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NATIONAL SCIENTIFIC STUDENT ASSOCIATION CONFERENCE (OTDK) THESIS

**Comprehensive Analysis of Groundwater Quality and Its Role in Chronic Kidney Disease of
Unknown Etiology (CKDu) in Gashua, Northeastern Nigeria**

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Declaration of authenticity

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Abstract

Groundwater quality in Gashua, Northeastern Nigeria, is of critical concern due to its role as the primary source of drinking water and its potential link to environmental contamination. This study offers a comprehensive hydrogeological assessment by integrating field surveys, GIS spatial analysis, borehole data, and existing groundwater chemistry results, focusing on heavy metals contamination which may contribute to the rise in Chronic Kidney Disease of unknown etiology (CKDu). A total of 25 groundwater chemistry results were statistically studied, revealing low pH, TDS, and ion levels (Ca, Mg, Cl) within the Nigerian Standard for Drinking Water Quality (NSDWQ), suggesting minimal geogenic contamination. However, heavy metals were above permissible limits: arsenic (As) ranged from 0.01 to 0.88 mg/l (NSDWQ limit: 0.01 mg/l), cadmium (Cd) 0.01-0.13 mg/l (limit: 0.003 mg/l), and mercury (Hg) 0.01-0.05 mg/l (limit: 0.006 mg/l). Hydrogeological studies showed contaminants move northward, likely from agricultural and waste disposal activities in the south. GIS mapping confirmed high contamination in southern areas. Urgent measures such as groundwater monitoring, waste management, and water treatment systems are needed to mitigate CKD risks.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Groundwater is the most preferred and effective source of water for domestic and agricultural uses. It is an essential resource for man's survival and is imperative for public health (Ravindra et al., 2023). Statistically, groundwater constitutes 97% of the global freshwater and is a major drinking water source and a critical resort for water resources for domestic and public use in Sub-Saharan Africa (Babiker, 2004; Xu et al., 2019). Groundwater occurs everywhere but sometimes its availability in economic quantity depends solely on the distribution of the subsurface geologic units that are referred to as the aquifers (Akpan et al., 2013). This suggests that in areas where groundwater is not potentially abundant enough, growing industrial and residential demands may result in either a total deficiency or an adequate supply. According to the (WHO - World Health Organization, 2013), about 1.1 billion people lack access to the drinking water supply. In most cities, town and villages in Nigeria, valuable man power are spent on seeking and fetching water which lacks regular quality assessment (Addo et al., 2009). Groundwater serves as a cheaper source of domestic water supply that includes natural springs, wells and boreholes. Groundwater that is accessible in an aquifer and may be drawn to users by installing pumps is known as borehole water. The primary challenges associated with boreholes stem from the chemical composition of groundwater. It is essential to conduct a comprehensive analysis of the dissolved constituents to determine whether they fall within permissible limits for safe human consumption, as defined by regulatory standards (Auwal & Kwaya, 2022).

Chronic kidney disease of unknown etiology (CKDu) has been increasingly reported in Gashua, with recent studies suggesting a possible link to environmental factors, including groundwater contamination. CKD is a condition characterized by impaired kidney function, which can lead to the accumulation of waste products in the body (Elendu et al., 2023). While CKD can have multiple causes, in regions like Gashua, where access to safe drinking water is limited, groundwater contamination by nephrotoxic substances, such as heavy metals, is suspected to be a contributing factor (Amshi et al., 2020). A study at the University of Maiduguri Teaching Hospital (UMTH) revealed that approximately 15% of the hospital's patients from surrounding regions suffer from kidney disease, with a significant number coming from Gashua (Musa et al., 2019). This raises concerns about the safety of

groundwater as the primary drinking water source in the area and highlights the need for a detailed hydrogeological investigation to assess potential contaminants. Given the high prevalence of CKDu and the known nephrotoxicity of heavy metals, it is imperative to explore the relationship between groundwater quality and public health in Gashua.

Hence, this thesis aims to investigate the geology and hydrogeology of Gashua by uniquely employing Geographic Information System (GIS) mapping and groundwater flow analysis to trace and identify sources of heavy metal contamination, while critically analyzing existing water chemistry data, with a specific focus on the potential contribution of heavy metals in groundwater to CKDu prevalence. Despite growing concern over the rising mortality rates from CKDu in the region, little is known about the extent of groundwater contamination and how local hydrogeological factors may influence the mobilization and concentration of contaminants. Given that groundwater is the primary source of drinking water, this study is crucial to understanding the safety of Gashua's water supply and determining whether hydrogeological conditions contribute to the elevated CKDu cases.

1.2 Statement of the Problem

Chronic Kidney Disease of Unknown Etiology (CKDu) is an escalating health crisis in Gashua, Northeastern Nigeria, where residents heavily depend on groundwater for drinking and agricultural needs. The rising prevalence of CKDu suggests a potential link to environmental factors, specifically groundwater contamination by nephrotoxic heavy metals. However, there is a lack of comprehensive research directly assessing groundwater quality and its impact on CKDu in this region. Gashua's geology and widespread anthropogenic activities, including agriculture and waste disposal, likely exacerbate groundwater contamination, posing significant risks to public health. This study seeks to fill this critical knowledge gap by evaluating groundwater quality, mapping contamination sources using GIS, and assessing the health implications of these contaminants on CKDu prevalence, providing a basis for targeted interventions to protect community health.

1.3 Aim and Objectives

The aim of this study is to investigate the quality of groundwater in Gashua, Northeastern Nigeria, and assess its potential role in the prevalence of Chronic Kidney Disease of Unknown Etiology (CKDu), with a focus on heavy metal contamination and its spatial distribution, with the objectives of:

1. Evaluating the physicochemical and heavy metal concentrations in groundwater samples from various locations in Gashua.
2. Identifying and map the spatial distribution of heavy metal contaminants, such as arsenic, cadmium, and mercury, using Geographic Information System (GIS) techniques.
3. Analyzing groundwater flow patterns in Gashua and determine how they may contribute to the transport and spread of contaminants.
4. Assessing the potential health risks associated with the consumption of contaminated groundwater and its link to CKDu prevalence in the region.
5. Recommending appropriate strategies for improving groundwater quality management and mitigating CKDu risks in Gashua.

1.4 Location, Climate, Vegetation and Accessibility

Gashua is a major and well-developed town in Yobe State. Since 1976, it has served as the headquarters of the Bade Local Government Area. It has an estimated landmass of about 50 km² with an estimated population of about 125,817 (NPC, 2006). It lies between Latitude 11°01'N to 11°04'N and Longitude 12°50'E to 12°54'E (Fig 1). The area lies close to the convergence of Hadeija and Jama'are rivers in the Chad Basin. The Chad Basin extends to Niger Republic, Chad and Cameroon. The Basin belongs to the West Africa rift subsystem and it has three water bearing horizons which are; the upper, middle and the lower zones (Agada et al., 2022). Temperatures are high throughout the year; the mean maximum temperature is 45°C and the mean minimum temperature is 25°C. The annual rainfall varies from 500 to 1000 mm. Indeed, there are two main seasons – the rainy season starts in June and ends in September while the dry season is from October to May (Nwankwoala, 2012). The area was accessible via a major road linking Gashua to other parts of Yobe State, several minor roads, and various footpaths.

1.5 Scope and Limitation of the Study

This study focuses on assessing the quality of groundwater in Gashua, Northeastern Nigeria, to understand its potential link to the prevalence of Chronic Kidney Disease of Unknown Etiology (CKDu). The research encompasses the collection and analysis of groundwater chemistry data from multiple boreholes across Gashua, targeting both physicochemical properties and heavy metal contaminants. Geographic Information System (GIS) mapping will be used to identify contamination sources and visualize the spatial distribution of these heavy metals. Additionally, groundwater flow modeling will be conducted to understand

contaminant transport patterns, with the goal of evaluating the potential health risks posed by contaminated groundwater.

This study has several limitations. The spatial distribution of boreholes is limited, which may not fully capture localized variations in groundwater contamination across Gashua. Sampling is restricted to a single period, which could overlook seasonal variations that may impact contaminant levels. The reliance on secondary data for groundwater flow modeling and contamination sources introduces potential uncertainties in interpreting contaminant movement. Finally, while this study assesses the link between groundwater contamination and CKDu, the complex etiology of CKDu suggests that other environmental and physiological factors may also play a role, and these are beyond the scope of this research.

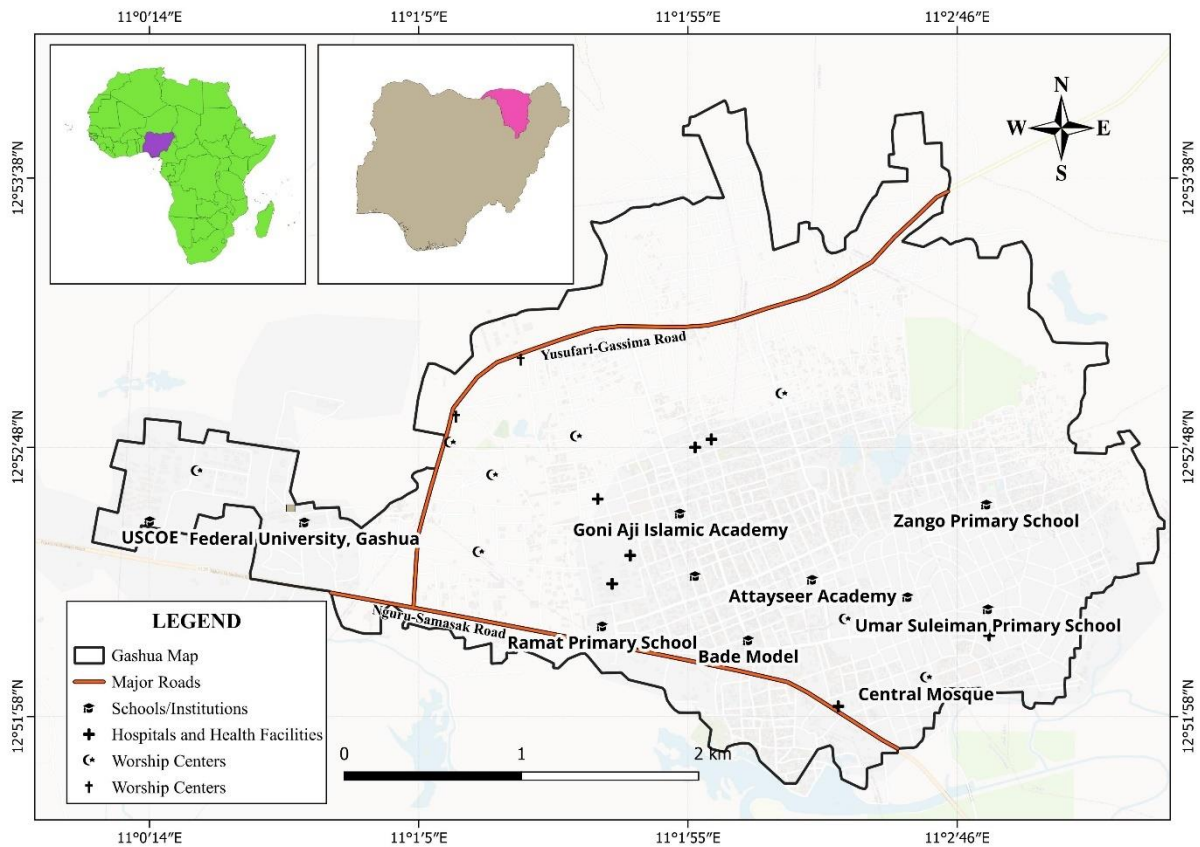


Figure 1: Location map of Gashua in Nigeria and Africa

CHAPTER TWO

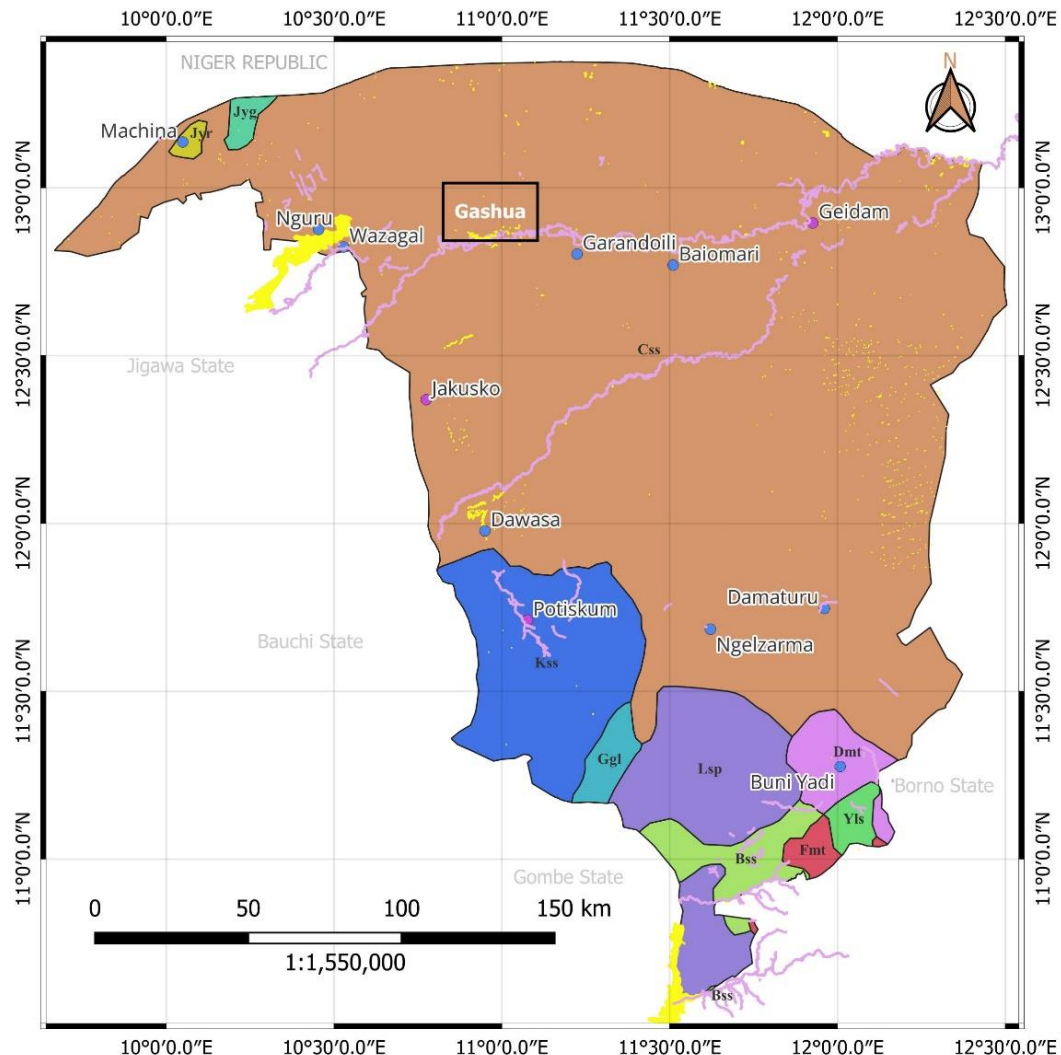
2.0 LITERATURE REVIEW

2.1 Geology of the Study Area

Gashua is located within the Chad Basin, a large inland sedimentary basin that spans five countries in Africa: Chad, Nigeria, Cameroon, the Central African Republic, and Niger. The Chad Basin lies between latitudes 11°N and 14°N and longitudes 9°E and 14°E, covering parts of Borno, Yobe, and Jigawa States in Nigeria (Obaje, 2009). Approximately 10% of the basin is located in the northeastern part of Nigeria (Obaje, 2009). The basin originated due to plate divergence along the West African continental margin which involved multiple geological processes, including regional thermal doming, volcanism, rifting, oceanic crust formation, and subsequent marine transgressions that widened and deepened the basin (Yikarebogha et al., 2013). Sedimentation in the Chad basin started in Albian times, the basal sedimentary sequence is the Bima sandstone, which was deposited unconformably over the Precambrian crystalline basement rock (Yikarebogha et al., 2013). Deposition of the Bima sandstone continued up to the Cenomanian. The Turonian was characterized by extensive transgression during which the Gongila Formation was deposited as a transitional sea deposit. The Fika shale was deposited during the transgression which began in the Turonian and continued up to the Senonian period (Matheis, 1986). Towards the end of the Cretaceous, during the Maastrichtian time, an estuarine deltaic environment prevailed in the basin and the Gombe sandstone, shale and limestone were deposited (Yikarebogha et al., 2013). The Keri-Keri Formation was deposited unconformably on the eroded surface of the Gombe sandstone in the Pleistocene (Matheis, 1986). An unconformable Pleistocene deposit of the Chad formation was deposited on the Keri-Keri Formation (Matheis, 1976). According to Boboye (2011), the Keri-Keri formation is Eocene in age.

Gashua lies within the Chad Formation which is primarily composed of recent sediments from the Quaternary period and is characterized by fine sand and clay deposits (Fig. 2). The Chad formation stretches over a wide area in Northeastern Nigeria in Yobe, Borno and parts of Niger Republic. The genesis of the Chad Formation as sedimentary deposits involved accumulation of sand, silt and clay moved by winds and rivers especially from lake Chad that had begun to retreat (Moussa et al., 2016). Because it is composed mostly of sand and clay, groundwater here tends to be stored in unconfined shallow aquifers which are highly vulnerable to contamination through surface sources like agricultural run-offs or waste disposal (Nowicki et al., 2023). In general, this formation's sandy layers are quite permeable

allowing for an easy movement of groundwater. But when there is clay present, they might act confining layers resulting into a storage within some strata and influenced the direction and speed of groundwater flow.



DESCRIPTION

Css	Sand and clay	Chad Formation	RECENT SEDIMENTS
Fmt	Dense, massive and leucocratic basalt	Late Younger Granitoids	TERTIARY
Dmt	Fine grained vassicular leucocratic basalt	Keri-Keri Formation	
Kss	Grit, sandstone and clay	Gombe Formation	
Ggl	Clayeyshale and limestone	Pindiga Formation	CRETACEOUS
Lsp	Shale and limestone	Yolde Formation	
Yls	Shelly limestone	Bima Formation	
Bss	Feldspathic sandstone with layers of sandy clay	Younger Granitoids	JURASSIC
Jyg	Granite		
Jyr	Rhyolite		
●	Major cities		
—	Rivers		
—	Streams		

Figure 2: Geological map of Yobe State showing Gashua, modified after NGSA (2006)

2.2 Groundwater

Groundwater is the water that lies beneath the ground surface, filling the pore space between grains in bodies of sediment and elastic sedimentary rocks and filling cracks and cavity in all types of rocks in geologic formations known as aquifer (Fig 3). Observations have shown that a good deal of surplus rainfall runs-off over the surface of the ground while the other part of it infiltrates underground and becomes the groundwater responsible for the springs, lakes and wells (Oseji et al., 2006). Groundwater is often withdrawn for agricultural, municipal and industrial use by constructing and operating extraction wells. Groundwater is also widely used as a source for drinking supply and irrigation (UNESCO, 2004).

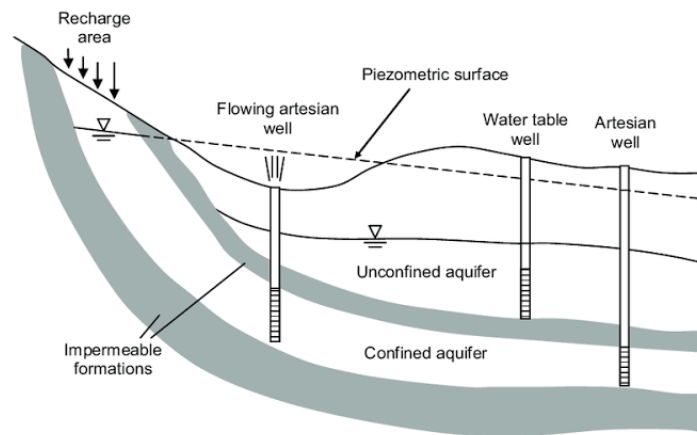


Figure 3: Groundwater recharge to aquifers (Chin & Qi, 2000)

2.2.1 Groundwater Occurrence

The principle source of borehole water/groundwater is meteoric water, juvenile water and connate water (Ojoawo & Adagunodo, 2023). Groundwater occurs in many geological formations. Nearly all rocks in the upper part of the earth's crust possess voids or pores filled with water or air; this is the vadoze/unsaturated zone. At greater depths, all empty voids are filled with water, this is the saturated zone, and hence groundwater refers only to the saturated zone below the water table. In consolidated rocks the only voids may be the fractures or fissures. The volume of water that will drain under gravity from initially saturated rock mass to the total volume of that rock is called the specific yield of that material. All water that occurs naturally beneath the earth's surface, including saturated and unsaturated zones is called sub-surface water (Pitot, 1996).

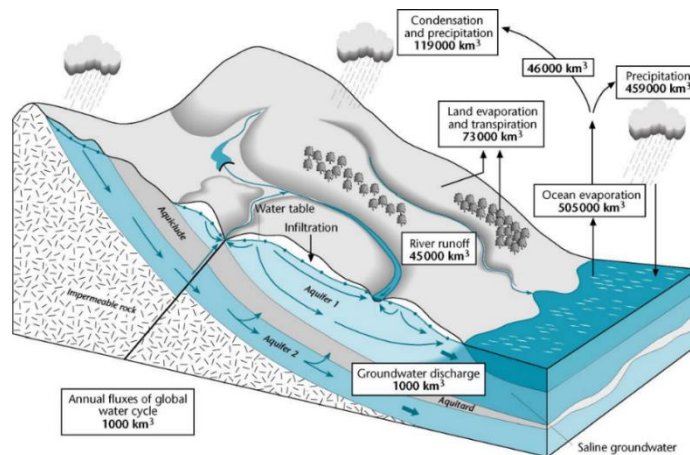


Figure 4: Groundwater occurrence from hydrologic cycle (CWP, 2005)

2.2.2 Groundwater Flow

Water aquifers are large in extent (1-10km) yet have variations in physical and chemical properties at small scales (1-100m). Transport of contaminants in soil is an important problem for different flow scales, from the fractured rocks to large underground aquifers (Galleani et al., 2011). The rate, residence time and direction of groundwater flow, the movement of micro-organisms, pathogenic bacteria and viruses depends on the size of the pores on reactions within media, on the amount of food available and on their life span which affects its quality (Cvetkovic, 2011). Deep, consolidated formations are characterized by slow groundwater movement, long residence times, ample opportunity for dissolution of minerals and therefore often poor natural water quality. These formations are confines under thick sequences of low permeability clays and are less vulnerable to anthropogenic influences (Pitot, 1996).

2.2.3 Surface Water-Groundwater interaction

Water can flow in both directions between unconfined aquifer and surface water bodies such as streams, rivers, lakes and wetlands. The level and nature of the interaction can change over distance and time. While the interaction between groundwater and surface water bodies cannot be directly measured, the effect can be seen in ecosystems that continue to thrive during dry seasons. Several estimation methods exist but the results can differ significantly (Winter, 2000). One specific class of inflow or outflow from groundwater systems results from surface water-groundwater interaction, wherein water may flow from aquifers into surface water bodies at seeps or springs, or infiltrate from rivers or lakes to the water table (Fig. 5). Alternatively, if the water table lies below the surface water body, the potential energy (hydraulic head) in the surface water body will be higher than in the groundwater system and water will percolate downward and/or through the stream banks, and flow to the

aquifer. In this configuration, the surface water body is said to be losing (i.e. a losing stream), because the stream or river discharge decreases downstream (Fig. 6). While the land surface and stream channel generally remain at the same elevation, the water table commonly fluctuates over time. As a result, it is common for stream to switch from gaining to losing – or vice-versa – due to major recharge events, seasonality in precipitation, & variations in pumping rates (Winter, 2000).

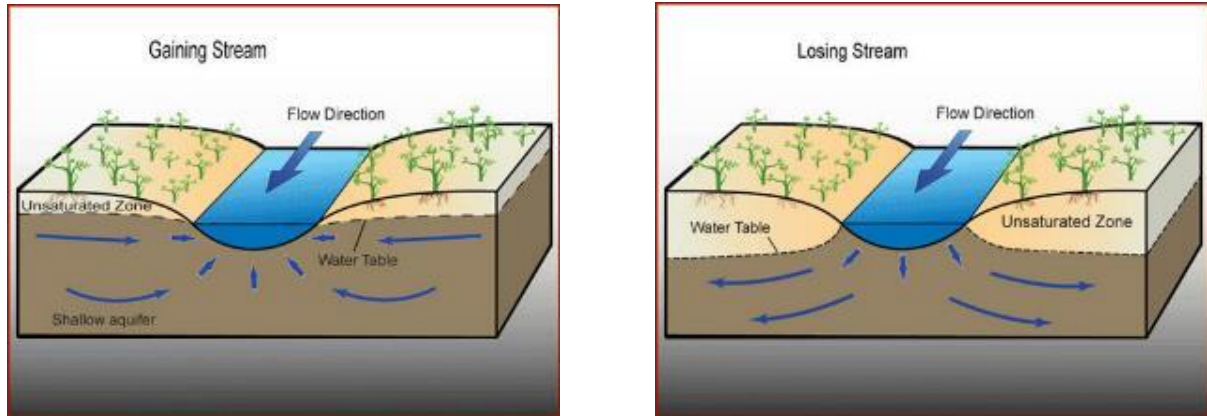


Figure 5: Stream losing water to the aquifer – influent (left) (Winter, 2000)

Figure 6: Groundwater discharging into the stream – effluent (right) (Winter, 2000)

2.3 Groundwater Quality

The quality of water is of vital concern for mankind since it is directly linked with human welfare. According to Agrawal (2010), the quality of public health depends to a greater extent on the quality of groundwater. Though groundwater quality is believed to be quite good compared to surface water, its quality is the sum of natural: geology of the environment and anthropogenic influences: withdrawal, land use change, and solid waste dumping (Pitot, 1996) Water quality parameters reflect the level of contamination in water resources and show whether water is suitable for human consumption. Contaminated water is unacceptable due to health effects, poor taste and aesthetic value to consumers (Morris et al., 2024).

2.3.1 The Water Quality Assessment Process

Water quality assessment refers to the total process of evaluating the physical, chemical, and biological characteristics of water, whereas water quality monitoring refers to the gathering of pertinent data. The practical guide by Bartram (1996) contains details on monitoring methods and approaches that can be used in the field.

2.3.2 Water Quality Assessment Needs

No assessment program should begin without a thorough examination of the true need for water quality data (i.e., the "need to know" as opposed to "good to know"). Because water

resources are often put to multiple competing beneficial purposes, the monitoring that is employed to gather data should match the data requirements of the various users involved (Calow et al., 2010).

As a result, depending on how many evaluation objectives must be satisfied, there are two types of monitoring programs:

- i. Single-objective monitoring, which can be set up to focus on a single issue.

pH, alkalinity, and a few cations for acid rain; nutrients and chlorophyll pigments for eutrophication; various nitrogenous compounds for nitrate pollution; or sodium, calcium, chloride, and a few other elements for irrigation.

- ii. Multi-objective monitoring which may cover various water uses and provide data for more than one assessment Programme, such as drinking water supply, industrial manufacturing, fisheries or aquatic life, thereby involving a large set of variables. The Commission of the European Communities has a list in excess of 100 micro-pollutants to be considered in drinking water alone.

Table 1: Relative abundance of dissolved constituents in groundwater

Major constituents (1.0 to 1000 mg l ⁻¹)	Secondary constituents (0.01 to 10.0 mg l ⁻¹)	Minor constituents (0.0001 to 0.1 mg l ⁻¹)
Sodium	Iron	Arsenic
Calcium	Aluminium	Barium
Magnesium	Potassium	Bromide
Bicarbonate	Carbonate	Cadmium
Sulphate	Nitrate	Chromium
Chloride	Fluoride	Cobalt
Silica		Copper
		Iodide
		Lead
		Lithium
		Manganese
		Nickel
		Phosphate
		Strontium
		Uranium
		Zinc

(Source: Todd (1980))

Table 2: Sources and concentrations of natural groundwater components

Components	Natural Sources	Concentration in Natural water
Dissolved solids	Mineral constituents dissolved in water	Usually < 5000 mg l ⁻¹ , but some brines contains as much as 300,000 mg l ⁻¹
Nitrate	Atmosphere, legumes, plant debris, animal excrement	Usually < 10 mg l ⁻¹
Sodium	Feldspars (albite), clay minerals, evaporates such as halite, NaCl, industrial wastes.	Generally < 200 mg l ⁻¹ , 10000 mg l ⁻¹ sea water, 25,000 mg l ⁻¹ in brines
Potassium	Feldspars (orthoclase, microcline), feldspathoids, some micas, clay minerals	Usually < 10 mg l ⁻¹ , but up to 100 mg l ⁻¹ in hot springs and 25,000 mg l ⁻¹ in brines
Calcium	Amphiboles, feldspars, gypsum, pyroxenes, dolomite, aragonite, calcite, clay minerals	Usually < 100 mg l ⁻¹ , but brines may contain up to 75,000 mg l ⁻¹
Magnesium	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals	Usually < 50 mg l ⁻¹ , about 1000 mg l ⁻¹ in ocean water, brines may 57,000 mg l ⁻¹
Carbonate	Limestone, dolomite	Usually < 10 mg l ⁻¹ , but can exceed 50 mg l ⁻¹ in water highly charged with sodium
Bicarbonate	Limestone, dolomite	Usually < 500 mg l ⁻¹ , but can exceed 1000 mg l ⁻¹ in water highly charged with CO ₂
Chloride	Sedimentary rock (evaporates), a little from igneous rocks	Usually < 10 mg l ⁻¹ in humid areas: up to 1000 mg l ⁻¹ in more arid regions:
Sulphate	Oxidation of sulphide ores, gypsum, anhydrite	approximately 19,300 mg l ⁻¹ I sea water and up to 200,000 mg l ⁻¹ in brines
Silica	Feldspars, ferromagnesian and clay minerals, amorphous silica, chert and opal	Usually < 300 mg l ⁻¹ , except in wells influenced by acid mine drainage: up to 200,000 mg l ⁻¹ in some brines.
Fluoride	Amphiboles(hornblende), apatite, fluorite, mica	Ranges from 1-30 mg l ⁻¹ but as much as 100 mg l ⁻¹ can occur ad concentrations may reach 4,000 mg l ⁻¹ in brines.
Iron	Igneous rocks: amphiboles, ferromagnesian micas, FeS, FeS ₂ and magnetite, Fe ₂ O ₃ . Sandstone rocks: oxides, carbonates, sulphides or iron clay minerals	Usually < 10 mg l ⁻¹ , but up to 1,600 mg l ⁻¹ in brines Usually < 0.5 mg l ⁻¹ in fully aerated water, groundwater withy pH < 8 can contain 10 mg l ⁻¹ ; Infrequently, 50 mg l ⁻¹ may be present
Manganese	Arises from soils and sediments. Metamorphic and sedimentary rocks and mica biotite and amphibole hornblende minerals contain large quantities of Mn	Usually < 0.2 mg l ⁻¹ contains > 10 mg l ⁻¹

(Source: Todd (1980))

2.3.3 Physical Characteristics of Groundwater

Physicochemical characteristics of ground water determine its quality and suitability for human consumption. All these characteristics have certain limit value established by NSDWQ (2007). Temperature of the water governs all other parameters in determining the quality status of the groundwater. pH is another important parameter of groundwater that decides its fitness for many households uses like drinking, cooking, washing, cleaning etc. the values of pH commonly range from 0 to 14. The value of pH determines the acidic, basic and neutral behavior of water. pH value less than 7 indicates the acidic water, while more than 7 indicates the water is basic. The exact 7 pH shows that water is neutral. The desirable limit of pH is 6.5-8.5 as per the standard. Different types of minerals present in water are represented by TDS. The quality of water is directly related to TDS. It is evaluated by TDS meter (Sonawane, 2020). As per the NSDWQ (2007) acceptable and permissible limit is 500 and 2000 mg/l. Total hardness equals the sum of calcium and magnesium hardness in water (Dohare et al., 2014). Hardness in underground water resources may be due to the natural salt accumulation or direct entry of polluted water (Todd, 1980).

2.3.4 Chemical Characteristics of Groundwater

Because groundwater is frequently associated with geological materials containing soluble minerals, larger dissolved salt concentrations are typically expected in groundwater compared to surface water. The geological environment, as well as the source and transport of water, influence the kind and concentration of salts. The following paragraphs describe the primary ways in which groundwater's natural properties affect water quality for various purposes. Groundwater is classified as meteoric, connate, or juvenile using a basic hydrochemical categorization. The most important type of groundwater is meteoric groundwater, which is produced by rainfall and infiltration within the regular hydrological cycle and subjected to hydro-chemical evolution. Groundwater's natural chemical quality is generally satisfactory, although high concentrations of a number of elements can pose difficulties with water consumption (Todd, 1980).

2.3.5 Measuring Groundwater Quality

The US Environmental Protection Agency (USEPA) and the American Public Health Association (APHA) have classified the criteria for private wells into the following categories: microbiological, inorganic (IOCs), secondary contaminants, volatile organic chemicals (VOCs), and synthetic organic chemicals (SOCs), and radio-nuclides, i.e., radioactive substances. The Nigeria Standard for Drinking Water Quality (NSDWQ) and

National Agency for Food and Drug Administration and Control (NAFDAC) have adopted the WHO water quality guidelines categorization. Microbiological (Total coliform, faecal coliform, and E coli) and physicochemical parameters may be included in drinking water (temperature, colour, and turbidity, and dissolved oxygen level, concentration of organic and inorganic compounds).

Table 3 shows the drinking water quality criteria established by the WHO in 2006 and the Nigeria Standards for Drinking Water Quality (NSDWQ) in 2007. These rules were put in place primarily to protect people's health. The rules, on the other hand, take into account the psychological influence and aesthetic aspect of drinking water, such as the objection of water due to colour or odour or turbidity.

Table 3: Drinking Water Quality Guidelines for the WHO, NAFDAC and NSDWQ

	WHO		NAFDAC	NSDWQ
	Highest Desirable	Maximum Permissible level		
Temperature (°C)	-	40	-	Ambient
Colour (TCU)	6	15	15	15
Turbidity (NTU)	5	25		5
pH	7.0-8.5	6.5-9.2	6.5-8.5	6.5-8.5
Total dissolved solids (mg/L)	500	1500	500	500
Iron (mg/l)	-	0.3	-	0.3
Chloride (mg/L)	-	250	-	250
Fluoride (mg/L)	-	1.5	-	1.5
Total hardness (mg/L)	-	500	-	500
Sulphate (mg/L)	-	100	-	100
Nitrate (mg/L)	-	50	-	50
Faecal coliform (per 100ml)	-	0	0	0
E.coli (per 100ml)	-	0	0	0
Total coliform count (per 100ml)	-	0	10	10

WHO (2006) - World Health Organization

NAFDAC (2008) - National Agency for Food and Drug Administration and

NSDWQ (2007) - Nigerian Standard for Drinking Water Quality

2.4 Groundwater Contamination and Public Health Implications

Groundwater contamination has become a significant concern worldwide, especially in arid and semi-arid regions where groundwater is the primary water source (WHO, 2013). Heavy metals such as arsenic, cadmium, and mercury have been identified as nephrotoxic agents, causing damage to kidney tissues with prolonged exposure (Järup, 2003). According to Cobbina et al. (2012), these metals can be introduced into groundwater through natural leaching from rocks or through anthropogenic activities such as agriculture and waste

disposal. The presence of these contaminants is particularly alarming in regions like Gashua, where agriculture and aquaculture practices often utilize chemical fertilizers and pesticides, leading to heavy metal accumulation in groundwater (Suleiman et al., 2021).

2.5 Heavy Metals and Chronic Kidney Disease

Research has shown a strong association between heavy metal exposure and the prevalence of CKD in various regions. Ma et al. (2023) discussed that cadmium, a known nephrotoxin, can cause irreversible damage to the kidneys by accumulating in the renal cortex over time. Furthermore, arsenic exposure is associated with oxidative stress and cellular damage, which compromise kidney function and elevate CKD risks (Mondal et al., 2010). Musa et al. (2019) found that individuals in Gashua and surrounding areas have a higher prevalence of CKD, which may be linked to heavy metal exposure through groundwater. Their study reported that about 15% of hospital patients from these catchment areas were diagnosed with CKD, with arsenic and cadmium detected at elevated levels in local water sources.

2.6 GIS and Groundwater Flow Analysis in CKD Research

In recent years, Geographic Information System (GIS) mapping and groundwater flow modeling have become valuable tools in assessing spatial contamination patterns and understanding the transport mechanisms of pollutants (Johnston et al., 2004). Studies applying these techniques have demonstrated that contaminants can be distributed across regions via groundwater flow, exposing larger populations to health risks associated with CKD.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This study integrates geological, hydrogeological, and groundwater quality data to analyze the groundwater contamination potential in Gashua, Northeastern Nigeria. The methodology combines field surveys, spatial analysis using GIS, borehole data, and existing groundwater chemistry results. The following steps outline the key procedures:

3.1 Geological and Hydrogeological Analysis

The geology and hydrogeology of the study area were assessed through a combination of existing published research on the geological evolution of the Bornu Basin, and field-based data collection. The aim was to understand the geological structures influencing groundwater occurrence and flow patterns. A geological map of Yobe State was developed using GIS (Fig. 2), based on previously available geological data and studies. For local-scale data, a field survey was conducted across the study area using a Global Positioning System (GPS) (Type 310 model) to record latitude, longitude, and surface elevation at 25 evenly distributed locations (Fig. 7). The GPS measurements were taken relative to mean sea level (MSL), providing accurate spatial reference for hydrogeological analysis.



Figure 7: GPS - Global Positioning System

3.2 Borehole Data Collection

To supplement field data, borehole information was sourced from the Yobe State Rural Water Supply and Sanitation Agency (RUWASSA). Drinking water borehole data included key hydrogeological parameters such as: borehole depth, depth to water table, drawdown, hydraulic head. These data points were critical for determining groundwater flow patterns and evaluating the potential hydraulic interaction between the groundwater system and Komadugu River (Gashua River), which flows through the area.

Table 4: Borehole data sourced from RUWASSA

Code	Location	Borehole depth (m)	Drawdown (m)	Active screen length (m)	Designed yield (l/s)	Efficiency (%)
BH 1	Kabala	66	57	3	3.5	44.7
BH 2	Kangalapaya	60	57	2	2.7	34.4
BH 3	Biltimari 1	30	18	3	2.1	20.4
BH 4	Biltimari 2	60	21	4	3.8	31.9
BH 5	Kabalankara	66	50	2	4.2	32.5
BH 6	Biltimari 3	66	25	3	3.8	37.1
BH 7	Yusufari Road	60	30	5	2.5	39.6
BH 8	Custom	60	37	2	1.46	99.5
BH 9	Isari	66	27	3	2.5	58.6
BH 10	State Lowcost	66	25	3	2.2	66.6
BH 11	Karamar Tanda 1	66	29	3	3.2	45.7
BH 12	Karamar Tanda 2	60	26	4	4.6	18.5
BH 13	PDP Dam	60	21	3	3.7	27.8
BH 14	Zango	60	17	3	4.1	29.2
BH 15	Takari	60	18	3	5	19.8
BH 16	Fire Service	66	33	4	7.4	18.0
BH 17	Kofar Fada	60	29	3	3	24.0
BH 18	Abacha Estate	60	18	3	4.8	22.7
BH 19	Famfon Kutare	60	24	3	9	16.1
BH 20	Dawari	63	30	4	6.1	18.2
BH 21	FUGA 1	54	40	3	8.7	75.1
BH 22	FUGA 2	48	32	2	6.2	69.4
BH 23	COE 1	39	28	2	9.1	78.3
BH 24	COE 2	46	31	2	5.6	86.5
BH 25	Ramat	51	33	3	4.7	65.4

3.3 Groundwater Flow Modelling

Groundwater flow direction was modeled using Surfer software, a widely-used contouring tool in hydrogeological studies. The groundwater level data from the field, measured in August, 2024 were organized into XYZ files. Surfer software was used to generate a computer-modeled map (Fig. 10), illustrating the groundwater flow direction across the study area. This enabled the identification of regional flow patterns and areas potentially at higher risk of contamination based on flow trends.

Table 5: Field data with calculated values of static water and groundwater level elevation for groundwater flow modeling (coordinates in WGS84 – DMS)

Code	Latitude	Longitude	Ground surface elevation (m)	Static water level (m)	GWL elevation (m)
BH 1	12° 52' 37" N	11° 02' 16" E	346.6	6	340.6
BH 2	12° 52' 36" N	11° 02' 25" E	354.56	1	353.6
BH 3	12° 52' 60" N	11° 02' 11" E	365.71	9	356.7
BH 4	12° 52' 56" N	11° 02' 12" E	316.79	35	281.8
BH 5	12° 52' 60" N	11° 02' 04" E	351.93	14	337.9
BH 6	12° 53' 06" N	11° 02' 09" E	354.87	38	316.9
BH 7	12° 53' 29" N	11° 02' 37" E	349.76	25	324.8
BH 8	12° 53' 13" N	11° 02' 07" E	344.12	21	323.1
BH 9	12° 53' 21" N	11° 01' 52" E	351.06	36	315.1
BH 10	12° 52' 38" N	11° 01' 41" E	352.13	38	314.1
BH 11	12° 52' 43" N	11° 01' 56" E	353.83	34	319.8
BH 12	12° 52' 42" N	11° 01' 59" E	354.13	30	324.1
BH 13	12° 52' 41" N	11° 02' 41" E	347.66	36	311.7
BH 14	12° 52' 51" N	11° 03' 06" E	359.96	40	320.0
BH 15	12° 52' 36" N	11° 03' 12" E	347.33	39	308.3
BH 16	12° 52' 10" N	11° 02' 53" E	359.46	29	330.5
BH 17	12° 52' 07" N	11° 02' 39" E	352.95	28	325.0
BH 18	12° 52' 04" N	11° 02' 30" E	348.37	39	309.4
BH 19	12° 52' 31" N	11° 02' 40" E	357.72	33	324.7
BH 20	12° 53' 19" N	11° 02' 31" E	358.23	29	329.2
BH21	12° 52' 47" N	11° 00' 39" E	348.57	11	337.6
BH22	12° 52' 43" N	11° 00' 37" E	346.67	14	332.7
BH23	12° 52' 33" N	11° 00' 05" E	351.92	9	342.9
BH24	12° 52' 38" N	11° 00' 16" E	352.65	13	339.7
BH25	12° 52' 15" N	11° 01' 39" E	357.81	15	342.8

The Static Water Level (SWL) in a borehole is defined as the depth to groundwater when the borehole is at rest, i.e., when it is not subjected to any pumping activity. The SWL is calculated using the borehole depth, active screen length, and the drawdown, where drawdown represents the decrease in water level due to pumping. The formula applied for determining SWL is as follows:

$$SWL = \text{Borehole Depth} - (\text{Drawdown} + \text{Active Screen Depth})$$

Equation 1: Static Water Level Calculation

where: SWL refers to the Static Water Level, representing the depth to water from the ground surface when the borehole is in a state of equilibrium.

Borehole Depth is the total vertical extent of the borehole from the ground surface.

Drawdown indicates the reduction in water level attributed to the influence of pumping.

Active screen length is the submerged part of the well screen below the pumping water level, ensuring efficient water extraction.

In hydrogeological studies, determining the Groundwater Level Elevation (GWLE) is crucial for understanding groundwater flow dynamics, hydraulic gradients, and aquifer behavior. The GWLE was calculated based on the Ground Surface Elevation (GSE) at the borehole location and the Static Water Level (SWL), which is the depth to groundwater measured from the ground surface when the borehole is at rest as calculated in equation 1.

The formula used to calculate the GLE is:

$$GWLE = GSE - SWL$$

Equation 2: Groundwater Level Elevation Calculation

where: GWLE represents the elevation of the groundwater surface relative to mean sea level.

GSE is the elevation of the borehole's ground surface relative to mean sea level.

SWL is the depth from the ground surface to the water table under static conditions.

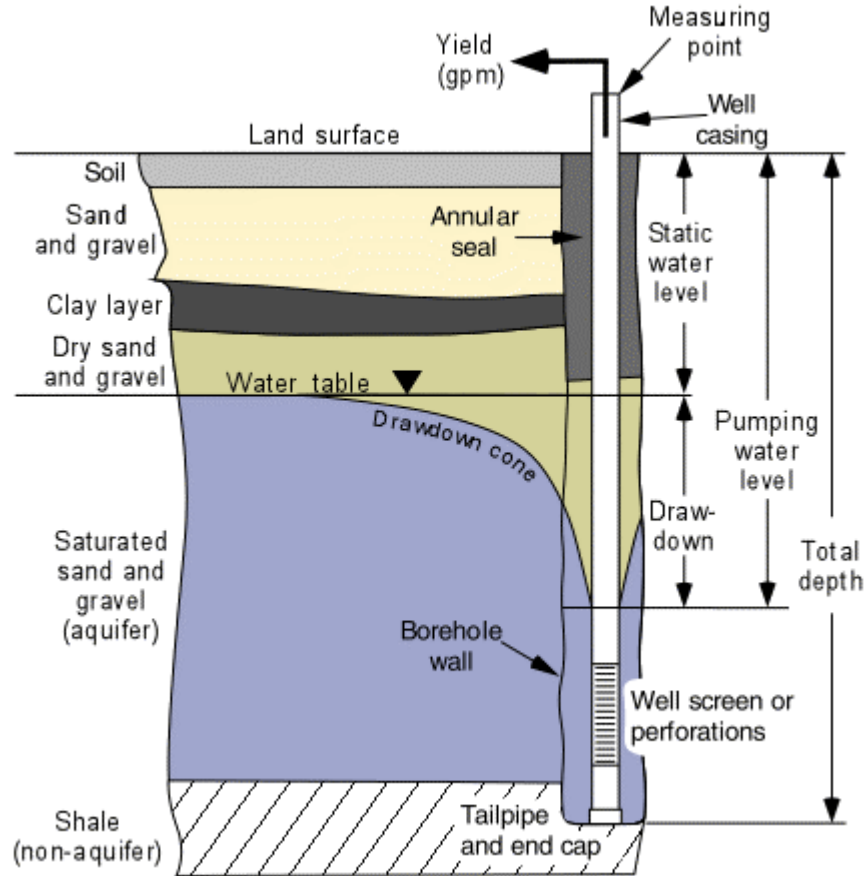


Figure 8: Borehole design parameters (GWIC, 2018)

3.4 Groundwater Chemistry Review

Groundwater chemistry data from 25 borehole samples were sourced from available literature and evaluated. These samples were analyzed in 2023 and had undergone physicochemical and heavy metals analysis. These results were mainly from an unpublished thesis of Joseph (2023) and few from a published research paper of Baffa (2022). The key water quality parameters reviewed included:

- Physicochemical parameters: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Total Hardness (TH).
- Major ions: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Sulfates (SO_4^{2-}), and Nitrates (NO_3^-).
- Heavy metals: Arsenic (As), Cadmium (Cd), Iron (Fe), Mercury (Hg), and Lead (Pb).

3.4.1 Collection of Samples

Before collection of samples, the pipeline of borehole pumps were flushed for a sufficient period of time, so that sample can be collected which represents the actual groundwater. Sample bottles were rinsed thrice with the water to be collected and then filled completely to avoid encroachment of air bubble. Sample bottles screw-caped tightly and brought to the

laboratory. The analysis of physical parameters; pH, Total Dissolved Solid (TDS), Total Hardness (TH) and Electrical Conductivity (EC) were made in field with Apera PC400 portable pH/COND/EC/Temp meter. The collected samples were transported to the Chemistry Department Laboratory Bayero University Kano for chemical parameters using different analysis techniques.

3.4.2 Measurement of Chemical Parameters

3.4.2.1 Calcium and Magnesium

A. Reagent solutions

- i Ca and Mg solution: The calcium and magnesium solutions were prepared by weighing 0.5g of CaCO_3 and 0.35g of MgCO_3 and dissolved completely in 2M HCl and diluted to 1 litre with 2M ammonium ethanoate (ammonium acetate).
- ii Eriochrome black T solution: Dissolve 0.1g of eriochrome black T indicator in 25ml analar grade methanol.
- iii 0.01M Zinc solution: Dissolve 0.6538g AR granulated zinc in 2 ml Conc. HCl, add few drops of bromine water and boil to remove the bromine.
- iv Ammonia-ammonium chloride buffer (pH10): Add 70g NH_4Cl to 570 ml $\text{NH}_4(\text{OH})$ solution (0.880) and dilute to 1 litre with distilled water.
- v Standard EDTA solution: Pipette 25ml zinc solution into a conical flask and add ammonium chloride buffer solution and few drops of the indicator. Shake and titrate with EDTA until the colour changes from wine red to blue. The end point corresponds

B. Procedure

Distilled water (50ml) was measured and transferred into 250ml Erlenmeyer flask and added 25ml concentrated ammonia solution, 10 drops of Ca and Mg solution, and 3 drops of eriochrome black T. The mixture was shaken to obtain wine red colour and titrated against standard EDTA solution to obtained blue end point. This aspect of titration accounted for Ca and Mg that might have been present in 50ml distilled water taken and the distilled water for reagent preparations. The water analyte sample (50ml) was added to the Erlenmeyer flask and shaken (initial wine colour is revived) and added 2ml of 1.5M KCN to mask Zn, Cu, Co; 2ml of 2% hydroxyl amine hydrochloride was added to mask Mn, and also 1ml of 30% triethanol amine was added to mask Fe, Al etc and finally titrated against standard EDTA with gentle shaken until blue end point was obtained and noted as the volume of the standard EDTA used.

Procedure for Ca alone

Distilled water (50ml) was measured and transferred into another Erlenmeyer flask and added 25ml of 20% KOH; 10 drops of Ca and Mg solution, and few grains of 1% calcein indicator and shaken to obtain light standard EDTA that gave fluorescent yellow end point. The water sample analyte (50ml) was added to the flask and shaken to revive the initial light colour followed by addition of 2ml of 1.5M KCN to mask Zn, Cu Co; 2ml of 2% hydroxyl amine hydrochloride to mask Mn, 1ml of 30% triethanol amine to mask Fe, Al etc. and titrated against standard EDTA, and shaken until the blue end point is obtained and noted as the volume of the standard EDTA used. This volume (B) is for Ca alone.

$$\text{Volume of Mg alone} = A - B$$

$$\text{Ca (mg/l)} = 40080 \times M \times B \text{ ml sample}$$

where

A = volume (ml) of EDTA for Ca and Mg

titration B = volume (ml) of EDTA for Ca

M = molarity of EDTA

Equation 3: Ca and Mg analysis formular

3.4.2.2 Chlorine

The method used here is iodimetry titrimetric using standard thiosulphate (0.0125M) as iterant. The standard thiosulphate was prepared by dissolving 3.101g of $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ in boiled cooled distilled water and diluted to 1 litre and standardized with the mixture of KI, H_2SO_4 and KH (IO_3) solutions. One gram of KI was dissolved in 5ml of glacial ethanoic and the sample was added, mixed thoroughly and titrated with the standard 0.0125M thiosulphate solution. When the color to pale straw, 2 ml of starch indicator solution was added, and the titration was completed to the first disappearance of the blue color. Blank titration was also carried out using a volume of distilled appropriate to the sample volume in the presence of all other reagents (USEPA, 1996).

$$\text{mg/l, available chlorine} = \frac{(A - B) \times M \times 70,900}{\text{ml of sample}}$$

Where

A = ml titration for sample

B = ml titration for blank

M = molarity of sodium thiosulphate

Equation 4: Cl formular

3.4.2.3 Sulphates

The water sample was measured (100ml), filtered and added 1:1 HCl in drops to litmus, 3 drops in excess was added and evaporated to 50ml. The solution was boiled and barium chloride solution was added until all the sulphates precipitated. The mixture was digested on water bath until the precipitate has settled. The precipitate was filtered with a vacuum pump through a sintered-glass crucible with a known constant weight. The residue was washed with hot water until the filtrate was chloride-free (tested with AgNO₃). The crucible precipitate was dried in an oven at 103-105°C to constant weight and the weight of the precipitate alone was obtained by the difference in weight as expressed in equation 5 (USEPA, 1996).

$$SO_4 \text{ (mg/l)} = \frac{\text{mg BaSO}_4 \times 411.5}{\text{ml of sample}}$$

Equation 5: SO₄ formular

3.4.2.4 Nitrate (NO₃⁻)

Concentration of nitrate-nitrogen was determined by distillation-titration. Before the titration, 10ml of each sample was poured in a 100ml beaker, mixed with 10ml of boric acid, 10ml of Devard's alloy (mixture of 50% Cu, 45% Fe, and 5% Zn) and 3 drops of methyl indicator until the samples changed to green. The greenish samples were then titrated, initial, final and actual titration value were determined. The NO₃⁻ was then calculated using the relation:

$$NO_3 \text{ (mg/l)} = \frac{TV \times N \times 14.01 \times 100}{V}$$

Where TV is the actual titre value

N is the concentration of EDTA (0.01ml)

V is the volume of sample used (10ml)

Equation 6: NO₃ formular

3.4.3 Analytical Procedure for Heavy Metals Analysis

The concentrations of heavy metals; Arsenic (As), Cadmium (Cd), Iron (Fe), Mercury (Hg) and Lead (Pb) in the borehole water samples were determined using Atomic Emission Spectrometer (AES). The equipment was switched-on and optimized based on the operating conditions presented in Table 3.1 and calibrated using the prepared reference standard

solutions of the metals of interest followed by the analysis of the sample analyte. The data generated were processed using relationship in equation 7:

$$\text{Metal } (\mu\text{g/ml}) = \frac{C \times V_2 \times d.f}{V_1(\text{ml}) \text{ of sample used}}$$

Where; C is the concentration obtained from the AAS machine (mg/L)
 V2 is the volume of the stock sample solutions in mL; V1 is the sample's quantity in ml
 d.f is dilution factor.

Equation 7: Heavy metals formular

Table 6: Instrument operating condition for the analysis

Element	Wavelength (nm)	Nebulizer Flow (L/min.)
As	193.695	0.75
Cd	326.106	0.50
Fe	371.993	0.65
Hg	253.652	0.75
Pb	405.781	0.75

3.5 Statistical and Spatial Data Analysis

Descriptive statistics were applied to the groundwater quality data, using mean, median, minimum, maximum, and standard deviation to understand the central tendencies and variation in water quality across the study area. Microsoft Excel and STATISTICA® software were used for data analysis and to generate comparative plots of the contaminant levels. The presence of heavy metals in the groundwater samples was evaluated in comparison to permissible limits defined by the Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) guidelines.

3.6 GIS-Based Spatial Distribution Mapping

To visualize the spatial distribution of heavy metals and other water quality parameters, ESRI® ArcMap™ (a component of ArcGIS) was used to generate spatial distribution maps. Kriging interpolation method was used for the geostatistical analysis following methods described by Johnston et al. (2004). GIS allowed for the overlay of contamination hotspots with land-use data, providing insight into the possible anthropogenic sources of contaminants, such as agricultural runoff and waste disposal sites. The resulting maps highlighted the concentration gradients of heavy metals like As, Cd, and Hg across the study area, identifying regions where groundwater is most vulnerable to contamination. These

maps were critical in linking the geology, land-use patterns, and groundwater quality, offering a spatial understanding of contamination risks.

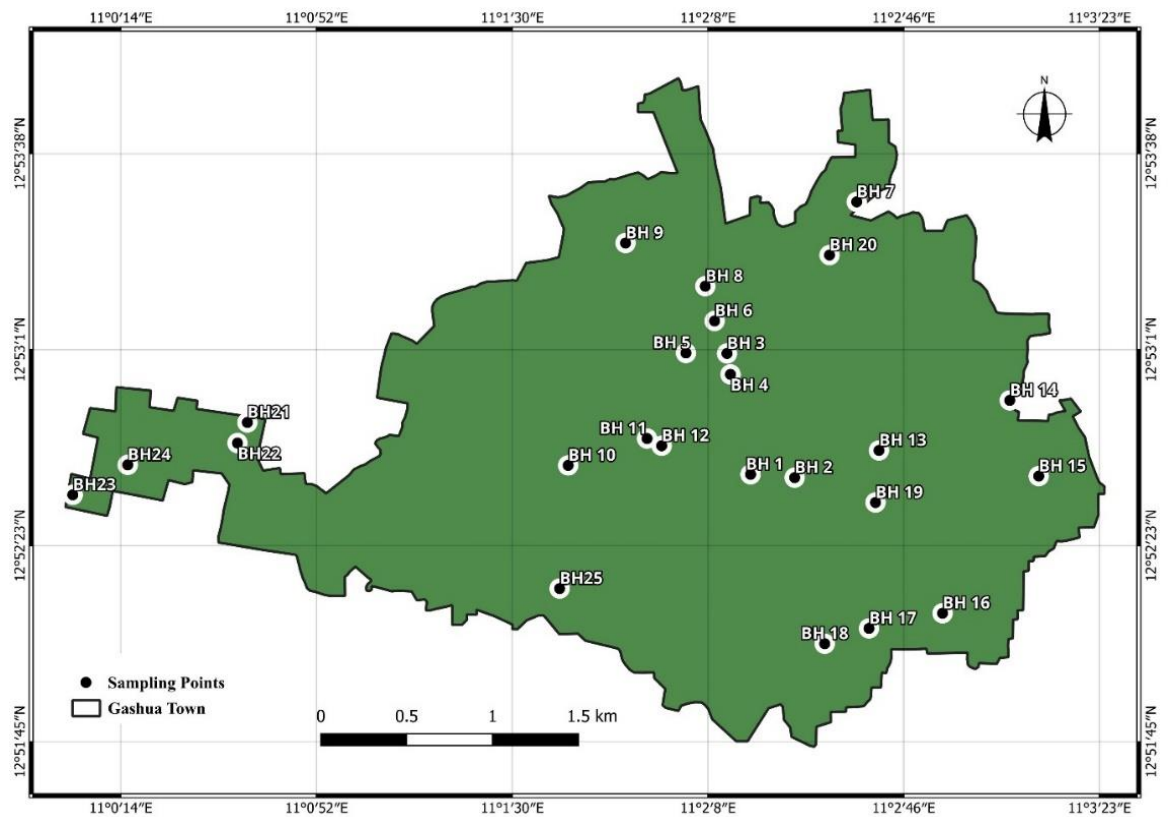


Figure 9: Distribution of boreholes for sampling, borehole data, and flow modelling

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 Groundwater Flow

The static water levels observed across the 25 boreholes in Gashua reveal significant spatial variability, with the highest level recorded at Zango (BH 14) in the eastern area and the lowest at Kangalapaya (BH 2) in the southeastern zone. The notably low water levels in the southern parts of Gashua indicate a shallow groundwater table, which increases the susceptibility of groundwater to contamination. In areas with a shallow water table, pollutants at the surface, such as agricultural runoff and waste byproducts, can easily infiltrate and enter the groundwater system, thereby compromising water quality. This is particularly concerning in Gashua where agricultural chemicals are prevalent due to intensive farming practices.

The groundwater flow model generated from the static water level data and the three-point method (groundwater elevation) indicates a predominant northward flow direction (Fig. 10). This northward trend implies that contaminants originating in the southern part of Gashua, where agricultural activities are concentrated, are likely to migrate through the aquifer system to the northern regions. Over time, this slow but persistent flow of groundwater can lead to the accumulation of contaminants in downstream areas, exacerbating health risks associated with contaminants like arsenic, cadmium, and mercury, all of which have established nephrotoxic effects and can contribute to the onset of CKD with prolonged exposure.

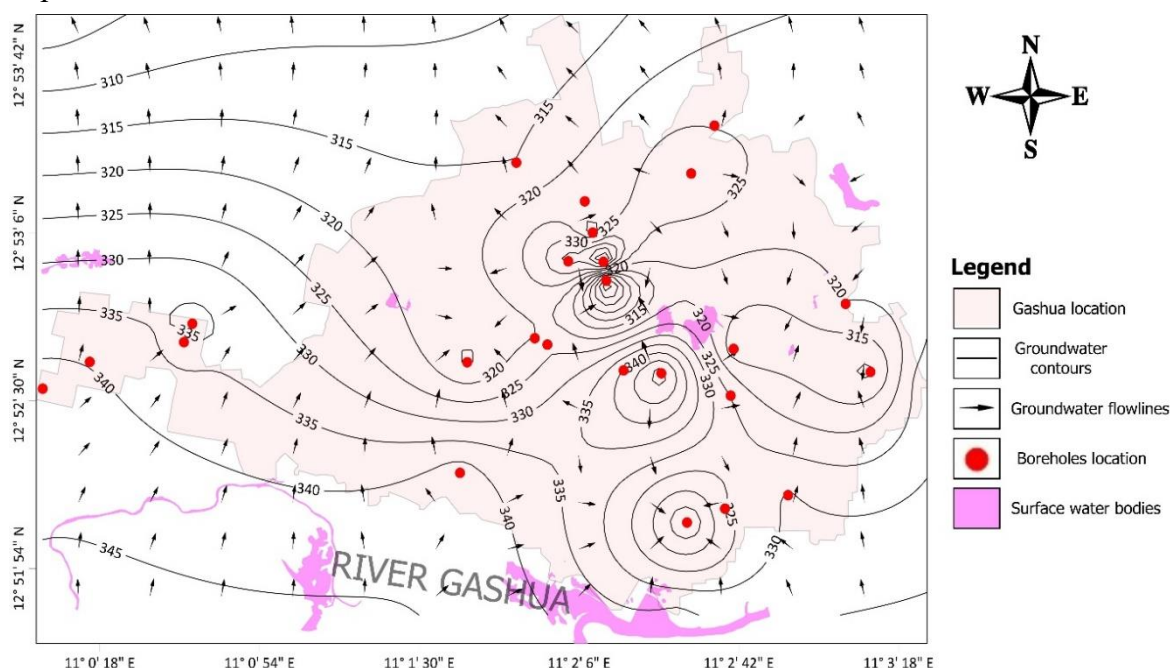
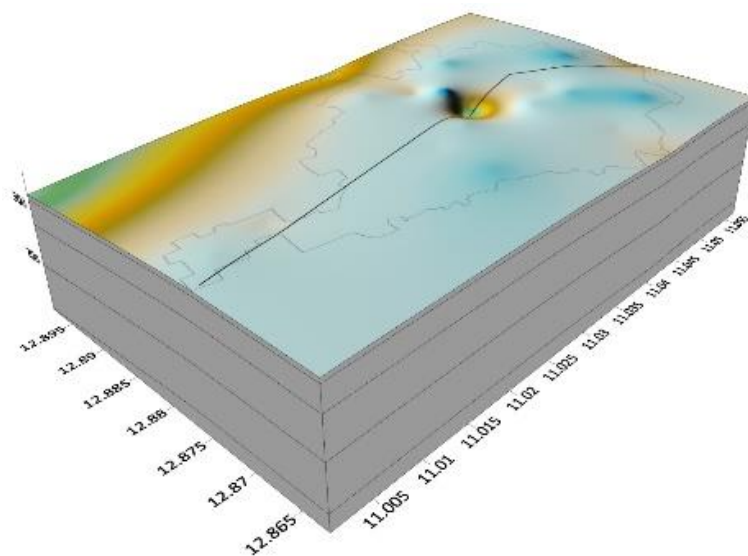


Figure 10: Groundwater level contour map showing groundwater flow direction

Understanding the groundwater flow direction is essential for pinpointing contamination sources and predicting the movement of pollutants within the aquifer. The observed pattern in Gashua suggests that agricultural and waste-related contaminants from the southern region, exacerbated by frequent flash floods, can be mobilized and spread through the aquifer during recharge events (Adeyeri et al., 2020). Agada et al. (2020) conducted a resistivity survey that further supports this, revealing a geoelectric profile in Gashua with a multi-layered structure: a topsoil layer followed by a low-permeability clay layer, coarse- to medium-grained sand, sandy clay, and medium- to fine-grained sand (Fig. 11). This stratigraphy allows contaminants to move vertically and laterally during periods of heavy rainfall, particularly where the clay layer's low permeability temporarily confines contaminants, creating potential for concentrated pollutant plumes to travel through more permeable sand layers once the clay is saturated.

Furthermore, recent studies, such as that of Goni et al. (2024), highlight a CKD hotspot associated with communities near the River Gashua. However, this study found no direct hydraulic connection between the river and the groundwater system, suggesting that CKD risks may not directly result from river water infiltration but rather from contaminants that percolate into the groundwater system from surface activities and then migrate northward. During flash floods, contaminants from agricultural practices along the riverbank infiltrate the groundwater, increasing the potential for heavy metals and other nephrotoxic pollutants to accumulate in the groundwater. Erratic rainfall is often extreme in Northern Yobe State, causing frequent occurrence of flash flood in recent times which increased the degree of groundwater pollution (Agada et al., 2022).



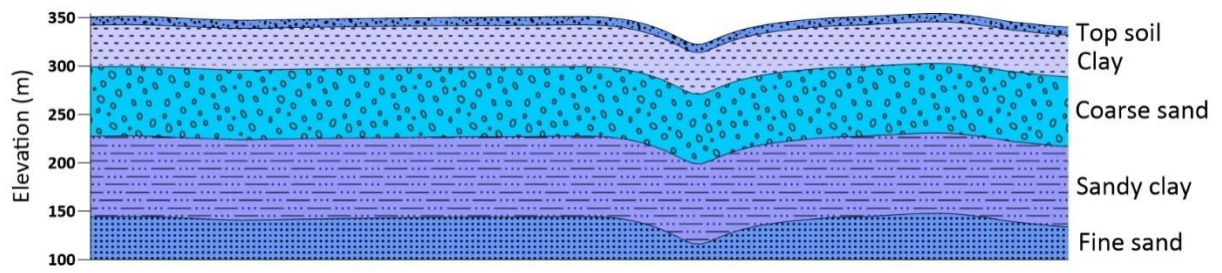


Figure 11: (a) 3D view of the surface and identified layers (b) cross-sectional view
modified after (Agada et al., 2022)



Figure 12: Flash flood scene in Gashua (Agada et al., 2022)

4.2 Physicochemical Characteristics of Drinking Water

A total of 25 results of physicochemical parameters of drinking water were statistically studied and summarized in Table 8, along with the drinking water quality standards recommended by NSDWQ. Selected parameters determined were pH, TH, TDS, EC, Ca, Mg, Cl, SO_4^{2-} , NO_3^- , As, Cd, Hg, Fe, and Pb. Statistical analysis can reveal the overall frame of hydro-chemical compositions (Adimalla et al., 2020). The variation of hydrochemical parameters was visualized in Box and Whisker plot (Fig. 14). Based on the results, the selected minerals and other physicochemical characteristics obtained from the geographical locations were almost identical. pH values of all the water samples were neutral to alkaline, the highest is 8.35 and the lowest is 5.84. Hardness of water is mainly caused by the presence of polyvalent metal cations mainly calcium (Ca) and magnesium (Mg) and the degree of hardness can be varied depending on the Ca and Mg content. Depending on the level of hardness, water can be categorized into 4 as shown in table 7.

Table 7: Water hardness scale (Bringolf et al., 2022)

Category	Concentration mg/l
Soft water	0 – 60
Slightly hard water	61 – 120
Hard water	121 – 180
Very hard water	> 181

The total hardness measurements for all the borehole samples were below the 120 mg/l recommended by the NSDWQ, suggesting that they were all compliant with the NSDWQ guideline. The low hardness values observed are attributed to the low concentration of calcium and magnesium, which makes 16 samples (64%) soft and 9 samples (36%) slightly hard water, as illustrated in Figure 13.

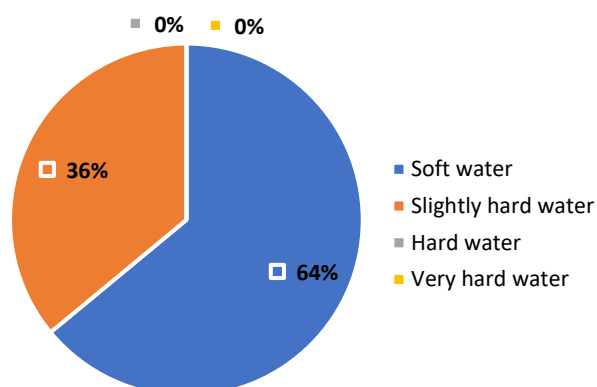


Figure 13: Graph for total hardness (TH) of the water samples

Total dissolved solids (TDS) in drinking water have been associated with natural source, sewage, industrial waste water, urban run-off and chemicals used in the water treatment process. High concentrations of TDS may confer undesirable taste, odour and colour on water, posing adverse reactions to the consumer (Spellman & Drinan, 2012). The TDS exhibited a wide variation with a minimum value of 25.17 mg/l and a maximum value of 233.67 mg/l. All the TDS values were below the maximum limit of 500 mg/l prescribed by NSDWQ.

The value of electrical conductivity depends on the concentration, types of soluble ions as well as the temperature of water. In this study, the conductivity values ranged between 0.06 and 0.95 mS/cm. Generally, groundwater in this study had low electrical conductivities, implying low mineral content.

4.2.1 Major Ions

The average calcium ion concentration for the samples was 14.79 mg/l. Calcium ion (Ca^{2+}) can occur naturally in groundwater through the dissolution of carbonate minerals and the decomposition of sulphate, phosphate and silicate minerals (Cobbina et al., 2012). The lack of rocks containing phosphate and sulphate in the research area may be the cause of the low Ca^{2+} values found in this investigation. The magnesium ion (Mg^{2+}) concentration in all borehole samples was lower than the NSDWQ standard of 20 mg/l for potable water with a mean of 5.05 mg/l (Table 8).

Na^{2+} is a naturally occurring element in groundwater. It is directly added into groundwater from industrial and domestic wastes and contributes to the salinity of water. Na^{2+} is one of the important cations occurring in natural waters and is derived from weathering of rocks (Rosinger et al., 2021). Domestic wastes and industrial wastes are rich in Na^+ and they contribute to the salinity of water. At lower concentrations there are no adverse effects on health. The Na^{2+} value of all the samples varies in the range of 8.31 to 76.78 mg/l. High concentration of Na^+ ion in drinking water may cause heart problems and high Na^+ in irrigation water may cause salinity problems (Rosinger et al., 2021). So, all of the groundwater sampled from the study area falls within the permissible limit (100 mg/l) suggested by NSDWQ.

Potassium concentration in all samples falls within the permissible limit of 50 mg/l, with a mean of 2.27 mg/l. The main reason for increasing potassium in groundwater is due to agricultural activities (Addo et al., 2009).

Chloride content in borehole samples has a mean of 8.77 mg/l lower than the maximum acceptable limit of 250 mg/l. Thus, the concentration of the chloride is considered good.

Nitrate and nitrite are the forms of nitrogen most commonly associated with groundwater contamination (Böhlke et al., 2006). Although the presence of nitrate does not pose any health threat to adults, ingestion by infants can cause low oxygen levels in the blood, a potentially fatal condition (Böhlke et al., 2006). For this reason, the NSDWQ has established a drinking water maximum allowable threshold of 50 mg/l nitrates as nitrogen. All samples analyzed contained varying concentrations of nitrate ranging from 0.51 to 33.21 mg/l with a mean of 9.53 mg/l (Table 8). The concentration of nitrate in the water samples was within the permissible range of 0.0 - 50 mg/l as recommended.

Table 8: Summary of physicochemical result of studied borehole water samples

	Minimum	Maximum	Mean $\pm$ SD	NSDWQ
pH	5.84	8.35	6.41 $\pm$ 0.15	8.5
TH (mg/l)	21.58	107.09	57.71 $\pm$ 5.35	100
TDS (mg/l)	25.17	232.67	12.48 $\pm$ 15.14	500
EC (mS/cm)	0.06	0.945	0.25 $\pm$ 0.05	1
Ca (mg/l)	6.50	25.90	14.79 $\pm$ 1.20	100
Mg (mg/l)	0.20	10.60	5.05 $\pm$ 0.77	20
Na (mg/l)	8.31	76.78	29.94 $\pm$ 4.2	100
K (mg/l)	0.63	5.82	2.27 $\pm$ 0.31	50
Cl (mg/l)	0.02	24.07	8.77 $\pm$ 1.54	250
SO ₄ ²⁻ (mg/l)	13.98	37.61	23.62 $\pm$ 1.37	100
NO ₃ (mg/l)	0.51	33.21	9.53 $\pm$ 1.93	50
As (mg/l)	0.18	0.88	0.44 $\pm$ 0.04	0.01
Cd (mg/l)	0.01	0.13	0.07 $\pm$ 0.006	0.003
Hg (mg/l)	0.01	0.05	0.022 $\pm$ 0.002	0.001

The results of physical parameters, cations, and anions are within the standard limit. This is because Gashua is located within the Chad Basin, a sedimentary basin composed primarily of alluvial and lacustrine deposits, with minimal igneous or metamorphic activity. These sediments, such as sand, silt, and clay, tend to have lower concentrations of heavy minerals that could leach harmful cations or anions into the groundwater. As a result, the levels of calcium (Ca), magnesium (Mg), chloride (Cl), and sulfate (SO₄²⁻) in the water remain low, contributing to soft water with minimal mineral content.

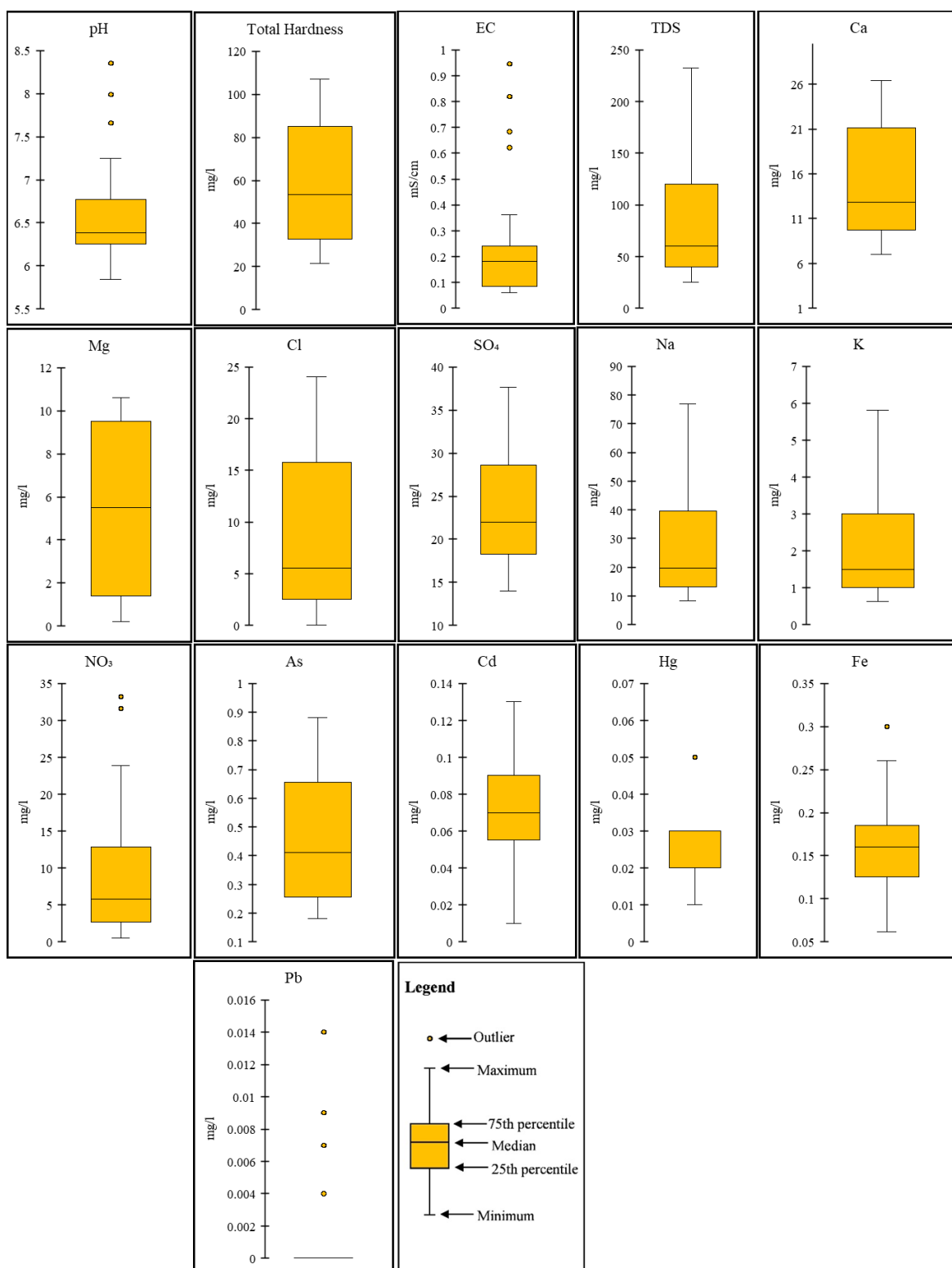


Figure 14: Box and Whisker plot of physicochemical parameters of the water samples

4.3 Heavy Metals Concentration

Heavy metal contamination concerns were the most alarming findings. The levels of arsenic ranged from 0.18 to 0.88 mg/l, with a mean concentration of 0.44 mg/l, way beyond the limit of NSDWQ which is 0.01 mg/l (Fig. 15). Cadmium levels ranging from 0.01 to 0.13 mg/l

(mean was 0.07 mg/l) were also above permissible by NSDWQ at 0.003 mg/l. Mercury concentrations (0.01-0.05 mg/l) exceeded standard set by the NSDWQ at 0.001 mg/l (mean was 0.022 mg/l) (Fig 14). While iron concentrations were within the acceptable range (0.062 to 0.3 mg/l), lead was detected at levels not more than 0.014 mg/l thus falling slightly above the threshold set by the NSDWQ at 0.01mg/l for drinking water quality. High concentration of iron in groundwater may not pose any health hazards but may not be patronized by consumers due to the unpleasant odour and taste that is normally associated with groundwater with higher iron concentration (Cobbina et al., 2012).

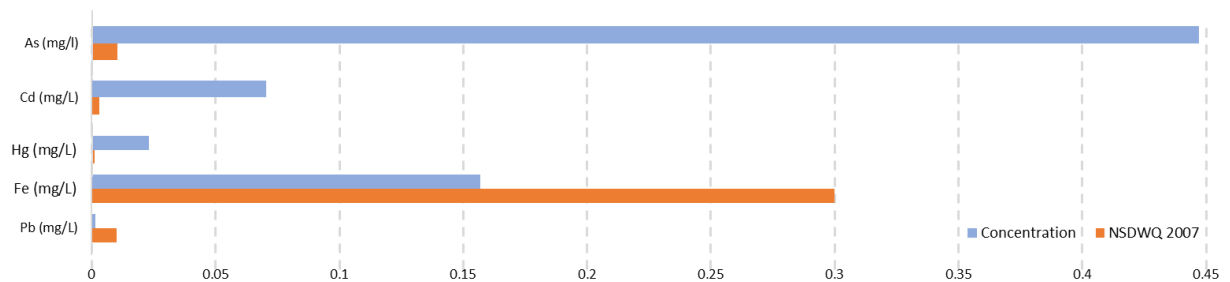


Figure 15: Graphical representation of As, Cd, Hg, Fe, and Pb concentrations in groundwater samples

The elevated levels of arsenic, cadmium, and mercury in Gashua's groundwater pose substantial health risks, particularly concerning CKD, as these metals are established nephrotoxins that impair kidney function with prolonged exposure. Unlike geogenic contaminants, which arise naturally from the geological makeup of the aquifer, the low concentrations of naturally occurring cations and anions in this area suggest that heavy metal contamination is predominantly anthropogenic. Agricultural activities likely contribute through the use of chemical fertilizers and pesticides, which contain metals that can leach into groundwater during irrigation or rainfall events. Additionally, improper waste disposal, particularly in southern Gashua, may introduce these toxic metals into the groundwater system as runoff or seepage from waste sites infiltrates the soil and reaches the aquifer.

This study identified elevated concentrations of heavy metals, specifically arsenic, cadmium, and mercury, in groundwater samples from Gashua. These metals are known to pose significant environmental and public health risks due to their toxicological properties and potential to bioaccumulate (Balali-Mood et al., 2021; García & Arceo, 2017; Sabath & Robles-Orsorio, 2012). Cadmium, mercury, and arsenic are particularly concerning as they often exceed permissible limits in groundwater, raising concerns about drinking water quality in the region. This finding can be supported by a study that measured heavy metal

concentrations in the blood and urine of CKD patients in Gashua. Aminu et al. (2021) revealed that CKD patients in Gashua had significantly higher concentrations of these toxic heavy metals compared to healthy individuals. For instance, cadmium levels in the urine of CKD patients from Gashua reached 0.074 mg/L, far exceeding the NSDWQ permissible limit of 0.003. Long-term exposure to high levels of arsenic in groundwater is associated with increased risks of CKD by promoting oxidative stress and cellular damage within kidney tissues (Yoshida, 2004). Cadmium absorbed primarily through water accumulates in the renal cortex, causing progressive kidney damage with prolonged exposure (Ma et al., 2023). Similarly, mercury exposure is known to disrupt cellular and protein functions within the kidneys (Balali-Mood et al., 2021).

4.3.1 Geospatial distribution of heavy metals concentration

According to the results of the interpolated data via GIS, the concentrations of these toxic elements originated from the south and southeastern part and flowed into the north. This confirms that they are the source of the waste disposal, fish farming, and other agricultural activities taking place in that location.

As shown in Fig. 16 (a) to (e), the spatial distribution patterns of nephrotoxic heavy metals (As, Hg, Cr, Pb, and Fe) assessed through the ArcMap software reveal a strong correlation between heavy metal clustering and agriculturally intensive regions in Gashua. The highest concentrations, identified through spatial autocorrelation, were 0.71 mg/L for arsenic (As), 0.13 mg/L for mercury (Hg), 0.026 mg/L for chromium (Cr), 0.014 mg/L for lead (Pb), and 0.19 mg/L for iron (Fe), all of which exceed the permissible limits set by the Nigerian Standards for Drinking Water Quality (NSDWQ).

The contamination appears to be driven by both natural and anthropogenic factors. Geochemical conditions such as pH and redox potential, may enhance the solubility and mobilization of these metals in groundwater. Additionally, agricultural activities in the region contribute significantly to contamination, with fertilizer runoff acting as a major source of heavy metals and other ionic agents. Fertilizers often contain trace amounts of

metals that leach into the soil and subsequently percolate into groundwater during irrigation or rainfall.

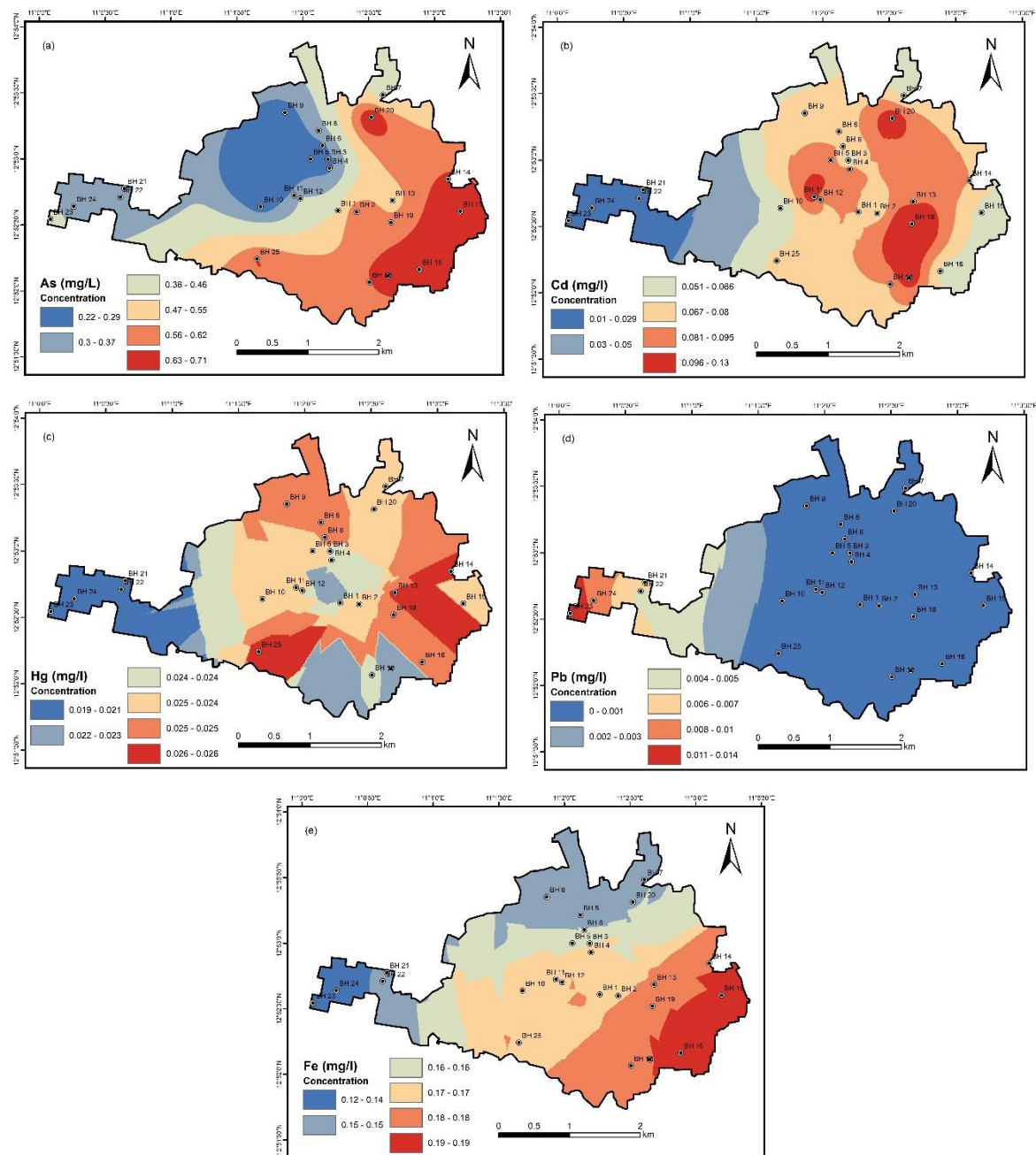


Figure 16: Geospatial distribution maps of (a) Arsenic, (b) Cadmium, (c) Mercury, (d) Iron, (e) Lead, generated by GIS through the kriging spatial interpolation method

This spatial pattern indicates that contamination is localized but significant in areas of high agricultural activity, raising concerns about the long-term impact on public health, particularly in relation to nephrotoxicity and CKDu.

The groundwater contamination patterns observed align with the region's hydrogeological features. The groundwater flow direction, as determined through GIS mapping and

hydrogeological analysis, indicates movement from potentially contaminated sources in the south and southeastern areas towards the northern regions of Gashua. This flow could facilitate the distribution of contaminants across a wider geographical area, thereby increasing exposure risks. While GIS and groundwater flow modeling provide valuable insights into contaminant pathways, the inherent geological heterogeneity of the Chad Basin presents challenges and introduces uncertainties that require further investigation.

4.3.2 Relationship Between Kidney Disease and Heavy Metals Contamination

Given the reliance of Gashua's population on groundwater for drinking and domestic purposes, the elevated concentrations of heavy metals highlight the urgent need for comprehensive water quality assessments and remediation strategies. While these metals are known for their potential nephrotoxic effects, this study does not aim to establish a causal relationship with specific health outcomes, such as CKD or CKDu. Instead, it emphasizes the critical need to monitor and address heavy metal contamination as a fundamental component of environmental and public health protection.

Future studies should explore the sources and pathways of heavy metal contamination in greater detail, including anthropogenic and natural contributions. This could involve sediment analysis, isotopic tracing, and assessments of land-use patterns in the region. Additionally, periodic water quality monitoring and implementation of treatment technologies could mitigate exposure risks associated with heavy metal contamination. Such studies could provide crucial insights and inform mitigation strategies to protect public health.



Figure 17: Rice farm along River Gashua (12.863933, 11.048336)

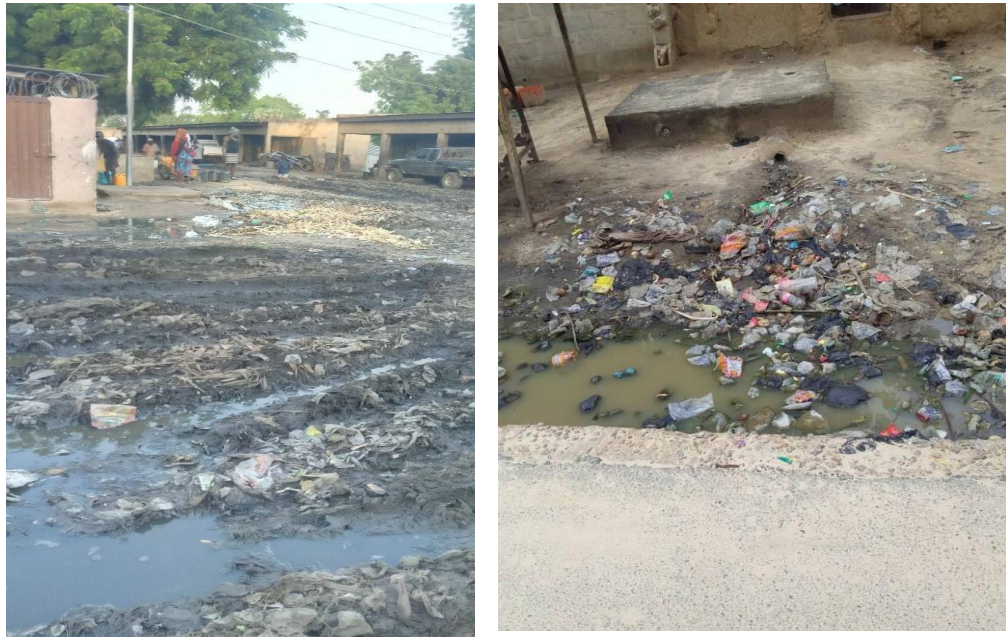


Figure 18: Wastewater in Central Market (12.868545, 11.038179) and from shallow soak away (Mshelia et al., 2021)



Figure 19: A dirty street in Gashua (12.881788, 11.038498)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The comprehensive study of groundwater in Gashua, northeastern Nigeria reveals that while physical parameters and prevalent cations and anion concentrations remain within acceptable limits, heavy metals such as arsenic, cadmium and mercury are detected at levels that exceed Nigerian Standard for Drinking Water Quality (NSDWQ) presents a significant health hazard. The high rate of chronic kidney disease in this region is believed to be caused by these nephrotoxic components. Long-term exposure to these pollutants can significantly impair kidney function. This can be seen from the increased incidence of chronic kidney disease. The geographical patterns of contamination suggest that the primary sources of these pollutants are anthropogenic, linked to agricultural runoff, improper waste disposal, and aquaculture practices, predominantly in the southern regions of Gashua. Groundwater flow analysis reveals that contaminants originating from these activities in the south are transported through the aquifer system to other areas, potentially exposing a larger population to health risks associated with CKD.

The findings underscore the need for improved groundwater management practices and further research to ensure the safety of water resources in the region. The persistent exposure to arsenic, cadmium, and mercury through contaminated groundwater is likely exacerbating CKD cases and highlights the need for an integrated response to ensure the long-term health of the community. To mitigate these risks and safeguard public health, a multi-faceted approach is essential.

5.2 Recommendation

- In order to establish a direct link between groundwater contamination and CKD prevalence in Gashua, detailed epidemiological studies should be considered. These studies should examine the incidence of CKD in populations with different heavy metals exposure levels in groundwater, hence strengthening the evidence for a causal relationship.
- Regular groundwater monitoring should be implemented to track heavy metal concentrations and provide early warning of increased contamination levels.
- Improved waste management practices, especially in agricultural and aquaculture zones, are also critical to prevent the release of contaminants.

- The installation of community-based water treatment systems, capable of removing heavy metals, would offer immediate relief from CKD risks.
- Additionally, exploring the possibility of accessing a deeper uncontaminated aquifer could also provide an alternative and safer drinking water source.
- Public health education on the dangers of contaminated water and promoting sustainable agricultural practices can empower the community and reduce environmental stress.

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APPENDICES

Appendix 1. The Nigerian Standard for Drinking Water Quality maximum permissible limits for drinking water

Parameter	Unit	Maximum Permitted	Health Impact	Note
Aluminum (Al)	mg/L	0.2	Potential Neuro-degenerative disorders	Note 2
Arsenic (As)	mg/L	0.01	Cancer	
Barium	mg/L	0.7	Hypertension	
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney	
Chloride (Cl)	mg/L	250	None	
Chromium (Cr ⁶⁺)	mg/L	0.05	Cancer	
Conductivity	µS/cm	1000	None	
Copper (Cu ²⁺)	mg/L	1	Gastrointestinal disorder,	
Cyanide (CN ⁻)	mg/L	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F ⁻)	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity	
Hardness (as CaCO ₃)	mg/L	150	None	
Hydrogen Sulphide (H ₂ S)	mg/L	0.05	None	
Iron (Fe ²⁺)	mg/L	0.3	None	
Lead (Pb)	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems	
Magnesium (Mg ²⁺)	mg/L	20	Consumer acceptability	
Manganese (Mn ²⁺)	mg/L	0.2	Neurological disorder	
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system	
Nickel (Ni)	mg/L	0.02	Possible carcinogenic	
Nitrate (NO ₃)	mg/L	50	Cyanosis, and asphyxia ("blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months	
Nitrite (NO ₂)	mg/L	0.2	Cyanosis, and asphyxia ("blue-baby syndrome") in infants under 3 months	
pH	-	6.5-8.5	None	
Sodium (Na)	mg/L	200	None	
Sulphate (SO ₄)	mg/L	100	None	
Total Dissolved Solids	mg/L	500	None	
Zinc (Zn)	mg/L	3	None	

Note 2: Parameter to be monitored only if aluminum chemicals are used for water treatment.