/EU. This directive, issued by the European Parliament and Council on August 12, 2013, amends previous water policy frameworks and highlights the importance of regulating these hazardous materials to protect water resources and public health.

The effects of heavy metal exposure can be virulent (acute, chronic, or sub-chronic), mutagenic, teratogenic, neurotoxic, or carcinogenic. Prolonged exposure may lead to the gradual progression of conditions like muscular dystrophy, Parkinson’s disease, and multiple sclerosis. Allergies are also common, and recurrent long-term contact with certain metals or their compounds can even trigger carcinoma. Given the potential for these heavy metals to cause deleterious bodily effects, a discussion of some common ones is warranted.

Lead, for instance, is a dangerous metal that readily accumulates in the human body. It is a heavy, soft metal found in forms like sulfide, cerussite ($PbCl2$), and galena. A primary source of lead in industrial effluent is wastewater from lead-acid battery manufacturing. Lead (Pb) is a hazardous heavy metal with no established safe exposure level, as even minimal amounts can be detrimental to human health. Its toxicity primarily targets the central nervous system (CNS), brain, and excretory system, with higher concentrations causing severe and often irreversible harm. Early detection of elevated blood lead levels (BLLs) through blood tests is crucial to prevent long-term damage, especially in vulnerable populations.

The manufacturing of pesticides that contain arsenic results in the release of arsine gas. Arsenic originates from many sources, including industrial and metallic wastes. It is extremely dangerous to human wellness, negatively affecting the nervous system, undermining muscles, and coagulating proteins, and it can also initiate cancer. Additionally, it impacts the endocrine, hepatic, and reproductive systems.

Mercury demonstrates neurotoxic effects when present in high quantities, with its vapors primarily targeting the CNS. Pregnant women who absorb high concentrations of mercury are at risk of involuntary abortion. A wide range of cognitive, personality, sensory, and motor disorders has been associated with mercury exposure. Long-term exposure to elemental mercury vapor has been linked to unsteady gait, poor concentration, tremulous speech, blurred vision, and decreased psychomotor skills. Chronic cough has also been reported in individuals exposed for several weeks. Earlier research suggests that inorganic mercury may be embryotoxic and teratogenic. Cardiovascular and gastrointestinal effects have also been observed following mercury ingestion.

Cadmium is naturally present in sediments along with other elements. It is also one of the most toxic heavy metals found in manufacturing effluents, playing a significant role in industries like plating, cadmium-nickel battery production, phosphate fertilizers, and stabilizers. Even at low concentrations, cadmium compounds are highly destructive and accumulate in the ecosystem. Cadmium accumulation can lead to "Itai-Itai" disease, which causes bone tempering and fractures in humans. It manifests renal toxicity when consumed in higher amounts, and long-term or high-dose exposure has been shown to cause kidney defects and bone softening. Elevated levels of Cd have also been linked to prostate cancer and are responsible for a significant risk of lung cancer.

Natural sources of atmospheric nickel include dust from volcanic emissions and the weathering of rocks and soils. Exposure through inhalation, ingestion, or skin contact occurs in nickel production plants and during welding, electroplating, and grinding operations. Nickel is known to cause various pathological effects and is recognized as a human carcinogen. Skin contact with metallic or soluble nickel compounds can result in allergic dermatitis. A significant reduction in body weight is also associated with nickel consumption , and a prominent effect of nickel overdose is hair loss. The most severe health effects from nickel exposure, including chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus, have occurred in individuals who inhaled dust containing certain nickel compounds.

Due to anthropogenic activities, natural water is being contaminated by chromium. Certain fish species are destructively affected by this metal. Various studies have demonstrated that chromium compounds can increase the risk of lung cancer. Damage to the circulatory system and collapse of nerve tissue can also occur. The presence of Cr with other metals has been reported to elevate glycogen levels in several organs, indicating stress from metal exposure.

The sources of zinc in water can be anthropogenic (industrial and domestic wastewater) or geological (rock weathering). Zinc plays essential roles in maintaining cytoplasmic integrity and is considered vital for immune responses. However, it can also increase the risk of cardiovascular diseases, cause hypertension, nausea, and stomach damage, and is responsible for neurotoxic effects on human health. When consumed in abundance, zinc can cause psychical dysfunctions and generate several neural changes in the body.

2.3 Empirical Review

Recent studies have underscored the escalating concern over heavy metal contamination in various global regions, Nigeria included. A systematic review spanning the years 2000 to 2019 identified alarming levels of heavy metal pollution across different environmental matrices like soil, water, and food. Specific research indicates that industrial activities are a major contributor to the elevated concentrations of heavy metals in surface waters. For instance, a study conducted on the Harike Wetland in India revealed that cadmium and lead concentrations surpassed safety thresholds during particular seasons. In Nigeria, investigations have demonstrated that groundwater sources frequently exceed the permissible limits for heavy metals, primarily due to industrial discharges and agricultural runoff.

Within Nigeria, heavy metal contamination is a significant environmental issue with multiple contributing factors. These include the improper disposal of waste, which leaches heavy metals into water systems; the use of pesticides and fertilizers in agriculture; and industrial activities such as mining, which release heavy metals directly into the environment. Since heavy metals are non-biodegradable, they tend to accumulate in groundwater or soil, leading to pollution that can adversely affect agricultural productivity. Exposure to these metals can result in a range of health problems, including cancer and reproductive issues, which can cause further damage if not addressed.

Heavy metals can become highly toxic when they mix with other elements in water and soil, and both humans and other organisms can be exposed to them through the food chain. The presence of heavy metals in high concentrations has been shown to reduce the size of microbial populations and disrupt community structures. Trace amounts of heavy metals like zinc, lead, and copper also occur naturally in groundwater, but their concentrations can be significantly increased by human activities, thereby impacting the ecosystem and rendering the groundwater unsafe for human consumption. The presence of lead in animal and human bodies interferes with the synthesis of hemoglobin, which can lead to anemia and more severe health complications. One of the primary sources of lead is petrol from filling stations; its oxidation within vehicle engines produces lead halides that are released into the air and subsequently inhaled by humans.

Although some heavy metals such as Zinc (Zn), Copper (Cu), Chromium (Cr), and Selenium (Se) are classified as micronutrients and are known to be essential for enzymatic processes in biological systems, they still become toxic at sufficiently high concentrations. Other metals, including Mercury (Hg), Cadmium (Cd), and Lead (Pb), offer no known benefits to living organisms and are highly toxic even at very low concentrations. Data compiled from various research studies have shown that the average concentrations of heavy metals such as Cd, Cr, Mn, Ni, Pb, and Fe in Nigerian surface freshwaters exceed the maximum desirable concentrations for drinking water as stipulated by the US EPA (2009). To effectively address heavy metal contamination in Nigeria, it is necessary to increase public awareness, strengthen regulations and enforcement, implement cleaner production technologies, and remediate contaminated sites.

2.4 Theoretical Framework

To comprehend the dynamics of heavy metal contamination in the water sources of Gaidau, a conceptual model can be developed based on the interplay of several factors.

2.4.1 Sources of Contamination

Heavy metals are ubiquitous in Nigeria and, indeed, in other parts of the world; however, their concentrations differ based on geological formations. Heavy metals, including lead, mercury, cadmium, and arsenic, are introduced into the environment through a variety of anthropogenic activities. Industrial operations are among the most significant contributors to heavy metal pollution. Factories and manufacturing plants frequently discharge waste containing heavy metals into adjacent water bodies or release them into the atmosphere via emissions. For example, industries engaged in mining and smelting are well-known for releasing high levels of lead and cadmium into their surrounding environments, which leads to the contamination of both soil and water. This industrial effluent can result in the bioaccumulation of these metals in aquatic organisms, which can then enter the food chain and ultimately impact human health.

Agricultural practices also have a crucial role in introducing heavy metals into ecosystems. The application of fertilizers and pesticides that contain heavy metals can lead to soil contamination. During rainfall, these metals can leach into the groundwater or be carried by runoff into surface waters. Studies have shown, for example, that cadmium is often a component of phosphate fertilizers, which can subsequently contaminate crops and present risks to consumers. This pathway underscores the interconnectedness between agricultural methods and public health outcomes.

Urbanization further contributes to heavy metal contamination through urban runoff. Rainwater has the capacity to wash contaminants from roads, construction sites, and industrial zones into nearby water bodies. This runoff typically contains a mixture of pollutants, including heavy metals like lead from vehicle emissions and zinc from roofing materials. As urban areas continue to expand, the risk of heavy metal exposure rises due to increased runoff and the concentration of pollutants in urban waterways.

Natural sources also contribute to the presence of heavy metals in the environment. Geological formations, for instance, may naturally contain heavy metals that can leach into groundwater or be released during natural phenomena such as volcanic eruptions. While these natural sources may not be as prominent as anthropogenic ones, they still contribute to the overall burden of heavy metals in particular regions.

The pathways of exposure represent another critical component of this conceptual model. Once heavy metals are released into the environment, they can enter the human body through various routes: ingestion, inhalation, and dermal contact. For example, contaminated water supplies can lead to the direct ingestion of heavy metals by humans. Similarly, the consumption of fish contaminated with mercury or other heavy metals poses a significant threat to human health. Furthermore, the inhalation of airborne particles containing heavy metals from industrial emissions can result in respiratory problems and systemic toxicity.

The health outcomes linked to heavy metal poisoning are both diverse and severe. Chronic exposure to lead has been associated with neurological impairments and developmental issues in children. Mercury exposure is linked to cognitive deficits and motor dysfunctions , while cadmium has been implicated in kidney damage and an elevated risk of cancer. A thorough understanding of these health outcomes is essential for the development of effective public health interventions.

2.4.2 Transport Mechanisms

Groundwater and surface water in Nigeria are particularly susceptible to contamination due to a combination of environmental and anthropogenic factors. A key factor is the proximity of the water table to the soil surface, which curtails the natural filtration distance for potential pollutants. Furthermore, the geological layers situated above the water table are highly permeable, allowing contaminants to easily infiltrate and reach the groundwater. Heavy metal poisoning is a significant environmental and health issue that arises from exposure to metals such as lead, mercury, cadmium, arsenic, and chromium. Understanding the transport mechanisms of these heavy metals within biological systems is crucial for assessing their toxicological effects and for devising effective remediation strategies.

Absorption and Distribution: Heavy metals can enter the human body through various routes, including ingestion, inhalation, and dermal contact. Once inside the body, their transport is primarily managed by the circulatory system. For instance, after ingestion, metals are absorbed in the gastrointestinal tract, though their bioavailability varies. Lead, for example, is poorly absorbed in the gut but can be significantly taken up when it is in a soluble form or when chelating agents are present. Once absorbed, heavy metals bind to plasma proteins and are distributed throughout the body. Cadmium, for instance, binds to metallothionein and other proteins, which aids its distribution to organs like the liver and kidneys. This binding process is critical as it influences both the toxicity and the eventual elimination of the heavy metals from the body.

Cellular Uptake Mechanisms: The uptake of heavy metals at the cellular level occurs through several mechanisms. One principal method is passive diffusion, whereby non-ionized forms of metals can traverse cell membranes. However, many heavy metals enter cells via active transport systems that use specific transport proteins. For example, lead can mimic calcium and utilize calcium channels to gain entry into cells. Similarly, mercury can enter cells through transporters that are designed for other essential metals, such as sodium or potassium. Once inside the cells, heavy metals can disrupt cellular functions by interfering with enzymatic activities and altering cellular signaling pathways. They often bind to sulfhydryl groups in proteins and enzymes, which can lead to a loss of function or misfolding. This interference can result in oxidative stress due to the generation of reactive oxygen species (ROS), causing further cellular damage.

Tissue Accumulation and Toxicity: Heavy metals have a tendency to accumulate in specific tissues over time. Lead, for instance, predominantly accumulates in bones and teeth, whereas mercury tends to concentrate in the kidneys and brain. This accumulation is influenced by factors such as the metal's chemical form, its solubility, and the physiological state of the body. The toxic effects of heavy metal accumulation are profound. In cases of lead poisoning, neurological impairment is a major concern, particularly in children whose developing brains are more vulnerable. Cadmium exposure is associated with renal dysfunction and bone demineralization due to its affinity for kidney tissues, while mercury exposure can lead to severe neurological disorders known as Minamata disease, resulting from its impact on neuronal function.

Elimination Mechanisms: The body possesses several mechanisms for eliminating heavy metals; however, these processes can be slow and inefficient. The kidneys play a crucial role in excreting water-soluble forms of heavy metals like cadmium and lead. Mercury, in contrast, primarily undergoes biliary excretion after being converted into organic forms. Chelation therapy is a medical intervention designed to enhance the elimination of heavy metals from the body. Agents such as dimercaprol or EDTA bind to heavy metals in circulation, forming complexes that are more readily excreted through urine. However, chelation therapy must be administered with caution due to potential side effects and the risks associated with the rapid mobilization of stored metals.

2.4.3 Bioaccumulation Pathways

This section examines how heavy metals accumulate in aquatic organisms and subsequently enter the human food chain. The bioaccumulation of heavy metals is a critical environmental issue that presents significant risks to both ecological systems and human health. This process involves the gradual buildup of toxic metals, such as lead, cadmium, mercury, and arsenic, within the tissues of living organisms over time. Understanding the pathways through which these metals bioaccumulate is essential for assessing their impact on health and the environment.

Heavy metals primarily enter ecosystems through anthropogenic activities. Industrial discharges are a major contributor, as factories often release effluents containing heavy metals into nearby water bodies. Studies have shown, for example, that industrial sites can significantly elevate metal concentrations in local waterways, thereby impacting aquatic life. Agricultural practices also play a role; fertilizers and pesticides containing heavy metals can leach into soil and water systems during rainfall, introducing these toxins into the food chain. Furthermore, urban runoff exacerbates the problem, as stormwater can transport contaminants from streets and industrial areas into rivers and lakes. Mining operations are another significant source of heavy metal pollution, as they can release metals into the environment during the extraction and processing of minerals.

Once present in the environment, heavy metals can be taken up by organisms through various mechanisms. Aquatic organisms, such as fish and invertebrates, absorb dissolved heavy metals directly from contaminated water through their gills or skin. This direct uptake is particularly concerning because it allows for immediate exposure to toxic substances. Benthic organisms—those that live on or in sediments—can accumulate heavy metals by ingesting contaminated sediments or by absorbing them from pore water. This means that even organisms not directly exposed to polluted water can still be affected by sediment contamination.

The pathways of bioaccumulation are not limited to aquatic environments; terrestrial organisms face similar risks. For instance, herbivores may consume plants that have absorbed heavy metals from contaminated soil or water. This leads to a process known as biomagnification, where the concentrations of heavy metals increase at higher trophic levels as predators consume contaminated prey. For example, a small fish may accumulate mercury from its diet of contaminated plankton, and when a larger fish consumes several of these smaller fish, the mercury concentration in its body increases significantly.

The accumulation of heavy metals occurs in various tissues of living organisms. Organs such as the liver and kidneys are particularly susceptible to high concentrations due to their roles in detoxification and excretion. In fish, muscle tissue often shows significant levels of heavy metals, which raises concerns about the human consumption of contaminated seafood. Furthermore, certain metals like lead and cadmium can be deposited in bone tissue, leading to long-term health effects even after the exposure has ceased.

The health implications of bioaccumulation are profound and varied. Exposure to heavy metals can lead to neurological disorders; for example, lead is a known neurotoxin that can impair cognitive functions and neurological development in children. Cadmium exposure is linked to renal dysfunction and damage, while some heavy metals like arsenic and chromium have been classified as carcinogens that increase cancer risk upon prolonged exposure. To mitigate the risks associated with the bioaccumulation of heavy metals, several strategies can be implemented. Regular monitoring of water quality is essential to identify contamination levels and their sources. Strict regulations on industrial discharges can help reduce the introduction of heavy metals into ecosystems. Phytoremediation—the use of plants that can absorb heavy metals from contaminated soil—has emerged as a promising remediation technique. Additionally, public awareness campaigns are crucial for educating communities about the risks associated with consuming contaminated water or food sources.

Health Outcomes

This section assesses the correlation between exposure levels and health impacts within the community. Heavy metal poisoning is a significant public health concern that can lead to a variety of adverse health outcomes. The effects of exposure to heavy metals such as lead, mercury, arsenic, and cadmium are complex and vary depending on several factors, including the type of metal, the duration and level of exposure, and individual susceptibility.

One of the most well-documented health outcomes of heavy metal poisoning is neurological damage. Lead exposure, particularly in children, has been linked to cognitive deficits and behavioral problems. Research indicates that even low levels of lead can negatively impact a child's intelligence quotient (IQ) and increase the likelihood of attention deficit hyperactivity disorder (ADHD). The neurotoxic effects of lead are attributed to its ability to interfere with neurotransmitter release and neuronal development, leading to long-term cognitive impairments.

Mercury is another heavy metal associated with severe health consequences. It exists in various forms—elemental, inorganic, and organic—and each form has distinct toxicological profiles. It can cause symptoms ranging from sensory impairment to severe neurological disorders. In cases of acute mercury poisoning, individuals may experience gastrointestinal disturbances, respiratory issues, and neurological symptoms such as tremors and memory loss. Additionally, chronic exposure can lead to kidney damage and an increased risk of cardiovascular diseases.

Arsenic exposure is also a critical public health issue, particularly in regions where groundwater is contaminated. Chronic arsenic poisoning can result in skin lesions, peripheral neuropathy, and an increased risk of cancers, particularly skin, bladder, and lung cancers. The carcinogenic effects of arsenic are linked to its ability to induce oxidative stress and disrupt cellular processes. Furthermore, studies have shown that arsenic exposure during pregnancy can adversely affect fetal development and lead to long-term health issues for children.

Cadmium is another heavy metal that poses serious health risks, primarily affecting the kidneys and bones. Chronic exposure can lead to renal dysfunction and osteoporosis. Cadmium accumulates in the body over time and can cause a range of symptoms including nausea, vomiting, diarrhea, and abdominal pain in acute cases. Long-term exposure has been associated with increased risks of lung cancer and cardiovascular diseases. The pathways through which these heavy metals exert their toxic effects often involve complex biochemical interactions. Heavy metals can disrupt normal cellular functions by generating reactive oxygen species (ROS), leading to oxidative stress that damages cellular components such as DNA, proteins, and lipids.

CHAPTER THREE: METHODOLOGY

This study utilized a descriptive cross-sectional design, a methodology well-suited for evaluating the prevailing levels of heavy metal contamination within the water sources of the Gaidau Community at a specific moment in time. This design facilitates the concurrent collection and analysis of data from a diverse range of water sources, thereby providing a comprehensive snapshot of the contamination landscape. Such an approach is highly appropriate for determining the prevalence of heavy metals in the community's water supply and for assessing the potential associated health risks.

The target population for this research comprised all water sources designated for drinking and other domestic uses within the Gaidau Community. This scope included water from boreholes, residential local wells, streams, and any additional water sources that were identified during the preliminary field survey. The sample size was determined to include all identifiable and accessible water sources within the community. Following the Taro Yamane formula, the calculated sample size was approximately seven water sources from a total population of ten water sources, which ensures a 95% confidence interval for the findings.

A comprehensive sampling approach was implemented, where water samples were collected from every available source. This process involved random sampling to ensure that the selected samples were representative of the different types of water sources in the community (e.g., wells, boreholes, streams). A purposive sampling technique was also selected for this study. This method entails the deliberate selection of specific water sources that are most likely to yield pertinent and thorough data regarding heavy metal contamination. The decision to use purposive sampling was made to guarantee that all categories of water sources utilized by the community—such as wells, boreholes, and streams—were sufficiently represented within the final sample. This strategy permits a more focused assessment of heavy metal contamination, concentrating on those sources that are crucial for daily consumption and are most predisposed to contamination based on their patterns of use and surrounding environmental factors.

Data analysis was conducted using the IBM SPSS statistical software package (version 25.0), and the analytical process incorporated both descriptive and inferential statistical techniques. The concentration of each heavy metal in the water samples was reported as mean values. To ascertain if there were statistically significant differences in contamination levels among the various types of water sources, inferential statistics, specifically ANOVA (Analysis of Variance), were employed.

Ethical considerations were paramount throughout this study. This included a commitment to maintaining the confidentiality and privacy of the community's residents and their water sources. Prior to the commencement of the study, verbal informed consent was secured from the community leaders. Furthermore, considerable care was exercised to minimize any potential adverse environmental effects during the sample collection phase, and all research findings were reported with complete objectivity to the relevant stakeholders, irrespective of the nature of the outcomes.

CHAPTER FOUR: RESULTS

Heavy Metal Concentrations in Domestic Water Samples

Table 1 details the measured concentrations of heavy metals in samples taken from boreholes, wells, and streams. The data reveal a clear and consistent pattern: for Cadmium, Copper, Nickel, Iron, and Zinc, the highest concentrations were recorded in streams, followed by wells, with the lowest levels of contamination found in boreholes.

Table 1: Heavy metal Concentrations in domestic water samples.

Heavy Metals	Boreholes (mg/L)	Wells (mg/L)	Streams (mg/L)
Cadmium (Cd)	0.02 ± 0.01	0.03 ± 0.01	0.04 ± 0.01
Copper (Cu)	0.14 ± 0.04	0.17 ± 0.05	0.23 ± 0.06
Nickel (Ni)	0.21 ± 0.06	0.26 ± 0.08	0.34 ± 0.09
Iron (Fe)	1.05 ± 0.25	1.38 ± 0.31	1.83 ± 0.40
Zinc (Zn)	0.58 ± 0.15	0.72 ± 0.18	0.95 ± 0.24

NB: mg/L = Milligram/Liter

The Exposure Rate of Heavy Metals within the Water Source (WS) Served Population in Gaidau Community

Table 2 presents the data for a single sample from each of the designated water sources (WS) in the Gaidau community, reflecting the concentrations of heavy metals in the drinking water. The table includes the minimum, maximum, and average exposure rate values calculated across all sampled water sources.

Table 2: The exposure rate of heavy metal within the Water Source (WS) served population in Gaidau Community

	Estimated exposure rate (mg/1,000p/day				
Water Source (WS)	**Cu (mg/L) ±**	**Cd (mg/L) ±**	**Ni (mg/L) ±**	**Zn (mg/L) ±**	**Fe (mg/L) ±**
WS1	8.50 ± 0.5	10.25 ± 0.3	70.00 ± 1.0	20.50 ± 0.5	450.00 ± 5.0
WS2	15.00 ± 0.4	18.30 ± 0.2	85.00 ± 1.5	30.00 ± 0.6	600.00 ± 10.0
WS3	45.00 ± 1.0	35.00 ± 0.5	200.00 ± 2.0	90.00 ± 1.0	1,200.00 ± 15.0
WS4	25.00 ± 0.6	15.00 ± 0.4	150.00 ± 1.5	50.00 ± 0.7	800.00 ± 12.0
WS5	60.00 ± 1.5	50.00 ± 0.8	300.00 ± 3.0	110.00 ± 1.5	2,000.00 ± 20.0
WS6	90.00 ± 1.0	40.00 ± 0.5	400.00 ± 4.0	150.00 ± 2.0	3,500.00 ± 25.0
WS7	120.00 ± 2.0	60.00 ± 1.0	500.00 ± 5.0	200.00 ± 3.0	4,800.00 ± 30.0
WS8	35.00 ± 0.7	20.00 ± 0.3	250.00 ± 2.5	80.00 ± 1.0	1,500.00 ± 15.0
Min.	8.50 ± 0.5	10.25 ± 0.3	70.00 ± 1.0	20.50 ± 0.5	450.00 ± 5.0
Max.	120.00 ± 2.0	60.00 ± 1.0	500.00 ± 5.0	200.00 ± 3.0	4,800.00 ± 30.0
Average	49.38 ± 1.0	31.79 ± 0.5	247.50 ± 2.0	73.44 ± 1.0	1,429.17 ± 15.0

Key: WS = water source, Cu = Copper, Cd = Cadmium, Ni = Nickel, Zn = Zinc, Fe = Iron, Min. = Minimum and Max. = Maximum.

CHAPTER FIVE: DISCUSSION

The analysis of heavy metal concentrations in domestic water samples from the Gaidau Community, as detailed in Table 1, indicates a troubling pattern of contamination. A consistent finding was that the most elevated concentrations of heavy metals were present in streams, followed by wells, and finally boreholes. To illustrate, cadmium (Cd) concentrations measured mg/L in boreholes, mg/L in wells, and reached mg/L in streams. This graduated increase suggests that surface water bodies like streams are significantly more vulnerable to cadmium pollution, a phenomenon likely attributable to surface runoff and direct pollution. This observation is congruent with research by Adesuyi et al. (2021), which similarly emphasized that surface water systems often exhibit higher levels of contamination due to their direct exposure to pollutants. Another study posited that industrial activity is the dominant factor responsible for the presence of heavy metals in household water, thereby heightening the community's risk of exposure through various channels, including air and water pollution, contaminated food, and occupational hazards.

A parallel trend was observed for copper (Cu), with levels recorded at mg/L in boreholes, mg/L in wells, and mg/L in streams, suggesting that factors such as agricultural runoff, industrial effluent, or the natural erosion of copper-bearing minerals may be contributing to the higher concentrations found in surface water. This aligns with the findings of Belle et al. (2023), who noted that extensive contamination by heavy metals like Cu, Fe, and Zn surpassed aquatic guideline limits and that pollution sources in their study area were anthropogenic, including legacy and active mining operations, agricultural activities, and wastewater discharges. According to Yang et al. (2022), high Cu concentrations were mainly observed in areas with intensive transportation and commercial activities, with pollution sources ordered as follows: industrial (31.08%), traffic (26.80%), coal-fired (23.31%), and natural (18.81%). Furthermore, Farhang (2020) pointed out that inadequate maintenance of pipe infrastructure can lead to its degradation, causing the release of metals such as copper and lead into the water distribution system, which then contaminates household water samples.

In this study, Nickel (Ni) displayed a comparable distribution, with concentrations of mg/L in boreholes, mg/L in wells, and mg/L in streams, all of which exceed the permissible limit. This finding is consistent with the work of Antoniadis et al. (2019), who reported that excessive amounts of Ni beyond the permissible limits in water (0.02mg/L) and soil (35mg/kg) cause toxicity in living organisms. According to research by Dusabe (2023), nickel contamination is frequently higher in surface water as a result of industrial effluents and urban runoff. A high intake of Ni can inflict serious harm on human health, including allergic reactions, cancer, and diminished lung function. Consequently, elevated concentrations of Ni in drinking water and soil, or its entry into the food chain through plant uptake, represent a significant health menace for both humans and animals, and jeopardize the ecological sustainability of the global ecosystem.

Iron (Fe) concentrations were markedly higher, with values of mg/L in boreholes, mg/L in wells, and mg/L in streams. Considering iron's natural abundance in the Earth's crust, its elevated presence in streams is likely a result of both natural geological processes and anthropogenic influences, such as industrial discharges and soil leaching. This finding, however, is contradicted by the work of El-Battrawy et al. (2022), who reported low iron levels (0.058mg/L) in surface waters affected by both natural and human activities.

Zinc (Zn) concentrations were measured at mg/L in boreholes, mg/L in wells, and mg/L in streams. While zinc is an essential micronutrient, its increased levels in streams point to potential pollution from industrial and domestic waste. This observation is in agreement with a study by Kumar et al. (2023) that reported significant stream contamination with Zn, finding elevated levels in surface waters due to industrial discharge and improper waste management. However, other contributing factors, such as soil erosion, urban runoff, or aerosol deposition, could also influence its prevalence.

Table 2 offers an estimation of the heavy metal exposure rates for the population dependent on various water sources within the Gaidau Community, which is vital for assessing potential health risks. For Cu, the exposure rate varied widely, from a low of mg/1,000p/day (WS1) to a high of mg/1,000p/day (WS7), demonstrating significant variability in copper contamination across the sources. The exposure rates for Cd ranged from mg/1,000p/day (WS1) to mg/1,000p/day (WS7). Given cadmium's extreme toxicity even at low concentrations, these figures are particularly alarming and indicative of serious contamination problems.

The Ni exposure rate spanned from mg/1,000p/day (WS1) to mg/1,000p/day (WS7). High levels of nickel exposure can precipitate a range of health conditions, including skin dermatitis and respiratory ailments. Similarly, Zn exposure rates fluctuated from mg/1,000p/day (WS1) to mg/1,000p/day (WS7); while zinc is essential in trace amounts, excessive intake can lead to health issues like stomach cramps and nausea. The exposure rates for Fe were the highest among all the metals analyzed, ranging from mg/1,000p/day (WS1) to a substantial mg/1,000p/day (WS7). Although Fe is crucial for bodily functions, an excessive intake can lead to conditions like hemochromatosis. The average exposure rates, such as mg/1,000p/day for Cu and mg/1,000p/day for Cd, underscore the overall risk level facing the community, reinforcing the urgent need for comprehensive intervention and remediation strategies. The World Health Organization (2023) has stated that long-term exposure to heavy metals, even at low concentrations, can result in severe health problems, which further validates the urgency of addressing these contamination issues in the Gaidau Community.

CHAPTER SIX: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

This research, centered in the Gaidau Community of Sokoto, Nigeria, has brought to light significant environmental and public health issues stemming from heavy metal contamination in domestic water sources. The study concentrated on quantifying the concentrations of cadmium (Cd), copper (Cu), nickel (Ni), iron (Fe), and zinc (Zn) in water specimens gathered from boreholes, wells, and streams. The results consistently show that streams harbor the highest concentrations of these heavy metals, followed in descending order by wells and then boreholes. This pattern strongly suggests that surface water systems are more susceptible to contamination, a vulnerability likely driven by surface runoff and direct pollution.

Cadmium levels were determined to be mg/L in boreholes, mg/L in wells, and mg/L in streams. These concentrations are substantially higher than the WHO's guideline value of 0.003 mg/L, indicating a severe health risk. Copper levels, measured at mg/L in boreholes, mg/L in wells, and mg/L in streams, fell within the WHO's limit of 2.0 mg/L, yet they still signal potential risks associated with long-term exposure. Nickel concentrations were found to be mg/L, mg/L, and mg/L in boreholes, wells, and streams, respectively; all these values exceed the WHO limit of 0.07 mg/L, raising significant health concerns. Iron levels were recorded at mg/L in boreholes, mg/L in wells, and mg/L in streams, figures that are considerably above the WHO standard of 0.3 mg/L and necessitate urgent remedial action. Zinc concentrations, while remaining below the WHO's 3.0 mg/L limit, were observed at mg/L, mg/L, and mg/L in boreholes, wells, and streams, respectively, which points to potential health risks over prolonged periods of exposure.

The calculated exposure rates for the population relying on these water sources reveal considerable variation, with copper exposure rates spanning from mg/1000p/day to mg/1000p/day, and cadmium exposure rates fluctuating between mg/1000p/day and mg/1000p/day. Considering cadmium's high toxicity, even at minimal concentrations, these figures are alarming and point to critical contamination issues. Nickel exposure ranged from mg/1000p/day to mg/1000p/day, a concerning finding given nickel's known adverse health effects. Similarly, the exposure rates for zinc and iron varied significantly, with iron exposure being the most pronounced among the metals tested, a fact that underscores the need for immediate intervention.

Conclusion

The investigation into heavy metal concentrations within the domestic water samples from the Gaidau Community has uncovered a substantial environmental and public health problem. A clear and consistent trend emerged, with the highest levels of heavy metal contamination found in streams, followed by wells, and then boreholes, indicating a heightened vulnerability of surface water sources to pollution. This pattern was observed across all tested heavy metals, including cadmium, copper, nickel, iron, and zinc, which speaks to the widespread and pervasive nature of the contamination issue.

Recommendation

Given the elevated concentrations of heavy metals identified in this study, it is strongly recommended that the surface water from streams in the Gaidau Community not be used for drinking or any other domestic purposes unless it undergoes thorough and effective treatment beforehand. As these water resources are currently being used for washing, drinking, cooking, and agricultural irrigation, it is imperative that regular monitoring of wells and boreholes, along with comprehensive quality control of all other drinking water sources, be implemented and maintained.

Limitations of the Study

Several limitations should be considered when interpreting the findings of this research. First, the geographical focus was confined to the Gaidau Community, which curtails the ability to generalize these results to other regions that may have different environmental contexts and pollution sources. This localized scope implies that the findings might not be representative of the broader situation in Sokoto State or Nigeria as a whole. Second, the investigation centered on a specific set of heavy metals (lead, mercury, cadmium, and arsenic), and did not extend to other potential contaminants such as organic pollutants or microbial pathogens. This constrained focus may have left other water-quality-related health risks unassessed.

Furthermore, the description of the sampling methodology could benefit from more detail regarding the number of samples and their distribution over time. A limited sampling strategy may not fully capture the dynamic variations in contamination levels that can occur due to seasonal shifts or differing patterns of water use. Moreover, while the study successfully identified contamination levels, it did not include a direct health impact assessment to determine how these heavy metals are specifically affecting the health of the residents. Establishing a clear correlation between exposure levels and specific health outcomes would necessitate additional, more targeted research. Finally, the study's six-month duration may not have been adequate to account for long-term trends or seasonal fluctuations in contamination, potentially resulting in an incomplete picture of heavy metal exposure over time.

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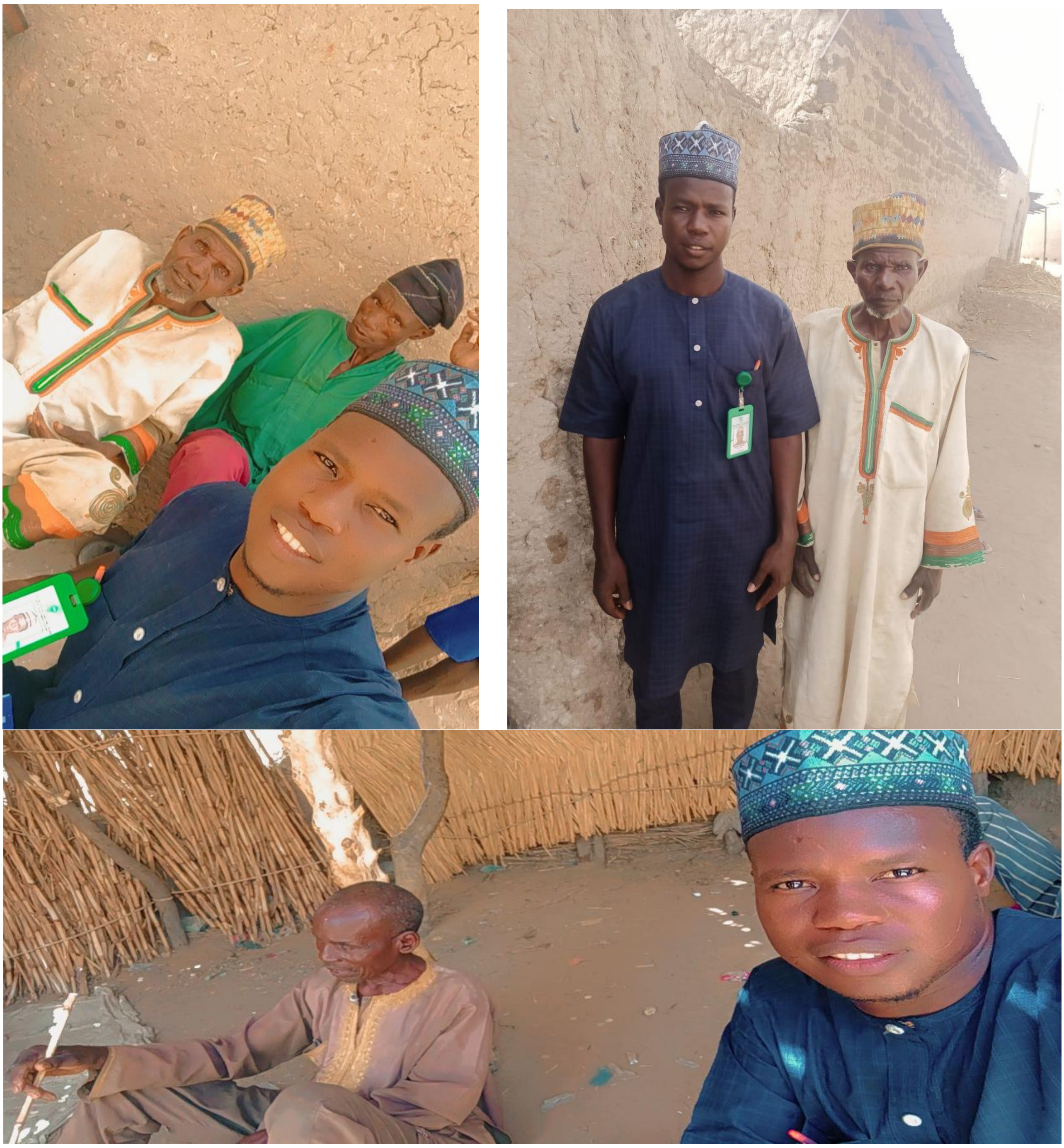
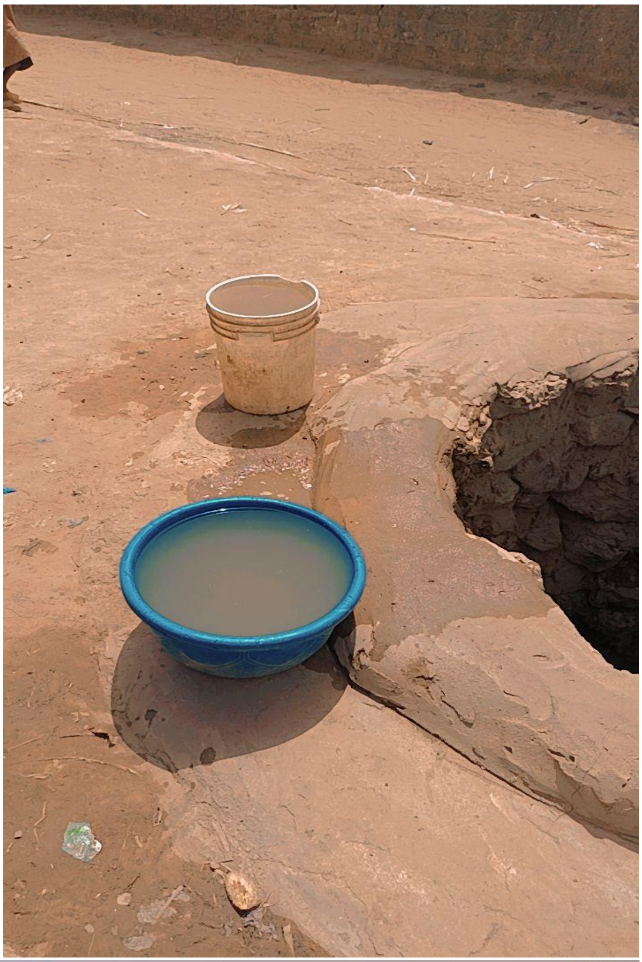
APPENDIX I: Advocacy Visit and Consent declaration



Requesting consent from Mai Gari Gaidau, the district head of Gaidau Community and his Council during Sample Collection at Gaidau Community of Gidan Katta ward of Illela LGA Sokoto State.

APPENDIIX II: Gaidau Community Domestic Water



APPENDIX III: Community Engagement

Awareness and sensitization to major stakeholders in Gaidau Community that include Health Personnel from Gaidau Health Post and the Head Master and his staff from Gaidau Primary School.