

ENVIRONMENTAL CONTAMINATION AND WATER HEALTH SYSTEMS:

TOXICITY,
QUALITY ASSESSMENT,
AND PUBLIC HEALTH
IMPLICATIONS



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**ENVIRONMENTAL CONTAMINATION AND WATER
HEALTH SYSTEMS: TOXICITY, QUALITY ASSESSMENT,
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PREFACE

Access to safe and sustainable water resources remains one of the most critical challenges affecting environmental sustainability and public health worldwide. Increasing chemical contamination, agricultural pollutants, and inadequate water quality management continue to threaten both ecological systems and human wellbeing, particularly in rapidly developing and vulnerable regions.

The chapters in this volume explore important issues related to water quality, environmental toxicity, and public health from interdisciplinary scientific perspectives. The examination of fungicide residues in surface waters highlights the growing environmental and human health concerns associated with agricultural chemical exposure. The assessment of drinking water quality in open wells emphasizes the significance of health risk evaluation and safe water management in local communities. In addition, the analysis of physicochemical properties of borehole and well water contributes to broader discussions surrounding water safety, environmental monitoring, and public health protection.

By integrating perspectives from environmental science, toxicology, water quality assessment, and public health studies, this volume contributes to contemporary academic discussions on environmental contamination and sustainable water systems. It also offers valuable insights for researchers, environmental scientists, health professionals, and policymakers engaged in improving water safety and reducing environmental health risks.

It is hoped that this book will serve as a meaningful academic resource while encouraging further interdisciplinary research on water sustainability, environmental monitoring, and public health resilience.

Editorial Team
May, 2026
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CHAPTER 1
FUNGICIDE RESIDUES IN ALGERIAN SURFACE
WATERS: OCCURRENCE AND HUMAN HEALTH
IMPLICATIONS OF CARBENDAZIM AND
PROPAMOCARB HYDROCHLORIDE

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INTRODUCTION

Pesticides are widely used in modern agriculture to enhance crop productivity and quality. However, their extensive application has led to contamination of environmental compartments, including air, water, and soil, raising concerns about ecological and human health risks (Sharma et al., 2019). Among pesticide classes, fungicides represent the second most widely used group worldwide, accounting for nearly one-third of global pesticide consumption (FAOSTAT, 2022). Despite their widespread use, the environmental and health implications of fungicides have received comparatively less attention than those of insecticides and herbicides (Pimentão et al., 2024; Sivasankary et al., 2025).

Because of their extensive agricultural use and varying persistence, fungicides are increasingly detected in surface waters, particularly in agricultural and peri-urban environments (Zubrod et al., 2019). Among these compounds, carbendazim (CBZ), a systemic benzimidazole fungicide introduced in the 1970s, has attracted particular attention due to its frequent detection in aquatic environments and potential implications for human health. CBZ has been widely applied to cereals, vegetables, fruits, and industrial crops (Singh et al., 2016; PPDB, 2025a), as well as in post-harvest treatments to prevent fungal growth during storage and transport (Crapnell et al., 2023). In addition to agricultural uses, it has also been incorporated into various industrial products such as paints, construction materials, and paper or textile products (Coutu et al., 2012; Merel et al., 2018). Furthermore, CBZ may occur as a degradation product of other benzimidazole fungicides, including benomyl and thiophanate-methyl, which further contributes to its environmental presence (Bai et al., 2024; Cui et al., 2024).

Consequently, CBZ has been widely reported in surface waters worldwide, including European river systems (Massei et al., 2018), and is frequently detected in environmental monitoring programs (de Souza et al., 2020). Toxicological studies associate CBZ exposure with multiple adverse effects, including histopathological alterations in the liver, kidney, and reproductive organs, as well as endocrine-disrupting and immunotoxic properties (Merel et al., 2018; Zhai et al., 2021; Hashim et al., 2023).

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Due to these concerns, regulatory restrictions have been introduced in several jurisdictions. In the European Union, CBZ was banned in 2014 and classified as a category 1B reproductive toxicant and mutagen (Bellisai et al., 2024). Nevertheless, its continued environmental detection raises concerns regarding surface-water contamination and potential human exposure.

Another compound of interest is propamocarb hydrochloride (PM), a systemic carbamate fungicide introduced in the late 1970s and primarily used to control Oomycete pathogens such as *Phytophthora* and *Pythium* (Hu et al., 2007; PPDB, 2025b). Unlike CBZ, PM remains authorized in many countries and is widely applied in open-field and greenhouse crop production. Both CBZ and PM may reach aquatic environments through agricultural runoff, leaching, spray drift, or wastewater discharges, with their environmental fate influenced by climatic conditions, soil characteristics, and agricultural management practices (Carazo-Rojas et al., 2018).

Despite increasing global attention to pesticide contamination, information on fungicide occurrence in African surface waters remains limited. In Algeria, most water-quality studies have traditionally focused on physicochemical parameters and heavy metals, while pesticide contamination has received comparatively little attention. Algeria's hydrographic network comprises seventeen major watersheds (Achite and Ouillon, 2016; Omran and Negm, 2020), most of which drain toward the Mediterranean Sea and include diverse surface-water systems such as rivers and wadis. Agricultural, industrial, and urban activities have been identified as major sources of contamination in several basins, including the Cheliff and Seybouse watersheds (Hallouz et al., 2025).

Evidence from neighboring regions also highlights the vulnerability of shared hydrological systems. For example, fungicide residues have been reported in the Medjerda River in Tunisia, an important transboundary basin partly shared with Algeria (Necibi et al., 2021; Omran and Negm, 2020). Such findings suggest that similar contamination pressures may occur within Algerian watersheds.

However, information on pesticide contamination in Algerian surface waters remains extremely scarce. To date, only two studies have reported the occurrence of fungicides in natural surface waters, specifically CBZ and PM.

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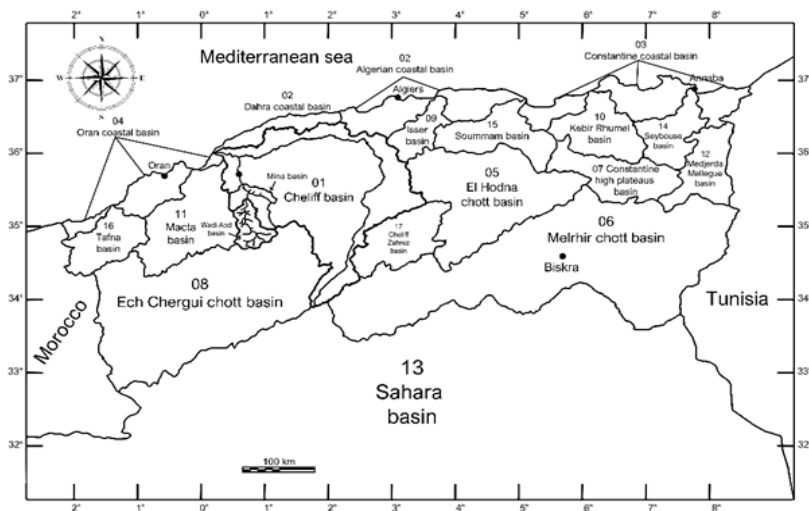
Khaled-Khodja et al. (2018) detected pesticide residues in Wadi Seybouse and Wadi Bouhamra, where CBZ and PM were the most abundant fungicides among the compounds identified. Similarly, Bettiche et al. (2017) reported pesticide contamination in Wadi Biraz, an ephemeral river belonging to the Melrhir watershed, where CBZ and PM were the only fungicide residues quantified. At the time of these investigations, both compounds were authorized for agricultural use in Algeria. Nevertheless, the absence of a national surface-water quality index limits systematic evaluation of pesticide-related environmental risks (Guettaf et al., 2017).

This structured narrative review addresses these knowledge gaps by synthesizing available information on CBZ and PM in Algerian surface waters within an environmental monitoring and human health perspective. Specifically, it (i) compiles and compares reported occurrence data from Algerian monitoring studies, (ii) summarizes physicochemical properties, environmental fate, toxicological evidence, and regulatory status based on authoritative databases and scientific literature, and (iii) examines potential human exposure pathways.

Given its broader toxicological profile, regulatory restrictions in several jurisdictions, and recurrent environmental detection, particular emphasis is placed on ingestion-related exposure pathways associated with CBZ, including drinking water and dietary intake via irrigated crops, animal-derived products, and fish. In contrast, PM remains authorized for agricultural use and appears less frequently detected in Algerian surface waters; therefore, exposure considerations for PM are discussed comparatively but in less detail.

By integrating environmental occurrence data with exposure considerations, this chapter aims to support the development of improved monitoring strategies, regulatory oversight, and risk-assessment frameworks for pesticide management in Algeria and other semi-arid regions.

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Basin	Mediterranean Drainage	Dominant Crop Type	Secondary Crop Types	Main Irrigation Sources
Cheiff Basin	+	MG	C, TC	SW/GW
Dahra Coastal Basin	+	C	TC, MG	RF/W/GW
Algerian Coastal Basin	+	MG	TC, C	SW/GW/Canals
Constantine Coastal Basin	+	MG	C, TC	SW/GW
Oran Coastal Basin	+	MG	TC, C	SW/GW
El Hodna Chott Basin	-	C	FC	RF/GW
Melmir Chott Basin	-	C	FC	RF/GW
Constantine High Plateau Basin	-	C	FC, TC	RF/GW
Ech Chergui Chott Basin	-	C	FC	RF/GW
Isser Basin	+	C	MG, TC, FC	RF/SW/GW
Kabir-Rhumel Basin	+	C	MG, TC, FC	RF/SW/GW
Macta Basin	+	MG	TC, C, FC	SW/GW
Medjerda-Mellegue Basin	+	C	MG, TC, FC	RF/SW/GW
Sahara Basin	-	OA	SV	GW/OW
Saybouse Basin	+	C	MG, TC	RF/SW/GW
Soummam Basin	+	C	MG, TC, FC	RF/W
Tafna Basin	+	MG	C, TC, FC	SW/GW/Canals
Cheiff-Zahrez Basin	+	MG	C, TC, FC	SW/GW

+ = yes (flows into Mediterranean); - = no (endorheic or inland); MG = Market gardening (vegetables); C = Cereals (wheat, barley, etc.); TC = Tree crops / Arboriculture (olives, citrus, fruit trees); FC = Fodder crops; OA = Oasis agriculture (date palms); SV = Small-scale vegetables; RF = Rainfed; SW = Surface water (rivers, dams, canals); GW = Shallow groundwater; W = Wadis / small rivers; OW = Oasis wells.

Figure 1. Hydrographic basins of Algeria with main crops, irrigation sources, and Mediterranean drainage (map adapted from Achite and Ouillon, 2016; agricultural data from MADR, 2021).

1. METHODOLOGY

1.1 Literature Search

A structured narrative review was conducted to identify studies reporting pesticide residues in Algerian surface waters, including rivers and wadis (ephemeral and perennial).

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Publications up to December 2025 were considered. Searches were performed in Google Scholar, Scopus, and Web of Science using:

“pesticides” OR “fungicides” AND “surface water” OR “wadis” AND “Algeria”. Reference lists of retrieved articles were also screened.

Studies were included if they:

- reported measured concentrations of pesticide compounds,
- were conducted in natural surface waters in Algeria, and
- provided quantitative analytical results above the limit of quantification.

Studies based solely on laboratory experiments, modelling, wastewater effluents without environmental sampling, or data from outside Algeria were excluded. For each eligible study, information on pesticide identity, concentration range, sampling location, and year was extracted for qualitative comparison.

1.2 Selection of Target Molecules

Fungicides repeatedly detected in at least two independent studies were considered indicative of recurring environmental presence. Based on this criterion, two compounds were prioritized: carbendazim (CBZ) and propamocarb hydrochloride (PM).

1.3 Compilation of Physicochemical, Environmental, and Toxicological Information

Data on physicochemical properties, environmental fate, toxicology, and regulatory status were compiled from the Pesticide Properties Database, PubChem, and peer-reviewed literature, including:

- regulatory status (approval, restriction, or ban),
- environmental persistence and degradation,
- toxicological effects (acute and chronic),
- reported occurrence in surface waters internationally, and
- potential human exposure pathways.

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1.4 Assessment of Potential Exposure Pathways

To explore potential human exposure, an additional search focused on the reported presence of CBZ and PM in food products and drinking water. Queries combined the compound names with: “residue”, “food”, “vegetables”, “fruit”, “milk”, “fish”, “honey”, and “drinking water”.

Studies documenting detection in food, animal products, fish, honey, or drinking water were included. Quantitative concentrations were not compiled, but the studies provided contextual evidence of exposure routes. Variability in analytical methods, sampling strategies, and reporting practices across studies was considered when interpreting the findings.

2. RESULTS AND DISCUSSION

2.1 Available Monitoring Studies in Algerian Surface Waters

Data on pesticide contamination in Algerian surface waters remain scarce. Only two studies have reported measured residues in natural systems. Khaled-Khodja et al. (2018) sampled two permanent rivers in northeastern Algeria, Wadi Seybouse and Wadi Bouhamra (Seybouse Basin), in 2009–2010, while Bettiche et al. (2017) investigated Wadi Biraz, an ephemeral watercourse in the semi-arid Chott Melrhir Basin, in 2014.

These studies constitute the sole evidence for pesticide occurrence in Algeria. While providing valuable initial insight, their limited spatial and temporal coverage restricts interpretation of contamination patterns and potential human exposure. The results underscore the need for broader, systematic surface-water monitoring to support robust risk assessment and management.

2.2 Occurrence and Quantification of Fungicides in Algerian Surface Waters

Cross-referencing available studies identified two fungicides carbendazim (CBZ) and propamocarb hydrochloride (PM) as consistently quantified in Algerian surface waters under diverse environmental conditions.

The earliest dataset comes from Khaled-Khodja et al. (2018), based on sampling in 2009–2010 in northeastern Algeria (Annaba region).

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Two perennial rivers, Wadi Seybouse and Wadi Bouhamra (Seybouse Basin), were analyzed using GC–MS. Multiple pesticides were detected, with CBZ and PM exhibiting the highest concentrations among fungicides. Maximum concentrations were 0.024 µg/L (CBZ) and 0.008 µg/L (PM) in Wadi Seybouse, and 0.046 µg/L (CBZ) and 0.016 µg/L (PM) in Wadi Bouhamra. The higher levels in Wadi Bouhamra were attributed to untreated sewage and industrial effluents. Both rivers are important sources for irrigation and domestic water and are exposed to urban, agricultural, and industrial pressures (Djabri et al., 2003; Guettaf et al., 2017).

Bettiche et al. (2017) examined surface water and groundwater from the intermittent Wadi Biraz in the semi-arid Biskra region (southeastern Algeria) in 2014. While groundwater was free of residues, CBZ (0.058 µg/L) and PM (0.047 µg/L) were quantified in surface water using LC–MS and GC–MS multi-residue analysis of 218 compounds. Analyses were conducted in the accredited Laboceca laboratory, ensuring consistency. CBZ was also detected in nearby soils, indicating both direct application and transformation from thiophanate-methyl, whereas PM occurrence was confirmed through local agricultural practices (Bettiche et al., 2017; Hamamouche et al., 2017).

Together, these studies demonstrate that CBZ and PM are present in both perennial and intermittent watercourses, reflecting persistence across contrasting hydrological conditions. Although concentrations remain below international regulatory thresholds, their repeated detection highlights the potential for diffuse contamination and underscores gaps in national surface-water monitoring. These findings provide the basis for subsequent assessment of environmental fate, toxicological properties, and human health relevance.

2.3 Compilation of Pesticide Information

2.3.1 Regulatory Status and Global Use Patterns

Carbendazim (CBZ) is under strict regulatory control worldwide, with use banned or severely restricted in many countries (Crapnell et al., 2023). In Algeria, the 2021 Phytosanitary Guide (MADR, 2025) lists four commercial formulations containing propamocarb hydrochloride (PM) and four containing thiophanate-methyl, whereas CBZ has been progressively deregistered, appearing in the 2015 and 2017 editions but absent from 2021.

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Historically, CBZ was applied to vegetables, grapevines, and pome and stone fruits (DPVCT, 2017), while thiophanate-methyl remains approved for crops such as beetroot, cucurbits, peas, onions, and strawberries (MADR, 2025).

Regional trends in North Africa are similar. Morocco banned CBZ in 2017 (Bellemjid et al., 2023), yet surveys indicated it was the second most applied pesticide in 2019 (44% of applications) (Ben Khadda et al., 2021). In Tunisia, CBZ remained authorized for fruit and apple trees as of 2020 (Grünberger et al., 2024).

In the European Union, CBZ was identified as a candidate for substitution in 2015 due to its classification as a category 1B reproductive toxicant and mutagen and has since lost approval for agricultural use, although residues may persist in some biocidal applications (Bellisai et al., 2021). Outside Europe, CBZ remained authorized in China, Brazil, and India as of 2015 (Singh et al., 2016), with more recent bans in the United Kingdom, Portugal, Australia, and the United States (Wang et al., 2020; PPDB, 2025a). India continues to register CBZ alongside mancozeb as of 2024 (Sivasankary et al., 2025), while intensive agricultural use in some Chinese provinces still results in high residues (Wang et al., 2024). These global patterns highlight concerns regarding over-application, environmental persistence, and potential health risks (Qian et al., 2023).

By contrast, PM remains widely authorized. In Algeria, it is applied to potatoes, tomatoes, peppers, and nursery crops, often for soil disinfection (Bettiche et al., 2017; DPVCT, 2017; MADR, 2025). Similar uses are reported in Egypt (Abd-Alrahman and Almaz, 2016). In Sweden, PM was detected in all six horticultural watercourses surveyed in 2008, despite no direct effluent discharges, with primary use on potatoes, lettuce, cucumbers, tomatoes, and ornamentals (Kreuger et al., 2010).

From a toxicological perspective, the World Health Organization (WHO, 2020) classifies both CBZ (and its precursors thiophanate-methyl and benomyl) and PM as Class U: “unlikely to present acute hazard under normal use.” However, this classification does not consider long-term risks associated with chronic exposure. Overall, while regulatory measures vary globally, both CBZ and PM continue to be applied in multiple regions.

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This persistence reflects gaps between policy and practice, driven by limited enforcement, scarce alternatives, and insufficient farmer awareness. Strengthening regulation, expanding residue monitoring, and improving farmer education are essential to reduce human and environmental exposure.

2.3.2 Global Occurrence

Carbendazim (CBZ) and, to a lesser extent, propamocarb hydrochloride (PM) are widely detected in surface waters worldwide, with concentrations spanning several orders of magnitude (Table 1). In Algeria, CBZ ranged from 0.024 to 0.058 $\mu\text{g/L}$, and PM from 0.008 to 0.047 $\mu\text{g/L}$, broadly consistent with values reported in Tunisia, Vietnam, and Brazil. Exceptionally high CBZ levels have been observed in Spain's Ebro Delta ($>200 \mu\text{g/L}$) and Costa Rica (2.2 $\mu\text{g/L}$), while Brazil's sugarcane regions reached up to 1.1 $\mu\text{g/L}$. PM sediment concentrations in Turkey (up to 97.4 $\mu\text{g/kg}$) illustrate localized accumulation under intensive agriculture. These extremes highlight potential contamination hot spots influenced by local hydrology and crop management.

Surface-water concentrations are strongly shaped by hydrology and land use. Semi-arid regions like southeastern Algeria have ephemeral wadis prone to short, intense contamination pulses after rainfall, whereas perennial rivers (e.g., the Nile or Dongjiang) exhibit more continuous but diluted levels. Agricultural intensity also influences patterns: Algeria's greenhouse-based horticulture resembles high-input systems in irrigated rice fields (Spain, Vietnam), monoculture cereals (Turkey), and intensively cultivated plains (Tunisia). Chemical properties and site-specific factors together drive observed environmental concentrations.

Environmental persistence further amplifies exposure potential. CBZ is moderately persistent under temperate conditions but degrades more slowly in arid and semi-arid soils with low organic matter and limited microbial activity, such as in Biskra (Mitchell et al., 2024). Continued detection in Algerian and Greek waters, despite regulatory bans, reflects historical use and contributions from wastewater effluents (Rousis et al., 2021). PM remains authorized and is consistently reported in European and North African waters (Kreuger et al., 2010; Hayouni et al., 2025).

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Reported concentrations in Algeria and internationally remain well below European Water Framework Directive (WFD) environmental quality standards (CBZ: 2.7 µg/L AA-EQS, 77 µg/L MAC-EQS; PM: 630 µg/L AA-EQS, 1800 µg/L MAC-EQS). Acute ecological effects appear unlikely, but chronic exposure—especially in semi-arid regions with shallow aquifers, repeated irrigation, and water reuse—may contribute to human exposure via irrigation, food chains, and drinking water. Highlighting extreme values alongside typical levels can identify regions or practices warranting targeted monitoring.

These patterns confirm CBZ and PM as priority fungicides for further evaluation of environmental fate and potential human health risks in Algeria.

Study site / Basin	CBZ / PM concentration (µg L ⁻¹)	Sampling period	Dominant crops	Connected to sea/major water body ^a	References
Melhir Clott Basin (Bizar Wadi), Biskra, Algeria	0.058 / 0.047	2014	Greenhouse vegetables (tomato, peppers, zucchini, melon), cereals, date palms	No (intermittent)	1
Seybouse Basin (Seybouse&Boukharma Wadis), Annaba, Algeria	0.046 / 0.016 (Boukharma); 0.024 / 0.008 (Seybouse)	2009–2010	Vegetable, cereals, industrial crops, citrus, grapes	Yes (Mediterranean Sea)	2
Monkey Boussellham&Oualidini Lagoons, Morocco	n.g. (CBZ)	2023	General agriculture	Yes (Atlantic Ocean)	3
Eizeze Lagoon (Wadi Guenziche), Tunisia	0.039 / 0.033	2019–2020	Cereals, vegetables	Yes (Eizeze Lagoon → Mediterranean Sea)	4
Lehrs Watershed (Cap Bon Region), Tunisia	0.07 (CBZ)	2018–2021	Cereals, legumes	No direct outlet	5
Kasserine Watershed, Tunisia	Detected (30–40% frequency, CBZ & PM)	2025	Mixed cropping	Ephemeral wadi → inland basins	6
Nile Delta Basin (Rosetta Branch), Egypt	0.082 (CBZ)	2018–2019	Mixed agriculture	Yes (Mediterranean Sea)	7
Kizilirmak Delta (Karabogaz Lake), Turkey	0.004–0.037 (CBZ); 5.40–97.4 ^a (PM, µg kg ⁻¹ in sediment)	2011–2012	Rice, corn, wheat, vegetables	Yes (Black Sea via Kizilirmak River)	8
Eivrik Manderes River Basin, Turkey	1.538 (CBZ)	2016–2018	Barley, wheat	Yes (Aegean Sea)	9
Maritsa-Meric Basin (Ergene River), Turkey	11.025 (CBZ); 0.2066 (PM)	2020	Wheat, barley, sunflower, corn	Yes (Aegean Sea via Maritsa)	10
Lake Vistonis Basin, Greece	n.d. (CBZ)	2010–2012	Wheat, cotton, corn, vegetables	Yes (coastal lake → Thracian Sea)	11
Athens WWTP Effluent Basin, Greece	>0.072 (CBZ)	2014–2020	Urban use	No (WWTP effluent)	12
Ebro River Basin (Ebro Delta), Spain	>100 (CBZ); 6.5 (PM)	1997	Rice	Yes (Mediterranean Sea)	13
Llobregat River Basin, Spain	0.697 (CBZ)	2015	Cereals, artichokes, lettuce, tomatoes	Yes (Mediterranean Sea)	14
Coastal Watersheds (Eneclouva Area), Spain	>1.425 (CBZ)	2019	Fodder, cereals	Yes (Mediterranean Sea)	15
Doungiang River Basin, China	Detected in all runoff samples (CBZ)	2018	Rice, vegetables	Yes (Pearl River → South China Sea)	16
Red River Basin, Vietnam	0.0667 (CBZ)	2010–2020	Rice, corn, peanut, soybean	Yes (Lake & river systems)	17
Great Lakes Basin, Ontario, Canada	>0.400 (CBZ)	2019	Soybean, corn, wheat, fruit crops	Yes (Great Lakes)	18
Legos dos Patos Basin (São Gonçalo Channel), Brazil	0.042 (CBZ)	2011–2014	Rice	Yes (Patos Lagoon → Atlantic Ocean)	19
Parna Basin (São Paulo Region), Brazil	0.003–1.114 (CBZ)	2015–2016	Sugarcane	No (inland)	20
Tocantins–Araguaia Basin (Araguaia River), Brazil	0.006 (CBZ)	2018–2019	Pasture, row crops	Yes (Amazon Basin)	21
Tempisque Basin (La Muña Creek), Costa Rica	2.239 (CBZ)	2009–2012	Rice, sugarcane	Yes (Tempisque → Gulf of Nicoya)	22

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Figure 1. Reported concentrations of carbendazim (CBZ) and propamocarb hydrochloride (PM) in surface waters in Algeria and worldwide, with study sites, sampling periods, dominant crops, and hydrological connectivity

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2.3.3 Environmental Fate

Carbendazim (CBZ) has low water solubility (8 mg/L at 20 °C) and is classified as non-persistent to moderately persistent in soils (PPDB, 2025a). Under certain conditions, however, CBZ may persist for several months, with reported half-lives up to 12 months (Zhang et al., 2013). Its degradation depends on soil organic matter, microbial activity, texture, and climate. In arid and semi-arid regions such as southeastern Algeria, low organic carbon, limited microbial diversity, and reduced soil moisture can slow breakdown, although repeated applications may induce microbial adaptation, enhancing biodegradation over time (Mitchell et al., 2024; Yu et al., 2009).

Laboratory studies show considerable variability in CBZ biodegradation. *Pseudomonas cepacia* degraded 35% of CBZ, while other *Pseudomonas* strains achieved over 80% under optimized conditions. Fungal species degraded CBZ even faster: *Trichoderma harzianum* removed up to 85% within five days, whereas *T. viride* and *T. atroviride* removed 47% and 21%, respectively (Bordjiba et al., 2010; Sharma et al., 2016). These findings illustrate that CBZ fate is highly dependent on microbial composition and local soil conditions.

In arid agroecosystems with sandy soils and low microbial biomass, CBZ persistence is likely prolonged, increasing the risk of leaching to shallow aquifers or runoff to surface waters. This can lead to chronic, low-level contamination of water resources and potential human exposure via drinking water and irrigation-based food production.

Propamocarb hydrochloride (PM), by contrast, is highly water-soluble and generally non-persistent to moderately persistent in soils (PPDB, 2025b). Its dissipation is mainly driven by microbial activity and plant–microbe interactions. Plant growth-promoting rhizobacteria (PGPR), such as *Bacillus amyloliquefaciens* IN937a and *B. pumilus* SE34, can accelerate PM degradation by 11–22% within 72 hours in soil and liquid cultures. PM exposure also stimulates PGPR growth in a concentration-dependent manner, suggesting feedback mechanisms that further enhance dissipation (Myresiotis et al., 2012).

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Overall, CBZ poses a higher risk of long-term environmental persistence in arid and semi-arid regions, with potential chronic exposure for humans and ecosystems. In contrast, PM is more readily dissipated under biologically active conditions. These differences emphasize the need for targeted monitoring and site-specific risk assessment for CBZ in regions with limited biodegradation potential.

2.3.4 Toxicological Profile and Human Health Relevance

Database summaries (PPDB, 2025a,b; PubChem, 2025a,b; Table 2) and toxicological reviews (Singh et al., 2016) indicate that carbendazim (CBZ) affects multiple biological systems, including reproductive, hepatic, renal, neurological, and hematological functions. The following synthesis highlights experimental evidence from rodent models relevant to human health considerations, without implying a direct quantitative risk assessment.

Reproductive and developmental toxicity

CBZ consistently induces adverse effects on male reproductive function, including disrupted spermatogenesis and hormonal imbalance. Rama et al. (2014) reported androgen-related alterations at low exposures, while Farag et al. (2011) observed fetal loss, congenital malformations, and hormonal disturbances. Testicular degeneration and altered spermatogenic indices were also reported by Tousson et al. (2023). These findings support CBZ's classification as a reproductive toxicant, although specific endocrine-disrupting mechanisms remain to be fully elucidated.

Hepatic and Renal Toxicity

CBZ exposure is linked to oxidative stress and inflammatory injury in liver and kidney tissues. Mo et al. (2022) documented histopathological changes and biochemical disruptions (ALT, AST, urea, creatinine), while Patil et al. (2018) reported lipid and protein metabolism disturbances. Co-exposure studies indicate enhanced toxicity; for example, Abolaji et al. (2017) found synergistic effects with chlorpyrifos. Genetic toxicity appears mainly aneugenic: Rai and Mercurio (2020) and Ilyushina (2020) observed DNA and chromosomal damage, consistent with EFSA evaluations, although direct mutagenic effects are limited (Bellisai et al., 2021).

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Neurotoxicity

Evidence for CBZ neurotoxicity is limited but suggests potential neurological effects, including reduced acetylcholinesterase activity, oxidative stress, and neuroinflammation (Khayal et al., 2024). Additional reports describe gliosis, cerebral edema, and behavioral alterations (PubChem, 2025a).

Propamocarb Hydrochloride (PM)

PM exhibits a narrower toxicological profile, primarily associated with acute and neuromuscular effects such as acetylcholinesterase inhibition, muscle weakness, bradycardia, and impaired coordination (Zhang et al., 2019). Rodent studies indicate altered neurotransmitter balance, reduced locomotor activity, anxiety-like behavior, and memory deficits. PM exposure can also affect metabolism, including bile acid pathways, gut microbiota composition, and trimethylamine (TMA) production, a cardiovascular risk marker (Wu et al., 2018). PM is classified as a skin irritant and sensitizer, whereas CBZ is generally non-irritant.

Comparative Outlook

Overall, CBZ exhibits broader multi-organ toxicity, reproductive effects, and confirmed aneugenicity, whereas PM is mainly associated with acute neurotoxic and metabolic disturbances. These contrasting profiles reflect differences in chemical structure and mode of action rather than persistence alone. CBZ can exert effects via oral, dermal, and inhalation routes (Hashim et al., 2023), supporting its prioritization for human health considerations in surface-water contamination. PM is relevant primarily under short-term or accidental exposure scenarios.

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Table 2. Health effects and toxicological evidence associated with carbendazim (CBZ) and propamocarb hydrochloride (PM), based on PPDB (2025a, b) and PubChem (2025a,b).

Health issue / effect category	PPDB (2025a) – CBZ	PubChem (2025a) – CBZ	PPDB (2025b) – PM	PubChem (2025b) – PM
Neurological effects	–	+ (neurotoxicity syndromes, gliosis, cerebral edema, hemorrhage, acetylcholinesterase inhibition, CNS symptoms)	?	ND
Reproductive and developmental effects	+ (reproductive and developmental toxicity, spermatogenic disorders, testicular effects)	+ (reproductive and developmental effects)	ND	ND
Hepatic effects	+ (liver disorders, hepatomegaly, inflammation, lipid metabolism disturbances)	+ (chemical- or drug-induced liver injury, hepatomegaly, lipid disorders)	ND	ND
Metabolic and nutritional effects	ND	+ (weight changes, lipid metabolism disturbances)	ND	ND
Hematological and immune effects	ND	+ (inflammatory responses, lymphatic disorders)	ND	ND
Carcinogenic / neoplastic effects	?	+ (neoplasms, lymphoma; not classified by IARC)	–	–
Gastrointestinal / microbiome-related effects	ND	+ (gastrointestinal toxicity, dysbiosis, poisoning symptoms)	ND	ND
Renal effects	ND	+ (kidney-related disorders)	ND	ND

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Health issue / effect category	PPDB (2025a) – CBZ	PubChem (2025a) – CBZ	PPDB (2025 b) – PM	PubChem (2025b) – PM
Dermatological effects	– (non-irritant)	ND	+ (skin irritant and sensiti zer)	ND
Acute systemic toxicity	ND	ND	ND	+ (nausea, vomiting, sweating, hypotension, convulsions)
Neuromuscular effects	ND	ND	ND	+ (muscle cramps, weakness, impaired coordination, paralysis)
Systemic / metabolic disturbances	ND	ND	ND	+ (hypoglycemi a, autonomic and gastrointestin al signs)

2.3.5 Dietary and Waterborne Exposure Pathways to Carbendazim

Carbendazim (CBZ) remains a priority for human health consideration due to its historical agricultural use, continued environmental detection, and broader toxicological profile relative to propamocarb hydrochloride. Human exposure to pesticides occurs via occupational, domestic, or environmental routes, including dermal contact, inhalation, and ingestion (Tudi et al., 2021; Hashim et al., 2023). For the general population, ingestion is typically the dominant pathway, mainly through contaminated food and drinking water (Kim et al., 2017).

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Experimental and epidemiological studies demonstrate that CBZ can induce systemic effects following oral exposure, impacting multiple organs in animal models (Hashim et al., 2023). Environmentally, surface waters receiving agricultural runoff, industrial effluents, or inadequately treated wastewater can serve as indirect sources of human exposure, particularly when reused for irrigation. Irrigation with contaminated water may transfer CBZ residues to soils and crops, contributing to dietary intake.

Although aquatic contamination could theoretically lead to trophic transfer, current evidence is largely qualitative, and direct measurements of CBZ bioaccumulation in food chains relevant to human consumption are limited (de Souza et al., 2020). Therefore, the exposure pathways described here represent potential rather than quantitatively established risks.

Exposure via Drinking Water

Drinking-water supply systems in Algeria vary geographically. Northern regions rely mainly on surface reservoirs (dams) and, increasingly, desalination plants, whereas southern areas depend predominantly on groundwater, occasionally supplemented by small dams or desalinated sources. Surface waters—including rivers, dams, and shallow wells—are particularly vulnerable to contamination from agricultural runoff, industrial effluents, and untreated or partially treated wastewater. During periods of intensive irrigation or episodic rainfall, carbendazim (CBZ) and related precursors, such as thiophanate-methyl, may be mobilized into surface waters and, in some cases, infiltrate groundwater.

The potential for drinking-water contamination is influenced by local hydrogeology, agricultural practices, and the efficiency of water-treatment processes. Systematic monitoring of pesticide residues in Algerian drinking-water remains limited, restricting the ability to quantify exposure. For context, the European Union sets a precautionary threshold of 0.1 µg/L for individual pesticides in drinking-water, while Australia's guideline for CBZ is substantially higher (90 µg/L), reflecting toxicological considerations (Dolan et al., 2013; NHMRC and NRMCC, 2011). In the absence of national standards, adopting similar precautionary limits could support protection of public health, especially for persistent compounds such as CBZ.

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Dietary Exposure via Crops

Plant-based foods represent a major potential route of carbendazim (CBZ) exposure for the general population (NHMRC and NRMCC, 2011). Maximum residue limits (MRLs) vary internationally, with stricter thresholds in the EU and UK than in China or Japan; Codex Alimentarius sets lower MRLs (0.05 mg/kg) for staples such as wheat, milk, and cucumbers, and higher limits for certain fruits, e.g., cherries (up to 10 mg/kg) (Wang et al., 2020).

In Algeria, dietary patterns emphasize fruits, vegetables, olive oil, and nuts, with increasing consumption of bread, sweets, and animal products in urban areas (Bach-Faig et al., 2011; Ouhaibi-Djellouli et al., 2021). Commonly consumed crops include potatoes, tomatoes, onions, peppers, strawberries, and nuts such as walnuts and almonds (Cherfi et al., 2014; Chaalal et al., 2019). Beverages like tea and coffee are widely consumed, and although no national residue data exist for coffee, CBZ residues have been reported in tea internationally (Zhou et al., 2018).

National monitoring in Algeria remains limited, but available studies indicate that wheat (mostly imported) and locally produced fruits and vegetables may contain pesticide residues, with occasional MRL exceedances (Mebdoua et al., 2017; Mebdoua and Ounane, 2019). Algeria's role as a wheat importer and exporter of olive oil, citrus fruits, and dates further emphasizes the importance of residue monitoring to protect consumers and comply with international trade standards (Garoui and Aissani, 2024; Mellab, 2025). Globally, CBZ residues have been reported in fresh and dried fruits, vegetables, and large-scale surveillance confirms frequent detection in food commodities, reflecting both field and post-harvest applications (Blasco et al., 2006; Xu et al., 2018; Bouagga et al., 2019; Jardim and Caldas, 2024; Su et al., 2003; Crapnell et al., 2023).

Dietary Exposure via Animal Products

Animals can ingest pesticide residues through contaminated feed or by-products, such as grape pomace or citrus pulp, leading to potential transfer into meat, milk, and eggs (Wadhwa et al., 2015; Alnaimy et al., 2017).

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Although carbendazim (CBZ) is not used in veterinary applications, such feed-to-food transfer has been documented internationally, with residues detected in bovine tissues, milk, and egg yolks (Nam and King, 1994; Choi et al., 2015; Ćosić et al., 2021). Concentrations are generally low or below regulatory limits, yet the pathway remains relevant.

In Algeria, data are extremely limited, as most monitoring focuses on antibiotics or trace metals (Layada et al., 2016; Balli et al., 2023). Dairy products including raw and imported milk are widely consumed (Sraïri et al., 2013), suggesting that animal-derived foods constitute a plausible, albeit unquantified, route of CBZ exposure.

Dietary Exposure via Honey and Pollen

Honey can accumulate pesticide residues from contaminated nectar, pollen, or water. Although carbendazim (CBZ) is not used in apiculture, residues have been reported in honey from Morocco, France, Poland, Romania, and Mexico (Lambert et al., 2013; Valdovinos-Flores et al., 2017; Blaga et al., 2020; Kędzierska-Matysek et al., 2022; Moussaif et al., 2024). In Algeria, pesticides have been detected in honey from Jijel, Tiaret, Laghouat, and Tindouf (Bouhala et al., 2020; Derrar et al., 2024), though CBZ has not yet been specifically reported. Given the mix of local and imported products, exposure via honey cannot be excluded (Haderbache and Mohammedi, 2015).

Pollen may retain higher CBZ concentrations (Li et al., 2017; Ostiguy et al., 2019), and as consumption of pollen supplements increases, it represents a potentially relevant, though poorly characterized, exposure pathway. Collectively, honey and pollen warrant targeted residue surveillance.

Dietary Exposure via Fish

Fish can bioaccumulate carbendazim (CBZ) from contaminated water, sediments, or prey. In Algeria, marine species (sardine, swordfish, little tunny) dominate consumption, with freshwater species (tilapia, pikeperch, carp) contributing less (Mehouel and Fowler, 2022; Naji et al., 2023; Alliouche et al., 2024).

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No Algerian studies have measured CBZ in fish. International reports document residues in edible fish from France, Brazil, Uruguay, and Mexico (Lazartigues et al., 2013; Oliveira et al., 2015; Ernst et al., 2018; Muñoz-Nájera et al., 2022). The absence of CBZ-specific MRLs for fish complicates dietary risk assessment, particularly where fish is a significant protein source (Wang et al., 2020).

Fish consumption therefore represents a plausible, yet unquantified, exposure pathway, highlighting the need to include aquatic food products in national pesticide monitoring.

Taken together, available evidence indicates multiple potential dietary entry points for carbendazim (CBZ), including drinking water, plant-derived foods, animal products, honey and pollen, and fish. Ingestion is likely the dominant exposure route, reflecting CBZ's persistence and mobility in the environment. Although Algerian data are limited, international reports suggest that exposure to carbendazim can occur even without current local use, due to legacy contamination, environmental transport, and global trade. These observations highlight the need to integrate dietary-focused exposure assessments when evaluating CBZ-related human health risks in Mediterranean and North African contexts.

CONCLUSION

This review synthesizes current knowledge on carbendazim (CBZ) and propamocarb hydrochloride (PM) in Algerian surface waters, focusing on environmental persistence and potential human health implications. Despite its deregistration, CBZ residues remain detectable, likely reflecting historical use, inconsistent regulatory enforcement, and continued application of related fungicides such as thiophanate-methyl. In contrast, PM remains authorized and widely used, particularly in greenhouse horticulture, contributing to ongoing diffuse environmental input.

Measured concentrations of both fungicides are generally below international guideline values. However, arid hydrological conditions, shallow aquifers, and intensive agricultural practices may favor chronic, low-level exposure and extended environmental persistence.

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Toxicological evidence, especially for CBZ, indicates potential multi-organ effects including reproductive, developmental, hepatic, renal, and neurological endpoints, highlighting its relevance for human health. Substantial uncertainties remain regarding long-term and cumulative exposures, particularly in the context of limited monitoring.

Table 3. Maximum residue limits (MRLs, mg/kg) for carbendazim in food products according to Codex Alimentarius and selected national regulations.

Food product	Codex (FAO/WHO, 2025)	China	EU	Japan	UK	Reference
Fruits						
Pome fruits	3	5	0.2	3	0.2	Wang et al. (2020)
Pear	3	3	0.2	3	0.2	Wang et al. (2020)
Cherry	10	0.5	0.5	3	0.5	Wang et al. (2020)
Grape	3	3	0.5	7	0.2	Wang et al. (2020)
Lemon	–	0.5	0.7	7	0.7	Wang et al. (2020)
Kiwi fruit	–	0.5	0.3	3	0.1	Wang et al. (2020)
Loquat	–	–	2	3	2	Wang et al. (2020)
Banana	0.2	2	0.1	3	0.1	Wang et al. (2020)
Orange	1	–	–	–	–	Codex
Peach / Nectarine	2	–	–	–	–	Codex
Plum	0.5	–	–	–	–	Codex
Vegetables						
Tomato Zucchini	0.5	–	–	–	–	Codex
Onion	–	–	–	–	–	Codex
Carrot	0.2	–	–	–	–	Codex
Cucumber	0.05	–	–	–	–	Codex
Lettuce	5	–	–	–	–	Codex
Staple crops						
Wheat	0.05	–	–	–	–	Codex
Rice (husked)	2	–	–	–	–	Codex
Potato	–	–	–	–	–	Codex
Peanut	0.1	–	–	–	–	Codex
Animal products						
Meat, milk, eggs	0.05	–	0.05	0.09	0.05	Wang et al. (2020)
Other products						
Honey	–	–	1	–	1	Wang et al. (2020)
Tea	–	5	–	10	0.1	Wang et al. (2020)

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Expanding environmental surveillance across surface waters, food commodities, and other exposure-relevant matrices would strengthen risk characterization. Overall, this synthesis provides a framework for understanding fungicide-related human health risks in Algeria and comparable semi-arid Mediterranean contexts.

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CHAPTER 2
HEALTH RISKS AND QUALITY ASSESSMENT OF
OPEN WELL WATER USED FOR DRINKING IN
BATAGARAWA TOWN, BATAGARAWA LOCAL
GOVERNMENT, KATSINA STATE NIGERIA

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INTRODUCTION

Drinking water quality is a critical factor affecting human health particularly in natural resources dependent countries including Nigeria (Sam et al., 2023). The availability and quality of water for domestic use can be a constraining factor in poverty alleviation and economic recovery resulting in poor health and low productivity, food insecurity and hampered economic development (Ruma, 2019).

The world's water supply is under severe strain because of the rising human population, climate change due to increased greenhouse gas (GHG) emissions, and agricultural intensification, posing a significant challenge in having enough water to meet current demand. According to Zaman et al. (2018), the current global population of 7.3 billion people is expected to rise to over 9 billion by 2050, with the bulk of this growth taking place in developing countries, the majority of which are already experiencing food and water shortages.

Approximately 2 billion people consume water contaminated with faeces (WHO, 2019). Forty-two percent of the people living in Sub-Saharan Africa rely on unimproved water sources for drinking and domestic use (Eberhard, 2019). These water sources contaminations are due to not only anthropogenic factors but also natural factors such as flooding, climate, weathering of parent material, topography, and others (Vadde et al., 2018). Each year, it is estimated that 485,000 people die from diarrhoea because of contaminated drinking water (WHO, 2019). Nigerian urban areas face continuous threat coming from ground water pollution, increasing industrial and agricultural activities coupled with environmental pollution/ degradation and indiscriminate disposal of all kinds of wastes (Ibe et al., 2019).

Water quality can be evaluated using physicochemical and biological parameters (Addisie, 2022). Drinking water quality should meet physicochemical pollutants criteria and be entirely free of pathogens that could harm people's health (Addisie, 2022). A growing concern is the heavy metal pollution of ground water used for drinking notably by the heavy metal Lead (Pb).

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This observation has been linked to rapid urbanization, population growth, agricultural practices, and industrial activities (Badeenezhad et al., 2023), and in Katsina State, the proposed area of study, insecurity that has led to displacement of populations has been linked to heavy metals build up in the environment (Yaradua et al., 2023a, b, c and d).

The availability of potable water for drinking is a problem in many parts of Nigeria (Ruma, 2019) and Batagarawa town the study area is not an exception. The town is located in the suburbs of Katsina City and they share similar physical and relief features. It has also been reported in a study that the water holding capacity of the soil of urban parts of Katsina city is extremely low, making borehole drilling and maintenance very difficult, expensive and uneconomical (Ruma and Tanko, 2016).

This condition has led to the scarcity of water for domestic use in Batagarawa town. A study has reported that about 95% of the population within the study area relied on groundwater as a result of scarce surface water resources in the area (Hassan and Yalwa, 2024). This scarcity of water and none supply of pipe-borne water in Batagarawa town has led to the exploitation of underground water from public open wells in order to meet the domestic demands.

Since the town is in a semi-urban agricultural area, run-off discharge by erosion channels, surface run offs from refuse dumps and auto mechanic repair workshops become necessary in view of the effect of permeability and seepage effects on the recharge and yield of the public open wells, raising the possibility of the pollution of the open wells water. Polluted drinking water has been reported as one of the most important causes of diseases and the transmission of infection (Mustafa et al., 2023).

The significance of the study lies in its potential to bring to light the level of well water quality in selected sampling sites of Batagarawa town and the contributing parameters to that effect. The scope of the study focuses specifically on Batagarawa town located in Batagarawa Local Government, Katsina State.

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The research explores the water quality of sampled public open wells within Batagarawa town. The investigated quality parameters include physico-chemical parameters (Cl⁻, Na⁺, Ca⁺, pH, E.C., Turbidity, Total hardness, Temperature, Dissolved oxygen), bacteriological analysis (Total Coliform; E. Coli) and some selected heavy metals (Pb, Cr, Mn and Fe).

1. MATERIALS AND METHOD

1.1 Study Area

1.1.1 Location

The study was conducted in Batagarawa town, the headquarters of Batagarawa Local Government Area, Katsina State, north-western Nigeria. Batagarawa town is located between Latitude 12°50' and 13°00' North of the equator, and Longitude 07°20' and 07°40' East of the Greenwich meridian (Hassan and Yalwa, 2024) covering an area of 43,300 hectares. Batagarawa town is located at an altitude of 513 m (1,683ft) above sea level.

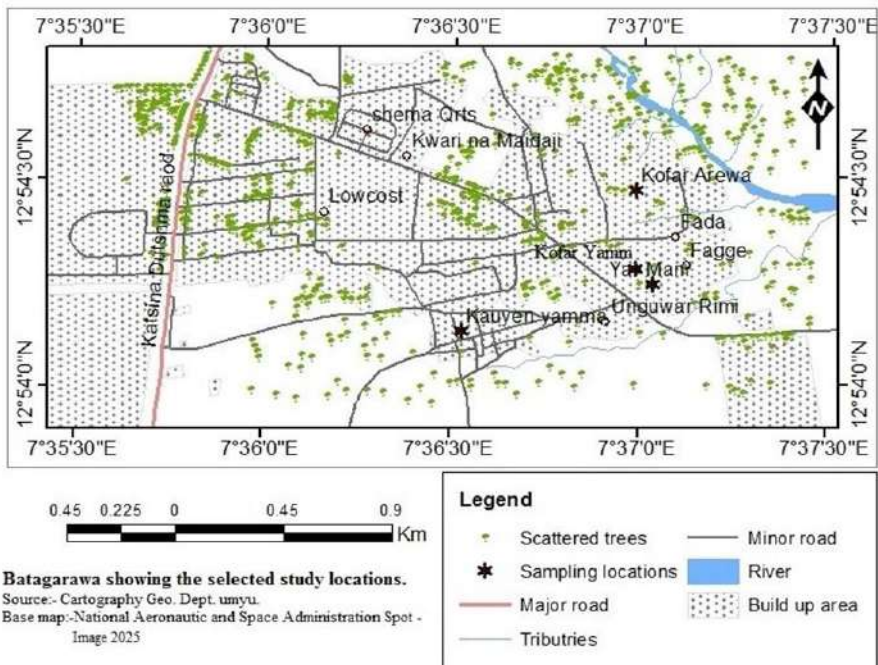


Figure 1. Batagarawa Town

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1.1.2 Climate

The climate of the study area is generally classified as semi-arid characterized by a relatively long period of dry season that last between 7 to 8 months (November to May) and a shorter period of wet season i.e. (June to September) (Ruma, 2016).

Rainfall starts in May and ends in September with an annual range of between 400 to above 800 mm, with an annual total of 877.9 mm (NIMET, 2023). The mean maximum temperature is 34°C (observed maximum of 41.60C), while the mean minimum temperature is 220C (observed minimum of 11.20C) (NIMET, 2023). Four distinct seasons are experienced in the area; these are dry and cool, dry and hot, wet and warm, and dry and warm seasons respectively.

1.1.3 Soil

The soil type includes the brown and reddish brown types, they are coarse light sandy soils which are said to have been formed from wind-sorted desert sand (MLSG, 1977).

1.1.4 Geology

Geologically, about 80% of Katsina state, the home state of Batagarawa town is underlined by the Basement Complex terrain which is characterized by nine geological formations consisting of biotite homeblend granite, coarse biotite homeblend granite, fine grained, granite gneiss, migmatite, porphyritic gneiss, rhyolite, sandstone and Solicited sheared rock (Hassan and Yalwa, 2024).

1.1.5 Vegetation

The study area is composed of the Sudan Savannah vegetation belt, with scanty trees, shrubs and short grasses (Hassan and Yalwa, 2024).

1.1.6 Economy

The main economic activity in the area is farming and majority of the population are peasant farmers that contributes greater percentage of

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agricultural output. Sorghum, millet, cowpea, sesame and groundnut are some of the major crops grown in the area (LawaI, 2010).

1.2 Sampling Location

The sampling for the study was conducted in Batagarawa town from four (4) major points (Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani) that were selected based on the presence of public open wells.

1.3 Sample Population and Size

A total number of nine (9) open wells were counted from 4 areas in the town that have public open wells. Four (4) wells from the 4 designated points were selected. The sample size determination was done following the Taro Yamane Formula (Yamane, 1973) as presented below:

$$n = \frac{N}{1 + Ne^2}$$

Where n = sample size, N = (9) population size, e = error (0.05) reliability level 95%

$$\text{Substituting} = \frac{9}{1 + [9(0.05)]^2} = 3.6 \text{ Approximating} = 4$$

1.4 Sampling Technique and Sample Collection

Simple Random Sampling (SRS) method was applied to collect the samples. Well water samples were collected from four (4) major points in the selected areas (Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani) in Batagarawa town in airtight plastic containers.

1.5 Laboratory Analysis Procedure

1.5.1 Determination of Temperature

The water samples temperature was measured with the help of a mercury thermometer. The bulb of the thermometer was dipped into the water and its temperature was noted down in °C.

1.5.2 Determination of pH

The pH was measured by pH meter of ATC-Model 8689 after the calibration with a standard buffer solution.

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1.5.3 Determination of Electrical Conductivity

The electrical conductivity of the well water samples was measured by conductivity meter (EC 4510 Janway). The device was dipped into the water sample and the reading was record in uS/cm.

1.5.4 Determination of Turbidity

Turbidity was measured by using a nephelometric turbidity meter and the value on the scale was recorded in NTU (Hach, 2020).

1.5.5 Determination of Total Hardness

Hardness was measured using standard analytical method (APHA, 2017).

1.5.6 Determination of Chlorides

A known volume of filtered sample (50 mL) was taken in a conical flask, to which about 0.5 mL of potassium chromate indicator were added and titrated against standard silver nitrate till silver dichromate (AgCrO_4) started to precipitate (APHA, 2017).

Chlorides (Cl^-) = $(A-B) (N) (35.45) / \text{Sample mL}$

Where A = Volume of silver nitrate consumed by the sample; B = Volume of silver nitrate consumed by the blank; N = Normality of silver nitrate.

1.5.7 Determination of Sodium

A standard sodium chloride (NaCl) solution of 1000 mg/L concentration was used. Potassium chromate (K_2CrO_4) was used as an indicator, while silver nitrate (AgNO_3) served as the titrant. The potassium chromate signals the endpoint of the reaction through a visible color change (APHA, 2017).

1.5.8 Determination of Dissolved oxygen (DO)

Dissolved oxygen (DO) was measured using a DO meter (HANNA HI 9143) calibrated with oxygen-saturated water. The sensor was submerged in the sample and allowed to stabilized for 2 minutes before taking the reading values in mg/L (APHA, 2017).

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1.5.9 Determination of Calcium

The calcium concentration in the samples were analysed using EDTA titration, which involves adding a standardized solution of ethylene-di-amine tetra acetic acid (EDTA) to the water sample until a colour change indicates the endpoint, allowing for calculation of the calcium concentration in milligrams per litre (mg/L) based on the volume of EDTA used (APHA, 2017).

1.5.10 Heavy Metals Analysis

The raw, unfiltered water samples (each 100 ml) were taken and subjected to wet digestion. Each 100 ml of the unfiltered water was measured into a 250 ml beaker followed by addition of 20 ml "Analar" nitric acid solution plus 10 ml of 50% hydrochloric acid solution. The acidified water was then evaporated on a hot plate to almost dryness and 5ml of 50% hydrochloric acid was again added and heated for 15 minutes. The beaker was removed and cooled to room temperature before transferring the contents into a 100 ml volumetric flask, and the volume made up to the mark with deionised water (EPA, 2007). Then, the digested water was filtered and analysed for the levels of Pb, Mn and Fe using AA210RAP BUCK Atomic Absorption Spectrometer flame emission spectrometer filter GLA-4B Graphite furnace (East Norwalk USA).

Health Risks Assessment for Heavy Metals in Water Samples

Daily Intake of Metals (DIM) in Samples

The chronic daily intake of metals from drinking the water sample was calculated using the following equation

$$CDI = D \times C_i / BW$$

Where D (L d⁻¹) represents average daily drinking water intake and has a value of 1.488 person⁻¹ d⁻¹ (Zhang et al., 2011), C_i represents the concentration of metal in a sample and the average body weight for the adult and children population was taken as 60 kg (Orisakwe et al., 2015) and 24 kg (Ekhatior et al., 2017) respectively.

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Non-cancer Risks

Non-carcinogenic risks for individual heavy metals of the sample were evaluated by computing the target hazard quotient (THQ) using the following equation (Micheal et al., 2015).

$$\text{THQ} = \text{CDI} / \text{RfD}$$

CDI is the chronic daily heavy metal intake (mg/kg/day) as obtained previously and RfD is the oral reference dose (mg/kg/day). The following reference doses from literature were used (Pb = 0.6, Cd = 0.5, Zn = 0.3, Cu = 0.04, Ni = 0.4) (Li et al., 2013; US-EPA, 2002). To evaluate the potential risk to human health through more than one heavy metal, chronic hazard index (HI) is obtained as the sum of all THQ calculated for individual heavy metals for a particular exposure pathway (NFPCSP Nutrition Fact Sheet, 2011). It is calculated as follows:

$$\text{HI} = \text{THQ}_1 + \text{THQ}_2 + \dots + \text{THQ}_n$$

Where 1, 2 ... n is the individual heavy metals in samples.

When $\text{HI} < 1$ the population is assumed to be safe, and when $1 < \text{HI} < 5$ is a level of concern (Guerra et al., 2012).

Cancer Risks

The possibility of cancer risks in the studied sample through intake of carcinogenic heavy metals was estimated using the Incremental Lifetime Cancer Risk (ILCR) (Liu et al., 2013).

$$\text{ILCR} = \text{CDI} \times \text{CSF} / 60$$

Where, CDI is the chronic daily intake of the carcinogenic heavy metal, mg/kg BW/day which represents the lifetime average daily dose of exposure to the metal, and CSF is the cancer slope factor which is heavy metal-specific and is the risk arising due to a lifetime average dose of 1 mg/kg BW/day (Micheal et al., 2015). The following cancer slope factor for the heavy metal Pb was used; 0.0085 mg/kg/day (Kamunda et al., 2016), ILCR value in the sample represents the probability of an individual's lifetime health risks from carcinogenic heavy metals exposure (Pepper et al., 2012). The level of acceptable cancer risk (ILCR) for regulatory purposes is considered within the range of 10^{-6} to 10^{-4} (Li and Zhang, 2010). The CDI value was calculated based on the following equation.

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$$CDI = (EDI \times EFr \times ED_{tot})/AT$$

Where EDI is the estimated daily intake of metal from ingestion of the sample; EFr is the exposure frequency (365 days/year); ED_{tot} is the exposure duration of 60 years, average lifetime for Nigerians; AT is the period of exposure for non-carcinogenic effects (EFr × ED_{tot}), and 60 years lifetime for carcinogenic effect (Micheal et al., 2015). The cumulative cancer risk as a result of exposure to multiple carcinogenic heavy metals is calculated by the following equation (Liu et al., 2013).

$$\Sigma I_n = ILCR_1 + ILCR_2 + \dots + ILCR_n$$

Where, n = 1, 2 ..., n is the individual carcinogenic heavy metal.

1.5.11 Bacteriological Analysis

Total coliforms and *Escherichia coli* were evaluated using the membrane filtration method (APHA, 2017).

1.6 Statistical Analysis

IBM SPSS Statistics for social statistics version 23 was used for the statistical analysis in the current study. Pearson Correlation was used to compare relationship of measured parameters relative to sampling sites. Descriptive statistics were used to calculate the mean, standard deviation, and range of the physicochemical properties.

2. RESULTS AND DICUSSION

2.1 Results

The public well water samples from Batagarawa town showed varying degree of physicochemical properties (Table 4.1). The mean temperature values recorded in the study for the water samples from Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani were 24.39, 25.19, 24.81 and 25.21 °C respectively (Table 4.1). There was no significant difference between the measured temperatures from the 4 sampling sites.

The mean pH values of the water samples were 6.78, 6.81, 6.72 and 6.71 for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani respectively (Table 4.1).

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These mean pH values were in compliance with the pH recommendation of (6.5 - 8.5) by SON (SON, 2015). There was no significant difference between the measured pH from the 4 sampling sites

Electrical conductivity is the measure of total dissolved ions in the water. From the result presented in Table 4.1, it was revealed that the mean electrical conductivity of the water samples from Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani were 0.250 (20 ms/cm), 0.753 (20 ms/cm), 0.423 (20 ms/cm), and 0.147 (20 ms/cm), with Unguwar Yamma and Yammani having the highest and lowest values respectively (Table 4.1).

The mean turbidity for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani varied between 4.167, 12.100, 6.700 and 2.233 NTU respectively (Table 4.1). The turbidity level of the water samples from Kauyen Yamma and Yammani were in conformity with the standard requirements of 5.0 NTU (SON, 2015). The turbidity of the water samples from Unguwar Yamma and Kofar Arewa were above the acceptable limit.

The highest mean total hardness of 173.470 mg/L was found in Unguwar Yamma while Yammani recorded the lowest mean total hardness of 66.8000 mg/L and for Kofar Arewa was 123.830 mg /L, while Kauyen Yamma has 90.067 mg/L (Table 4.1). The average total hardness for three public open wells samples from Yammani, Kofar Arewa and Kauyen Yamma were not greater than 150 mg/L which was the permissible limit for drinking water by the Standard Organisation of Nigeria (SON, 2015). But in contrast the water sample from the public open well from Unguwar Yamma has a mean total hardness value that was above the regulatory standard.

The mean sodium concentration of the open public wells samples was 4.667 mg/L, 14.333 mg/L, 8.333 mg/L, 3.267 mg/L for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani respectively (Table 4.1). These values are less than WHO and SON desirable limit of 200 mg/L (WHO, 2011; SON, 2015).

The mean chloride concentration of the open public wells samples were 20.300 mg/L, 54.733 mg/L, 30.667 mg/L, 12.433 mg/L for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani respectively (Table 4.1). These values are less than WHO and SON desirable limit of 250 mg/L (WHO, 2011; SON, 2015).

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The mean calcium concentration of the open public wells samples were 12.300 mg/L, 11.600 mg/L, 10.200 mg/L, 12.270 mg/L for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani respectively (Table 4.1). These values are less than WHO and SON desirable limit of 75 mg/L (WHO, 2011; SON, 2015).

The mean dissolved oxygen concentration of the open public wells samples were 5.300 mg/L, 3.867 mg/L, 4.067 mg/L, 5.800 mg/L for Kauyen Yamma, Unguwar Yamma, Kofar Arewa and Yammani respectively (Table 4.1). The values for Unguwar Yamma and Kofar Arewa were within the WHO and SON desirable limit of 5.0 mg/L (WHO, 2011; SON, 2015). While the values for Kauyen Yamma and Yammani were above the desirable limit.

Table 1. Physicochemical Parameters of Open Public Wells Drinking Water Samples in Batagarawa Town

Parameter	Sampling Site			
	Kauyen Yamma	Unguwar Yamma	Kofar Arewa	Yammani
Temperature °C	24.390 ± 0.0208	25.190 ± 0.0153	24.810 ± 0.0200	25.210 ± 0.0200
pH	6.780 ± 0.0116	6.810 ± 0.0153	6.720 ± 0.0153	6.710 ± 0.0252
Conductivity (20 ms/cm)	0.250 ± 0.0173	0.753 ± 0.0289	0.423 ± 0.0153	0.147 ± 0.0058
Turbidity (NTU)	4.167 ± 0.1528	12.100 ± 0.1062	6.700 ± 0.1732	2.233 ± 0.0577
Total Hardness (mg/L)	90.067 ± 2.7590	173.470 ± 1.2740	123.830 ± 1.150	66.800 ± 0.4359
Sodium (Na) mg/L	4.667 ± 0.3055	14.333 ± 0.2082	8.333 ± 0.2309	3.267 ± 0.3786
Chloride (Cl) mg/L	20.300 ± 0.3606	54.733 ± 0.7371	30.667 ± 0.6506	12.433 ± 0.3786
Calcium (Ca) mg/L	12.300 ± 0.1000	11.600 ± 0.1000	10.200 ± 0.1732	12.270 ± 0.2082
Dissolve Oxygen (mg/L)	5.300 ± 0.1732	3.867 ± 0.1155	4.067 ± 0.1155	5.800 ± 0.2646

Values are presented as mean ± standard deviation

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The result of the bacterial count of water samples of open public wells of Batagarawa town is shown in Table 2. From the results, all the bacterial count in the water samples represented by the total Coliforms and *Escherichia coli* lies within the stipulated standards of WHO/SON (2017; 2015) for total Coliforms and *Escherichia Coli* count in drinking water.

Table 2. Bacterial Count in Open Public Wells Drinking Water Samples in Batagarawa Town

Parameter	Sampling Site			
	Kauyen Yamma	Unguwar Yamma	Kofar Arewa	Yammani
Total Coliforms (CFU/10ml)	0.5774 ± 3.333	BDL	BDL	BDL
<i>Escherichia coli</i> (CFU/100ml)	5.300 ± 0.1732	3.867 ± 0.1155	4.067 ± 0.1155	5.800 ± 0.2646

Tables 3 present the heavy metals (Pb, Fe, Mn, and Cr) in the well water samples analysed. From the table, the heavy metal Pb from Unguwar Yamma water sample has the highest concentration, while Mn from Kofar Arewa water sample recorded the lowest concentration. From the results the mean concentrations for the heavy metal Pb in the water samples from all the sampling sites were above the permissible limit for the heavy metal Pb in drinking water (WHO, 2011; SON, 2015).

The mean concentration values for the heavy metals evaluated is in the decreasing order Pb > Mn > Cr > Fe. From the results, except for the mean Pb concentrations in the water samples which are above the safety limit, the concentrations of the heavy metals Mn, Cr and Fe in the water samples were lower than the recommended levels proposed by WHO/SON.

The results for the statistical analysis using Pearson Correlation (Table 4) has revealed that a positive correlation exist though not significant in the heavy metals concentration in water sample from Kofar Yamma and Unguwar Yamma (.631), an indication that the source of metal pollution is from the same source. There was a negative correlation between heavy metals in the water sample from Kofar Yamma and Kofar Arewa (-.386), an indication that the source of metal pollution is from different source.

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The correlation between Yammani and Kofar Arewa was also negative (-.373.), while Yammani and Kofar Yamma have a significant correlation at the 0.01 level (2-tailed).

Table 3. Mean Heavy Metals Concentrations (mg/L) in Open Public Wells Drinking Water Samples in Batagarawa Town

Heavy Metal	Sampling Site			
	Kauyen Yamma	Unguwar Yamma	Kofar Arewa	Yammani
Lead	1.417 ± 0.0005	1.514 ± 0.0009	1.112 ± 0.0012	1.335 ± 0.0007
Iron	0.196 ± 0.0010	0.787 ± 0.0006	0.036 ± 0.0006	0.644 ± 0.0010
Chromium	1.014 ± 0.0016	1.436 ± 0.0014	1.417 ± 0.0008	1.372 ± 0.0011
Manganese	0.339 ± 0.0003	0.377 ± 0.0008	0.033 ± 0.0012	0.227 ± 0.0006

Table 4. Heavy Metals Correlation Analysis For the Sampling Sites from Batagarawa Town

Site	Correlation		Site		
		Kofar Yamma	Unguwar Yamma	Kofar Arewa	Yammani
Kofar Yamma	Pearson Correlation Sig. (2-tailed) N	1 4	.631 .369 4	-.386 .614 4	1.000** .000 4
Unguwar Yamma	Pearson Correlation Sig. (2-tailed) N	.631 .369 4	1 4	.402 .598 4	.636 .364 4
Kofar Arewa	Pearson Correlation Sig. (2-tailed) N	-.386 .614 4	.402 .598 4	1 4	-.373 .627 4
Yammani	Pearson Correlation Sig. (2-tailed) N	1.000** .000 4	.636 .364 4	-.373 .627 4	1 4

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Table 5. Regulatory Standards for Water Quality Parameters

Parameter	Regulatory Body	
	WHO	SON
Temperature	Ambient	Ambient
pH	6.5 - 8.5	6.5 - 8.5
Conductivity ($\mu\text{S}/\text{cm}^2$)	500	1000
Turbidity (NTU)	5 Units	5 Units
Total Hardness (mg/L)	100	150
Sodium (Na) mg/L	200	200
Chloride (CL) mg/L	250	250
Calcium (Ca) mg/L	75	75
Dissolve Oxygen (mg/L)	5.0	5.0
Lead (mg/L)	0.05	0.01
Iron (mg/L)	0.3	0.3
Mn(mg/L)	0.1	0.2
Total Coliforms (CFU/10ml)	10	10
<i>Escherichia coli</i> (CFU/100ml)	0	0

The results for the Chronic Daily Intakes of Heavy Metals (CDI) in adults and children were lower than the tolerable daily intake limit set by the USEPA (tables 6 and 7). The order of sequence of CDI in both adults and children is as follows: Pb> Cr > Fe > Mn.

Table 6. Chronic Daily Intakes of Heavy Metals in Adult from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	Heavy Metal			
	Pb	Fe	Cr	Mn
Kofar Yamma	0.0351	4.8608E-03	0.0252	9.3000E-03
Unguwar Yamma	0.0376	0.0195	0.0356	9.3496E-03
Kofar Arewa	0.0258	8.9280E-04	0.0351	8.1840E-04
Yammani	0.0331	0.0160	0.0340	5.6296E-03

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Table 7. Chronic Daily Intakes of Heavy Metals in Children from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	Heavy Metal			
	Pb	Fe	Cr	Mn
Kofar Yamma	0.0843	0.0117	0.0604	0.0224
Unguwar Yamma	0.0901	0.0468	0.0855	0.0224
Kofar Arewa	0.0662	2.1427E-03	0.0843	1.9642E-03
Yammani	0.0795	0.0383	0.0817	0.0135

Tables 8 and 9 represents the calculated THQ and HRIs in the children and adult population from consumption of the water samples. From the results, the THQ and HRI are all below 1 for the adults population, an indication of low non-cancer health risks from drinking of the water samples in the adults population. While the calculated HRI in the children population was above 1, an indication of a heightened non-cancer health risks to the children population from intake of the water samples. The order of THQ sequence for individual heavy metals is as follows: Mn > Cr > Pb > Fe, a trend similar for both the adult and children population.

Table 8. Target Hazard Quotient (THQ) and Health Risk Index (HRI) in Adult from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	THQ				HRI
	Pb	Fe	Cr	Mn	
Kofar Yamma	0.0585	6.9440E-03	0.0840	0.6643	0.8137
Unguwar Yamma	0.0627	0.0279	0.1187	0.6679	0.8772
Kofar Arewa	0.0430	1.2754E-03	0.1170	0.0585	0.2198
Yammani	0.0552	0.0229	0.1133	0.4021	0.5935

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Table 9. Target Hazard Quotient (THQ) and Health Risk Index (HRI) in Children from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	THQ				HRI
	Heavy Metal				
	Pb	Fe	Cr	Mn	
Kofar Yamma	0.1405	0.0167	0.2013	1.6000	1.9585
Unguwar Yamma	0.1502	0.0669	0.2850	1.6000	2.1021
Kofar Arewa	0.1103	3.0610E-03	0.2810	0.1403	0.5347
Yammani	0.1325	0.0547	0.2723	0.9643	1.4238

The Incremental lifetime cancer risks (ILCR) and the cumulative incremental lifetime cancer risks (Σ ILCR) are presented in tables 10 and 11. From the tables, the ILCR values were at the threshold level of 1.0×10^{-4} for Pb in both the children and adults population and Cd in adult and above the threshold for Cd in children and Ni in adult and children, while the Σ ILCR is above the threshold in both adult and children in the water sample. The highest contributor to cancer risk is Ni.

Table10. Incremental Lifetime Cancer Risk (ILCR) and Cumulative Incremental Lifetime Cancer Risk (Σ ILCR) in Adult from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	ILCR		Σ ILCR
	Pb	Cr	
Kofar Yamma	2.9834E-04	0.0125	0.0128
Unguwar Yamma	3.1960E-04	0.0178	0.0181
Kofar Arewa	2.1930E-04	0.0176	0.0178
Yammani	2.8135E-04	0.0170	0.0178

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Table 11. Incremental Lifetime Cancer Risk (ILCR) and Cumulative Incremental Lifetime Cancer Risk (Σ ILCR) in Adult from Drinking Water from Open Public Wells Drinking Water Samples in Batagarawa Town, Katsina state, Nigeria

Site	ILCR		Σ ILCR
	Pb	Cr	
Kofar Yamma	7.1655E-04	0.0302	0.0309
Unguwar Yamma	7.6585E-04	0.0428	0.0436
Kofar Arewa	5.6270E-04	0.0423	0.0429
Yammani	6.7575E-04	0.0485	0.0492

3. DISCUSSION

3.1 Temperature

It has been stated that high water temperature enhances the growth of microorganisms (WHO, 2008). Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature (APHA, 2017). The mean values of water samples from the public open wells in this study is an indication that the open water wells of Batagarawa town have mean temperatures that can support the growth of mesophilic microorganisms which requires temperature ranges of 20 to 45 °C (Bakobie et al., 2015). The mean temperature range in this study was below the temperature range reported by Ruma and Tanko (2016) in water samples from Ajiwa dam irrigation area, Katsina state. But the values reported are in agreement with the report of Onah et al. (2019) for well water samples from Agbani Road, Abakpa and Obiagu, Enugu Nigeria.

3.2 pH

pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration (Spellman, 2017; Edzwald, 2010). It is a dimensionless number indicating the strength of an acidic or a basic solution (Das et al., 2017). The mean pH reported in study is in agreement with the report of Ibrahim and Nuraddeen (2014) in water samples from hand dug wells in Dutsinma metropolis, Katsina State and the report of Mustapha and Saidu (2020) in well water samples from rural areas of Katcha Local Government Area, Niger State.

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3.3 Electrical Conductivity

Conductivity is the numerical expression of the ability of water to carry an electric current at 25°C and a measure of free ion (charged particles) content in the water (Ogunkolu et al., 2021). These ions can come from natural sources such as bedrock, or human sources such as storm water runoff. The values indicate the extent to which chlorides, nitrates, sulphates, phosphates, sodium, magnesium, calcium, iron and aluminium ions are present in the water samples (Ogunkolu et al., 2021). The mean electrical conductivity values obtained for the water samples were in compliance with the SON standards of 1000 $\mu\text{S}/\text{cm}^3$ (SON, 2015) for drinking water. This also shows that contaminations due to dissolve ions are relatively low. Conductivity of a body of water has no health implications, but it is an important criterion in determining the suitability of water and waste water for irrigation and other uses (Thriodore, 2004). The mean E.C finding in this study is in line with the studies of Owuna (2012) in Otukpo town, Benue state, Ruma (2011 and 2013) in Urban Katsina, Katsina state, Ruma (2016) in Ajiwa dam irrigation area, Katsina state and Ogunkolu (2021) in Idah, Kogi state. Where all the electrical conductivity falls within the regulatory bodies standard for EC of drinking water (SON, 2015; WHO, 2017). But the mean values were lower than the EC values (range: 13730-20470 mg/L) reported for water samples from Rupsha river of Khulna region of Bangladesh (Shahidul Islam et al., 2018).

3.4 Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to presence of suspended particles. Turbidity has no direct health impact but can harbour microorganisms protecting them from disinfection and can entrap heavy metals and biocides. This can bring problem in water treatment process and can also be a potential risk of pathogen in treated water (SON, 2015). The mean turbidity values recorded in this study that was within the permissible limits for WHO and SON differ with reported mean value of 119mg/L reported by Godwin and Oborakpororo (2019) in a study conducted the Nigerian city of Warri.

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3.5 Total Hardness

Hardness is the traditional indicator of a water's ability to react with soap. The mean values of Total Hardness in this study ranged between 66.800 to 173.470 mg/L. The highest mean range obtained in this study were found to be above the standard limit set by WHO/SON for drinking water (100/150 mg/L).

3.6 Chlorides

Chlorides are mineral salts and are not affected by biological actions (Sulaiman et al., 2018). High chloride concentration increases the corrosive nature of water. It renders the water salty which makes it unsuitable for household use and commercial food production (Jidauna et al., 2013). In this study, the content of chloride ion ranged from 12.433 to 54.733 mg/L in the well water samples. Thus the water from all the samples recorded low levels of chloride and were within permissible limit recommended by the WHO/SON (250 mg/L) for drinking water. The recorded values in this study were lower than those reported by Ruma (2013) in Urban Katsina, Katsina state, Odiba et al. (2014) in well water samples from Wukari town Taraba state, Nigeria, but are higher than the range reported by Ruma and Tanko (2016) in water samples from irrigated site of Ajiwa dam, Katsina state and Sulaiman et al. (2018) in water samples from different sources in Gombe city, Gombe state Nigeria

3.7 Sodium

The mean Sodium concentration recorded in this study is similar to the findings of Mustapha and Saidu (2020) of mean sodium concentration in well water samples from rural areas of Katcha Local Government Area, Niger State.

3.8 Calcium

The mean calcium concentrations from all the sampling sites in this study that was within the acceptable limits for calcium in drinking water (WHO, 2011;SON, 2015) is in agreement with the values reported by Oluwagbayide and Abulude (2018) and Ojo et al. (2016) in their studies.

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3.9 Dissolved Oxygen (DO)

Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality, it is a key test of water pollution (APHA, 2017). The higher the concentration of dissolved oxygen, the better the water quality. Dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people (Omer, 2019). The present study has revealed that the mean concentration of dissolved oxygen ranged between 3.867 to 5.800 mg/L. This observation is in line with what was reported earlier by Sulaiman et al. (2018).

3.10 Total Bacterial Count

Total Coliform Count Indication of faecal contamination (SON, 2015). *E. coli* is one of the main cause of morbidity and mortality among children. It is responsible for urinary tract infections, bacteraemia, meningitis, diarrhoea acute renal failure and haemolytic anaemia (SON, 2015). The mean total Coliform and *E. coli* recorded in this differ from what was reported by Mustapha and Saidu (2020) of which they reported their water samples as having traces of *E. coli* (cfu/ml), total coliform (cfu/100ml) and total bacterial count (cfu/ml) that exceeded the World Health Organization (WHO) limit for drinking.

3.11 Heavy Metals

The mean concentration values for the heavy metals evaluated is in the decreasing order $Pb > Mn > Cr > Fe$. From the results, except for the mean Pb concentrations in the water samples which are above the safety limit, the concentrations of the heavy metals Mn, Cr and Fe in the water samples were lower than the recommended levels proposed by WHO/SON. Compared to values reported in the literature, the mean Pb concentrations in water samples are higher than the values reported for well water samples in selected communities Gbaramutu Kingdom, Niger Delta, Nigeria (Sam et al., 2023), Tembalang District, Semarang city, Indonesia (Prabowo et al., 2021) and rural areas of Katcha Local Government Area, Niger State (Mustapha and Saidu, 2020).

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Mean Pb values that were above the permissible limits have been reported in well water samples from urban Katsina city, Katsina State, Nigeria (Ruma, 2019). Similar mean Pb concentrations in water above permissible limits have been reported in various studies conducted in Katsina (Yaradua et al., 2018; Yusuf et al., 2018; Yaradua et al., 2021). The observed mean concentration values of the heavy metals Mn, Fe and Cr in the present study were within the range of mean values reported for well water samples in Ilorin Metropolitan communities, Kwara state (Adebayo et al., 2022), Smeda south Gundar zone of Amhara regional state Ethiopia (Addisie et al., 2022).

3.12 Heavy Metals Health Risk Assessment

Heavy Metals Health risk assessment was based on the assumption that a particular population exposed to metals through water may suffer harmful effects. The assumption was that human adults and children are exposed to metals through drinking of the water samples all the days in a year during the life span. Health risk to the population was assessed by estimating the target hazard quotient (THQ), and health risk index (HRI) for non-carcinogenic health risks and the incremental lifetime cancer risk (ILCR) for carcinogenic health risks for the study metals. The results of THQ and HRI in the values above 1 reported in this study for the children population is in contrast to what was earlier reported for water sample from Are-Dam Katsina state Nigeria, with a THQ and HRI values below 1 (Yaradua et al., 2021). The Incremental lifetime cancer risks (ILCR) values were at the threshold level of 1.0×10^{-4} for Pb in children and in adults, and above the threshold for Cr in children and in adults, while the Σ ILCR is above the threshold in both adults and children in the water samples. The highest contributor to cancer risk is Cr. Similar to the results in this study, heavy metals have been reported to contribute to the cancer burden in a previous study in cancer risks of heavy metals in water sample conducted in Katsina state, Nigeria (Yaradua et al., 2021).

CONCLUSION

This study investigated some physicochemical parameters, total bacterial count and selected heavy metals used to evaluate water quality in water samples from public open wells in Batagarawa town.

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The water samples showed varying degree of physicochemical properties. The turbidity of the water samples from Unguwar Yamma and Kofar Arewa were above the acceptable limit. But in contrast the water sample from the public open well from Unguwar Yamma has a mean total hardness value that was above the regulatory standard. The mean dissolved oxygen concentration values for Kauyen Yamma and Yammani were above the desirable limit. All the rest of the physicochemical parameters and the total Coliforms and Escherichia coli bacterial in the water samples lies within the stipulated standards. From the results the mean concentrations for the heavy metal Pb in the water samples from all the sampling sites were above the permissible limit. The calculated HRI in the children population indicated a heightened non-cancer health risk. The ILCR for the heavy metal Cr indicated a potential cancer risk to both the children and adult population. In all, the water samples from the open public wells of Batagarawa town, Katsina state, Nigeria are not fit for human consumption.

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**CHAPTER 3
ASSESSMENT OF PHYSICOCHEMICAL
PROPERTIES OF BOREHOLE AND WELL WATER
AND THEIR IMPLICATIONS FOR PUBLIC HEALTH
IN KAZAURE, NIGERIA**

¹Oyebanji Kehinde AMINAT

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INTRODUCTION

Background of The Study

Water is an essential resource for human survival, economic development, and environmental sustainability. Access to safe drinking water is a fundamental human right and a key component of public health. However, in many developing countries, including Nigeria, access to clean and safe water remains a major challenge due to rapid population growth, urbanization, and environmental pollution.

In Kazaure, Jigawa State, a significant proportion of the population depends on borehole and well water for daily consumption due to the inadequacy of municipal water supply. While these sources are often considered reliable, their quality is not always guaranteed. Groundwater contamination can occur due to natural geological processes as well as human activities such as agricultural runoff, improper waste disposal, and industrial discharge.

Physicochemical parameters such as pH, turbidity, dissolved solids, and hardness play a crucial role in determining water quality. Deviations from acceptable standards may pose serious health risks, including waterborne diseases and long-term health complications. Therefore, regular assessment of water quality is essential to ensure public safety.

This study aims to assess the physicochemical characteristics of borehole and well water in Kazaure and evaluate their compliance with international water quality standards.

The degradation of water quality poses significant public health concerns. The consumption of contaminated water can lead to waterborne diseases such as gastroenteritis, cholera, and other gastrointestinal illnesses. Moreover, prolonged exposure to certain contaminants may have chronic health effects, including potential links to diseases such as cancer, developmental disorders, and endocrine disruption. Vulnerable populations, such as pregnant women, children, and the elderly, are at an increased risk, necessitating urgent attention to ensure their well-being

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Statement of the Problem

The increasing reliance on borehole and well water sources in Kazaure Town has become a critical concern given the rapid urbanization and industrialization observed in the region (Smith et al., 20XX; Jones and Brown, 20YY). Despite their vital role in meeting the water demands of the community, there is a notable dearth of comprehensive physicochemical analyses, leaving the residents vulnerable to potential health risks associated with waterborne contaminants (World Health Organization, 20ZZ).

The burgeoning demand for borehole and well water in Kazaure Town, exacerbated by rapid urbanization and industrial growth, underscores a pressing concern: the lack of comprehensive physicochemical analyses of these alternative water sources. This absence of detailed assessments leaves the community vulnerable to potential health risks associated with waterborne contaminants and impedes the development of effective strategies for sustainable water resource management.

The escalating demand for borehole and well water in Kazaure Town, coupled with the burgeoning urbanization and industrialization, underscores a critical issue that demands immediate attention: the lack of in-depth physicochemical analyses of these alternative water sources. This absence not only places the community at risk of potential health hazards but also obstructs the formulation of comprehensive strategies essential for sustainable water resource management.

1. AIM OF THE STUDY

The aim of this study is to assess the quality of borehole and well water in Kazaure by determining their physicochemical parameters.

Objectives of the Study

The overarching aim of this study is to conduct a comprehensive physicochemical analysis of borehole and well water in Kazaure Town, addressing the critical gaps in understanding the quality and safety of these alternative water sources. The following objectives have been formulated to guide the research, ensuring a thorough exploration of the various facets influencing water quality in the region.

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- To assess the physicochemical parameters of borehole and well water in Kazaure.
- To identify potential contaminants and possible sources of pollution.
- To evaluate compliance of the water samples with WHO drinking water standards.
- To Explore the Impact of Climate and Land Use Dynamics.

Research Questions

- What are the key physicochemical parameters characterizing borehole and well water in Kazaure Town?
- What contaminants are present in borehole and well water in Kazaure Town?
- To what extent do these water sources comply with established quality benchmarks?
- How do climate patterns influence the physicochemical parameters of borehole and well water?

Significance of the Study

The significance of this study transcends the immediate geographic context of Kazaure Town. It encompasses improvements in public health, environmental sustainability, policy development, community empowerment, climate change resilience, global knowledge sharing, and scientific advancements, collectively contributing to the overall well-being of communities and ecosystems. Again, this study extends far beyond the immediate geographic context of Kazaure Town. It encompasses improvements in public health, environmental conservation, informed policy development, community empowerment, climate change resilience, and global contributions to the understanding of water quality dynamics in evolving urban landscapes.

Scope of the Study

The scope of this study is defined by the geographical, temporal, and thematic boundaries within which the research will be conducted.

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It is crucial to delineate the parameters to ensure the research is focused, feasible, and able to generate meaningful insights. By establishing a clear scope, this study aims to provide a focused and comprehensive analysis of borehole and well water in Kazaure Town, offering valuable insights and actionable recommendations for local authorities, policymakers, and the community at large.

Limitation of the Study

Despite the meticulous design and execution of the research, it is essential to acknowledge certain limitations that may influence the interpretation and generalizability of the study findings. These limitations include:

- **Limited Generalizability.** The findings of this study are specific to the geographical context of Kazaure Town. While the insights gained are valuable for local water management, caution should be exercised when generalizing the results to other regions with distinct geological, hydrogeological, and socio-economic characteristics.
- **Sampling Constraints.** The study's scope involves a representative sample of boreholes and wells in Kazaure Town. However, variations in water quality may exist at a more granular level, and the chosen sampling sites may not capture all potential sources of heterogeneity in the town.
- **Temporal Dynamics.** The study's temporal scope is limited to a defined period, potentially overlooking long-term trends or cyclical variations in water quality. Longer-term monitoring would provide a more comprehensive understanding of seasonal and annual fluctuations.
- **Resource Constraints.** The extent of the study may be constrained by available resources, including financial, human, and time resources. This could impact the number of sampling sites, the frequency of data collection, and the depth of analysis that can be feasibly conducted.

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Operational Definition of Key Terms

- Borehole Water. For the purpose of this study, borehole water refers to groundwater extracted through drilled wells specifically designed to tap into underground aquifers.
- Well Water. Well water, as defined in this study, pertains to groundwater sourced from traditional wells, typically excavated or dug to access shallow aquifers.
- Physicochemical Parameters. Physicochemical parameters encompass measurable attributes that describe the physical and chemical characteristics of water.
- Contaminants. Contaminants in this study refer to substances present in borehole and well water that may have adverse effects on human health or the environment
- Compliance with Water Quality Standards. Compliance with water quality standards denotes the degree to which the physicochemical parameters and contaminant levels in borehole and well water align with established national and international guidelines.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Water quality assessment is a multidimensional process that involves analyzing physical, chemical, and biological parameters. Previous studies have shown that groundwater quality is influenced by both natural and anthropogenic factors.

Physicochemical parameters such as pH indicate the acidity or alkalinity of water, while turbidity reflects the presence of suspended particles. High turbidity levels may indicate contamination and can affect water treatment processes. Electrical conductivity provides information about dissolved ions, while total dissolved solids (TDS) measure the concentration of dissolved substances in water. Urbanization and agricultural activities have been identified as major contributors to groundwater contamination. Fertilizers, pesticides, and industrial waste can introduce harmful substances into water

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sources. Additionally, poor sanitation practices increase the risk of microbial contamination.

The World Health Organization (WHO) has established guidelines for drinking water quality to protect public health. Compliance with these standards is essential to prevent waterborne diseases and ensure safe water consumption.

Recent studies emphasize the importance of community engagement and sustainable water management practices. Public awareness and education play a vital role in protecting water resources and promoting safe usage.

2.1 Conceptual Review

2.1.1 Water Quality

Water quality assessment is a multidimensional endeavor, focusing on parameters that determine the suitability of water for consumption and ecological sustainability. Parameters such as pH, turbidity, dissolved oxygen, hardness, and specific ion concentrations serve as crucial indicators of water quality, providing insights into the composition of borehole and well water (EPA, 2012; Sawyer et al., 2003).

2.1.2 Urbanization and Industrialization

Unplanned urbanization and industrial expansion have profound implications for water quality. The literature underscores that rapid urban growth introduces pollutants into groundwater, impacting the physicochemical parameters of alternative water sources like boreholes and wells (Bartram et al., 2014). Understanding the dynamics of urbanization is crucial for contextualizing water quality challenges in Kazaure Town.

2.1.3 Regulatory Frameworks

Effective water quality management relies on robust regulatory frameworks and standards. The World Health Organization (WHO) provides guidelines, but the implementation and enforcement of these standards vary globally (Bartram et al., 2014). A critical review of existing regulatory frameworks is imperative to identify gaps and challenges in governing the quality of borehole and well water in Kazaure Town.

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2.1.4 Community Engagement

The literature emphasizes the role of community engagement in water quality research. Local knowledge, practices, and perceptions are integral components for a holistic understanding of water usage (Hurlimann et al., 2015). Engaging the community in monitoring and managing water resources fosters a sense of responsibility, contributing to sustainable practices.

2.2 Conceptualizing Physicochemical Parameters

pH as a Key Indicator

The pH level of water serves as a critical indicator of its acidity or alkalinity. In the context of water quality, pH profoundly influences chemical reactions, the solubility of minerals, and the overall stability of aquatic ecosystems (EPA, 2012). The conceptualization of pH involves recognizing its dynamic nature and the potential influence of anthropogenic activities on this parameter.

Turbidity and its Implications

Turbidity, a measure of water clarity, holds implications for both aesthetic and health-related aspects of water quality. High turbidity levels can affect light penetration, disrupt aquatic habitats, and indicate the presence of suspended particles or pathogens (Sawyer et al., 2003). Conceptualizing turbidity involves considering its multifaceted role in assessing water quality and potential sources of turbidity in the study area.

Dissolved Oxygen and Aquatic Life

Dissolved oxygen is vital for the survival of aquatic organisms, and its concentration reflects the health of water bodies. This parameter is intricately linked to factors such as temperature, atmospheric pressure, and the presence of organic matter (EPA, 2012). Conceptualizing dissolved oxygen involves recognizing its role as an essential indicator of water quality and understanding the factors influencing its levels.

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Hardness and Water Composition

Water hardness, determined by the concentration of calcium and magnesium ions, influences the taste, texture, and suitability of water for various purposes. Conceptualizing water hardness requires an understanding of the geological characteristics of the region, as well as the potential impacts of human activities on the mineral composition of borehole and well water (Sawyer et al., 2003).

Specific Ion Concentrations

The presence of specific ions, such as nitrate and chloride, can have significant implications for water quality. Nitrate contamination, often linked to agricultural activities, poses health risks, particularly for infants (EPA, 2012). Conceptualizing specific ion concentrations involves considering the sources and potential health consequences of these ions in the study area.

Integrating Physicochemical Parameters

The review of these physicochemical parameters highlights their interconnectedness and the need for a holistic approach to water quality analysis. A conceptual framework that considers the simultaneous influence of pH, turbidity, dissolved oxygen, hardness, and specific ion concentrations is crucial. This integration ensures a comprehensive understanding of the physicochemical composition of borehole and well water in Kazaure Town.

Heavy Metals as Contaminants

Heavy metals, including lead, arsenic, and cadmium, are significant contaminants that can infiltrate groundwater. These pollutants often originate from industrial discharges, agricultural runoff, or geological sources (EPA, 2012). Conceptualizing heavy metal contamination involves recognizing their toxicity, persistence, and the potential health risks associated with their presence in water sources.

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2.3 Conceptualizing Physicochemical Parameters

Pathogens and Microbial Contamination

Microbial contamination, primarily in the form of bacteria, viruses, and parasites, poses a direct threat to public health. Fecal coliforms, for instance, are indicative of sewage or fecal contamination and can lead to waterborne diseases (Sawyer et al., 2003). Conceptualizing microbial contamination involves understanding the sources, pathways, and preventive measures to address potential health hazards.

Organic Pollutants and Agricultural Runoff

Organic pollutants, such as pesticides and herbicides, can enter water sources through agricultural runoff. These contaminants have implications for both human health and ecosystem integrity (EPA, 2012). Conceptualizing the presence of organic pollutants involves considering agricultural practices, soil composition, and the potential for runoff to impact borehole and well water quality.

Emerging Contaminants

The conceptual framework expands to include emerging contaminants, encompassing pharmaceuticals, personal care products, and industrial chemicals. These substances, though not traditionally monitored, have gained attention for their potential long-term effects on human health and the environment (Richardson and Kimura, 2016). Conceptualizing emerging contaminants involves acknowledging the evolving nature of water quality challenges and the need for proactive monitoring.

Interactions and Synergies

A critical aspect of this conceptualization is recognizing the potential interactions and synergies among various contaminants. For instance, the presence of heavy metals alongside microbial contamination may exacerbate health risks. Understanding these complex interactions ensures a more accurate assessment of the overall water quality profile in Kazaure Town.

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Localized Sources and Variation

Conceptualizing physicochemical parameters also requires consideration of localized sources and variations. The geological composition of the region, industrial activities, and specific land use patterns contribute to the heterogeneity of water quality. Recognizing these localized influences is crucial for targeted and context-specific interventions.

**2.4 Conceptualizing Physicochemical Parameters (Part C):
Water Quality Standards and Compliance**

Established Water Quality Standards

Water quality standards, set by international organizations like the World Health Organization (WHO) and local regulatory bodies, define acceptable levels of contaminants and physicochemical parameters in drinking water. These standards serve as crucial reference points for assessing the quality of borehole and well water (Bartram et al., 2014). Conceptualizing these standards involves recognizing the comprehensive criteria they encompass.

Parameters and Limits

The conceptual framework extends to delineating the specific parameters and their permissible limits outlined in water quality standards. For instance, acceptable pH ranges, maximum levels of heavy metals, and limits on microbial contamination are defined to safeguard public health. Conceptualizing these parameters involves understanding their individual and collective significance in maintaining water quality within safe bounds.

Compliance Assessment Methods

Conceptualizing compliance assessment methods is essential for gauging adherence to established standards. This involves developing an understanding of the techniques and protocols used to measure and monitor physicochemical parameters. Compliance assessments typically entail regular sampling, laboratory analyses, and comparison of results against predefined standards (Bartram et al., 2014).

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Temporal and Spatial Variations

The conceptual framework recognizes that water quality is subject to temporal and spatial variations. Compliance assessments need to consider seasonal fluctuations, long-term trends, and localized influences that may impact the adherence to standards. Conceptualizing these variations ensures a nuanced evaluation that goes beyond static assessments.

Implications of Non-Compliance

Understanding the implications of non-compliance is a crucial aspect of the conceptual review. Non-compliance with water quality standards can have severe consequences for public health, ranging from acute waterborne illnesses to chronic health conditions (Prüss-Ustün et al., 2019). Conceptualizing the potential outcomes of non-compliance underscores the urgency of maintaining water quality within established limits.

Stakeholders Responsibilities

Conceptualizing water quality standards also involves recognizing the responsibilities of various stakeholders, including water management authorities, regulatory bodies, and the community. Stakeholders play a vital role in ensuring that standards are upheld through effective governance, monitoring, and community engagement.

Community Awareness and Empowerment

Incorporating community awareness and empowerment into the conceptual framework recognizes the role of informed communities in ensuring compliance. Conceptualizing strategies for raising awareness and empowering the community to actively participate in water quality monitoring enhances the overall effectiveness of compliance assessments (Hurlimann et al., 2015).

2.4.2 Sampling Strategies and Representatives

Empirical studies often vary in their sampling strategies, influencing the representatives of data. Understanding the considerations behind random, stratified, or purposive sampling methods is crucial.

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Additionally, recognizing the impact of sampling depth, frequency, and location on data quality ensures that the study's sampling strategy aligns with the specific characteristics of borehole and well water in Kazaure Town (Abdul et al., 2019; Jaiswal et al., 2017).

2.4.3 Analytical Techniques for Physicochemical Parameters

The choice of analytical techniques significantly influences the accuracy and reliability of physicochemical parameter measurements. Examining the strengths and limitations of methods such as titration, spectrophotometry, and chromatography guides the selection of appropriate techniques for pH, turbidity, dissolved oxygen, hardness, and specific ion concentration analyses (EPA, 2012; Sawyer et al., 2003).

2.4.4 Inclusion of Emerging Contaminants

Given the evolving nature of water quality challenges, the conceptual review includes the consideration of emerging contaminants. Methodological approaches for detecting pharmaceuticals, personal care products, and industrial chemicals may differ from traditional methods. Acknowledging the need for advanced analytical techniques and monitoring protocols ensures the study's capacity to identify and assess emerging contaminants (Richardson and Kimura, 2016).

2.4.5 Integrating Community Engagement

Community engagement strategies play a pivotal role in the success of water quality research. Drawing from methodologies that involve local communities in the monitoring process helps establish a participatory approach. Techniques such as citizen science, participatory mapping, and workshops facilitate collaboration and knowledge exchange between researchers and community members (Hurlimann et al., 2015; Ballard et al., 2008).

2.4.6 Temporal and Spatial Dynamics

Methodological considerations extend to addressing the temporal and spatial dynamics inherent in water quality.

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Designing a sampling regime that captures seasonal variations and accounting for localized influences ensures a comprehensive understanding. Time-series analyses, GIS mapping, and spatial modeling techniques contribute to unraveling the complexities of physicochemical variations over time and space (Sawyer et al., 2003; Huang et al., 2018).

2.4.7 Health Risk Assessment

Incorporating methodologies for health risk assessment is integral, particularly when examining contaminants with potential health implications. Quantitative risk assessment models, exposure pathway analyses, and epidemiological approaches contribute to evaluating the health risks associated with specific physicochemical parameters and contaminants (Fewtrell and Bartram, 2001; Ahmed et al., 2018).

2.4.8 Data Management and Analysis

Effective data management and analysis are critical for deriving meaningful insights. Methodological considerations encompass data storage, quality control measures, statistical analyses, and the integration of diverse datasets. Recognizing the importance of robust data management ensures that the study can draw reliable conclusions from the collected information (Bartram et al., 2014; Petts and Foster, 2013).

2.5 Review of Empirical Studies

Advances in Water Quality Assessment Techniques. This literature review by Smith et al. (2018) surveys recent advances in water quality assessment techniques, focusing on physicochemical parameters. The authors delve into innovative methodologies such as sensor technologies, remote sensing applications, and machine learning algorithms. The review emphasizes the potential of these advancements to enhance the precision and efficiency of water quality monitoring, providing a valuable foundation for the current project. Community Participation in Water Quality Monitoring. Wilson and Garcia (2019) present a comprehensive review of community participation in water quality monitoring initiatives worldwide.

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The literature review explores successful models of participatory action research, citizen science, and community-based monitoring. By synthesizing lessons learned from various projects, the review guides the integration of community engagement strategies into the physicochemical analysis of borehole and well water in Kazaure Town.

Approaches to Groundwater Quality. This literature review by Chen et al. (2017) provides a global perspective on regulatory frameworks for groundwater quality management. The authors examine diverse approaches, regulatory standards, and governance structures implemented in different regions. The review's insights inform the consideration of regulatory aspects in the current project, guiding the development of effective strategies for ensuring water quality compliance in Kazaure Town.

Health Risks Associated with Borehole and Well Water Contamination. Patel and Rahman (2021) conduct a systematic review of epidemiological studies investigating health risks linked to borehole and well water contamination. The literature review synthesizes evidence on the association between specific physicochemical parameters (such as heavy metals and microbial contaminants) and adverse health outcomes. The insights gained from this review contribute to the formulation of health-focused objectives in the current project.

Water Management Strategies. Smith and Khan (2016) offer a comprehensive review of sustainable water management strategies, with a focus on case studies from diverse geographical contexts. The literature review explores successful interventions, community-led initiatives, and policy measures aimed at ensuring long-term water quality sustainability. The insights from this review guide the development of sustainable practices and policies in the physicochemical analysis of borehole and well water in Kazaure Town.

2.6 Theoretical Framework

This study adopts the Eco-Hydrological Systems Theory as the theoretical framework to guide the exploration of physicochemical analysis of borehole and well water in Kazaure Town.

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Eco- Hydrological Systems Theory is a conceptual framework that integrates ecological and hydrological principles to understand the dynamic interactions between ecosystems and water systems. Rooted in the recognition that water and ecological processes are interconnected, this theory emphasizes the importance of considering the environment as a holistic system when studying water-related phenomena. The basis of Eco-Hydrological Systems Theory establishes a comprehensive understanding of water-ecosystem interactions by considering interconnections, dynamic feedback, land-water connectivity, resilience, temporal dynamics, a holistic perspective, community inclusion, adaptive governance, and interdisciplinary research. While the Eco-Hydrological Systems Theory offers a valuable conceptual framework, criticisms highlight challenges related to holism, limited quantification, implementation difficulties, neglect of social dynamics, lack of methodological guidance, operationalization challenges, potential for misinterpretation, and insufficient attention to climate change impacts. Addressing these critiques could enhance the theory's applicability and relevance in diverse contexts.

3. MATERIAL AND METHOD

3.1 Study Area

The study was conducted in Kazaure Town, Jigawa State, Nigeria, where groundwater is a primary source of drinking water.

3.2 Sample Collection

Five water samples were collected from different boreholes and wells using a simple random sampling method.

3.3 Parameters Analyzed

The following parameters were analyzed:

- pH
- Temperature
- Turbidity
- Electrical Conductivity
- Total Solids (TS)

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- Total Dissolved Solids (TDS)
- Total Suspended Solids (TSS)
- Total Hardness
- Alkalinity
- Calcium
- Chemical Oxygen Demand (COD)

3.4 Analytical Methods

Standard laboratory techniques including titration, photometry, and instrumental analysis were used.

3.5 Materials

Some Equipment Used Are

- Beaker
- Conical Flask
- Hot plate
- Photometer
- Weighing Balance
- pH Meter
- Digital Thermometer
- Measuring Cylinder
- Spatula
- Rotor Stand
- Dropper
- Water Bath
- Filter Paper
- Distilled Water
- Funnel
- Water Samples
- Burette with clamp
- Round test tube, 10ml glass

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- Cotton Wool

Some Reagents Used in The Lab

- EDTA Solution
- Buffer Solution
- Eriochrom Black T indicator
- 0.01KMnO
- 8% sodium hydroxide
- Oxalic Acid
- 5N HCL
- Meroxide
- Alkalinity reagent tablets
- NaOH
- Methanol
- 0.1M NaOH

3.6. Physical Parameters

3.6.1 Determination of Turbidity

Procedure

- The machine was put on for 5-10 minute.
- The standard that match was rinsed with distilled.
- The empty cell was rinsed with distilled water sample
- The clean cell was filled with water sample to be analyzed.
- After removing the standard, the cell with water sample was immediately placed into the machine, cover it and read the turbidity in (NTU) (Adamu and Sagir,, 2018).

3.6.2 Determination of Odor

Procedure

A 20ml volume of each water sample was poured into a clean beaker. The sample was then shaken vigorously to check for any frothing and allowed to settle. Odors were determined through the sensation of smell.(Sagir, 2021)

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3.6.3 Determination of Taste

Procedure

A 20ml volume of each water sample was poured into a clean beaker. The sample was then shaken vigorously to check for any frothing and allowed to settle. Taste test was determined by putting a small volume of the water sample in the tongue and then immediately raised with distilled water (taste free) after sample (Sagir, 2021)

3.6.4 Determination Of Temperature

Procedure

An ATC digital pen-type portable temperature/pH meter [(model PH-009 (III)] was used to measure temperature and pH in situ. The meter was switched on and standardized with a buffer solution. The meter was then immediately introduced into the water sample and measurement was taken after a stable reading was observed. The probe was then rinsed with distilled water before taken another measurement (Njib, 2020).

3.6.5 Determination Of Color

Procedure

A 20ml volume of each water sample was poured into a clean beaker. The sample was then shaken vigorously to check for any frothing and allowed to settle. Color was determined through visual examination (Tijjani, 2016)

3.6.6 Electrical Conductivities

Procedure

- The probe of the conductivity meter was rinsed in a beaker containing distilled water
- The probe was inserted in a beaker containing the water sample iii. Take reading was taken in (uS/cm or mS/cm) (Nazifl, 2020)

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3.7 Chemical Parameters

3.7.1 Determination of pH Value

Procedure

- 100ml of the sample was taken.
- The probe of the pH meter was inserted carefully in to the sample container.
- The reading was taken. (Saminu, 2020).

3.7.2 Determination Of Total Hardness

Procedure

- 60ml of water was measured into the conical flask.
- 3 drops of buffer solution was added.
- 2-3 drop of eriochrome T black Indicator was added.
- It was titrated with EDTA as a titrant until the Pink color turned blue (Ahmad, 2021).

3.7.3 Determination Of Total Solids (TS)

Procedure

- Take a clear dry glass beaker of 150ml capacity, wash it thoroughly and keep it for some minutes to dry. Put the appropriate identification Mark on it. Weight the beaker and note the weight.
- Pour 100ml of the waters ample, measured by measuring cylinder.
- Place the beaker in an ovum maintained at 103°C for 24 hours. After 24hours, when the whole water the has evaporated, cool the beaker and weight. Find out the weight of solid by subtracting the weight of the clean beaker determined in step one. (Sagar and Gawande, 2015).
- Calculate the total solid as $TS \text{ mg/l} = \frac{W_f - W_i}{\text{volume of sample}} \times 1000$ Where, W_i - Initial weight of the beaker, W_f - Final weight of the beaker (Lakhanpal, 2017).

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3.7.4 Determination of Total Suspended Solid (TSS).

Procedure

In order to obtain the Total suspended solid the values of TS and TDS were added

That Total Suspended Solid = TS-TDS (Kendre, 2017).

3.7.5 Determination Of Total Dissolved Solid (TDS)

Procedure

- Take a clear dry glass beaker of 150ml capacity, wash it thoroughly and keep it for some minutes to dry. Put the appropriate identification Mark on it. Weight the beaker and note the weight.
- Take a 100 ml of a sample and filter it through double layered filter paper or Gooch crucible and collect the filtrate in a beaker.
- Place the beaker in an ovum maintained at 103°C for 24 hours. After 24hours, when whole has evaporated, cool the beaker and weight. Find out the weight of solid by subtracting the weight of the clean beaker determined in step one.

Calculate the Total Dissolve solid as $TS \text{ mg/l} = \frac{W_f - W_i}{V} \times 1000$ / volume of sample Where, W_i - Initial weight of the beaker, W_f - Final weight of the beaker (Lakhanpal, 2015)

3.7.6 Determination of Chemical Oxygen Demand (Cod)

Procedure

- Measure 100ml of water sample in to the conical flask.
- Add 2ml of 8% sodium hydroxide and boil.
- Add 10ml of $KMnO_4$ solution and continuous boiling for 10 minute.
- Then add immediately 10ml of O oxalic acid, mix and titrate the excess oxalic acid with $KMnO_4$
- The calculate COD by using formula as: $COD \text{ ml of oxalic acid} \times 0.01KMnO_4 \times 1000/\text{ml of sample}$ (Abdulmutallib, 2018),

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3.4.7 Determination of Alkalinity

Procedure

- Filter the water sample if necessary to obtain the clear solution.
- Fill the test tube with sample to the 10ml mark. iii. Add alkalinity reagent tablet in to the 10ml sample water, crush and mix to dissolve.
- Wait for one minute to allow full color development.
- Select the wavelength 570nm on the photometer.
- Take the photometer reading in the usual manner. (Bello, 2022)

3.7.8 Determination Of Calcium

Procedure

- Measure 50ml of the water sample in to the beaker.
- Add 2ml of NaOH to the sample.
- A small amount of murexide was also added to the sample.
- The solution was titrating with Ethylendiaminetetraacetic acid (EDTA) until the color changes from pink to purple.
- The titer values of both raw and final water were multiply with (18.025) as the standard conversion factor. (Yahaya, 2021)

3.7.9 Determination of Magnesium

Procedure

- After the end point of Ca²⁺ titration 3ml of 5n HCL acid was added the same solution.
- Add 6ml of concentrated ammonium solution.
- Small amount of Eriochrom black T indicator was also added to the solution (Yahaya, 2021).

Where, V1 volume of BOD bottle, V2 volume of content titrated and V volume of MnSO₄ and Alkaline-iodide-acid

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3.8 Preparation Of The Ragents Used During Reseach Work

3.8.1 Preparation of 0.1M EDTA

3.72g of disodium dihydrogen-ethylenediaminetetraacetate dehydrate was dissolved in water (?) and the resulting solution was transferred into a liter volumetric flask, and de-ionized water was added to the mark (Ikeme, 2016)

3.8.2 Preparation of Buffer Solution (pH=10)

17.5 g of ammonium chloride was weighed and 142 ml of concentrated ammonia solution was added, and the resulting mixture was diluted to 250 ml of distilled water (Vogel, 2019).

3.8.3 Preparation of 0.1m NaOH

4 g of sodium hydroxide was dissolved in a beaker and then transferred into 1000 cm³ volumetric flask and the volume was made to the mark with distilled water (Chukwu, 2014).

3.8.4 Preparation of Merocide Indicator

1g of merocide indicator was dissolved in 100ml of methanol (Ikeme, 2014)

3.8.5 Preparation of Eriochrome Black Indicator

1 g of eriochrome black indicator was dissolved in 100ml of ethanol (Vogel, 2019).

3.8.6 Preparation of 0.01KMnO₄

0.157g of KMnO₄ dissolved in to 100ml of water (Olasusi, 2017).

3.8.7 PREPARATION OF 8% NaOH

8g of NaOH was dissolved in 100ml of water (Vogel, 2020).

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4. RESULT AND DISCUSSION

4.1 Result

4.2

Table 1. Physical Parameters

S/NO	Parameters	Sample A1	Sample A2	Sample B1	Sample B2	Sample C1	WHO Standard
1.	Turbidity (NTU)	2.6	1.5	2.5	4.1	1.8	5
2.	Conductivity (S/m)	2.8	16.9	34.4	21.3	29.6	< 400
3.	Color	colorless	colorless	colorless	colorless	colorless	
4.	Taste	tasteless	tasteless	tasteless	tasteless	tasteless	
5:	Temperature (°c)	25.8	26.0	26.8	26.9	26.2	25-39
6	Odor	odorless	odorless	odorless	odorless	odorless	

Table 2. Chemical Parameters

S/NO	Parameters	Sample A1	Sample A2	Sample B1	Sample B2	Sample C1	WHO Standard
1.	pH	5.48	5.30	5.70	4.85	5.92	6.5-8.5
2.	Total Hardness (mg/L)	106.34	32.92	113.72	28.33	58.35	500
3.	COD	1.43	1.05	1.35	1.30	1.20	500
4.	Total Solid	305.6	401.1	503.6	601.7	312.0	500
5:	Total Dissolved	179.3	250.8	287.5	320.8	209.5	500

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S/NO	Parameters	Sample A1	Sample A2	Sample B1	Sample B2	Sample C1	WHO Standard
6.	Calcium (mg/L)	103	42	30	64	175	200
7.	Alkalinity	65	40	145	25	1000	30-400
8.	Total Suspended Solid (mg/L)	126.3	150.3	216.3	280.9	101.5	500

Table 3. Samples Symbol and Sources

Symbol	Location	Source of water
A1	Shagari Quarters	Borehole
A2	Guru	Well
B1	Baya Gods Siasa	Borehole
B2	Sabuwan Jowa	Well
C1	Sabuwan Jowa	Borehole

4.2 Discussion

4.2.1 Turbidity

Turbidity is an important parameter used in assessing water quality, as it measures the degree of cloudiness or haziness in water caused by suspended particles. According to the results presented in Table 1, the turbidity values for all the water samples ranged between 1.5 NTU and 4.1 NTU, which fall within the recommended limit of 5 NTU set by the World Health Organization.

Sample A₁, collected from Shagari Quarters borehole, recorded a turbidity value of 2.6 NTU, indicating relatively clear water with minimal

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suspended particles. Sample A₂ from Guru well had a turbidity value of 1.5 NTU, which also indicates good water clarity.

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Similarly, sample B₁ from Baya Gida Siasa borehole showed a turbidity value of 2.5 NTU, suggesting low levels of suspended materials.

Sample B₂ from Sabuwan Jowa well recorded the highest turbidity value of 4.1 NTU among the samples; however, it still falls within the acceptable limit. Sample C₁ from Sabuwan Jowa borehole recorded a turbidity value of 1.8 NTU, indicating relatively clear water. Overall, the turbidity values obtained suggest that the water samples from the studied locations are generally clear and suitable for consumption with respect to turbidity.

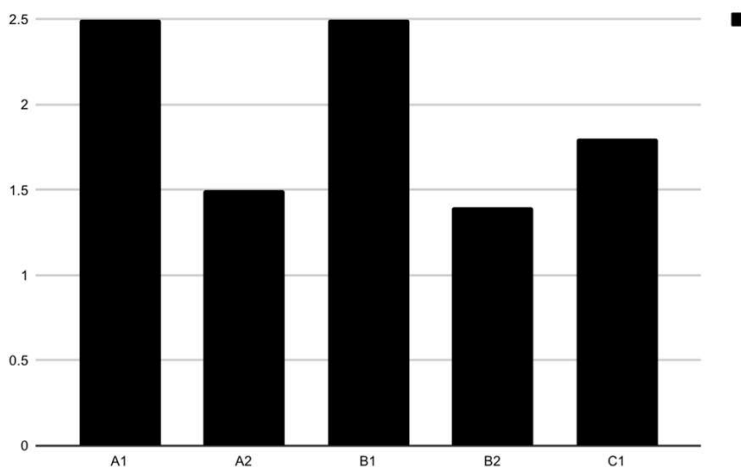


Figure 1. Turbidity Value

4.2.2 Conductivity

Electrical conductivity is another important parameter for assessing water quality because it indicates the ability of water to conduct electrical current, which depends on the presence of dissolved ions. Pure water has low conductivity, while higher conductivity values suggest the presence of dissolved salts or minerals.

The conductivity values obtained for the samples ranged from 2.8 to 34.4, indicating relatively low ionic concentration in the water sources. Low conductivity generally suggests low salinity and a limited presence of dissolved salts. However, factors such as temperature, pressure, and dissolved solids can also influence conductivity levels.

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The results indicate that all water samples contain relatively low levels of dissolved ions and therefore fall within acceptable limits for potable water.

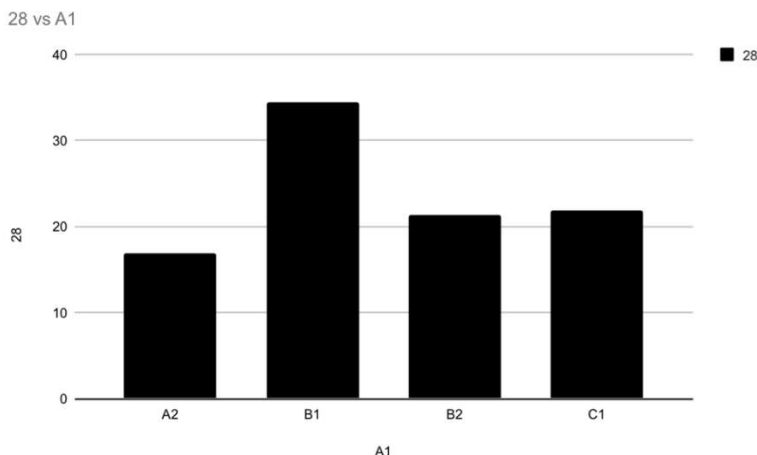


Figure 2. Conductivity Value

4.2.3 Color, Odor and Taste

The aesthetic properties of drinking water such as colour, odour, and taste are important indicators of water quality and acceptability to consumers. The results show that all water samples analyzed in this study were colourless, odourless, and tasteless.

These characteristics fall within the acceptable guidelines recommended by the World Health Organization for drinking water. Colour in natural water is often caused by dissolved organic substances or suspended materials; however, the absence of colour in the analyzed samples suggests minimal contamination from such sources.

Similarly, the absence of unpleasant odour and taste indicates that the water samples do not contain significant levels of organic pollutants or harmful chemical substances. Therefore, based on these parameters, the water samples are considered suitable for drinking and domestic purposes.

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4.2.4 Temperature

Temperature plays an important role in water quality because it affects chemical reactions and the growth of microorganisms in water. The temperature values recorded for the water samples ranged from 25.8°C to 26.9°C, which fall within the recommended range for drinking water.

High temperatures can promote the growth of microorganisms and may influence taste, odour, and chemical reactions in water. However, the relatively stable temperature values observed in this study suggest that the water samples are within acceptable limits and do not pose any immediate risk related to temperature effects.

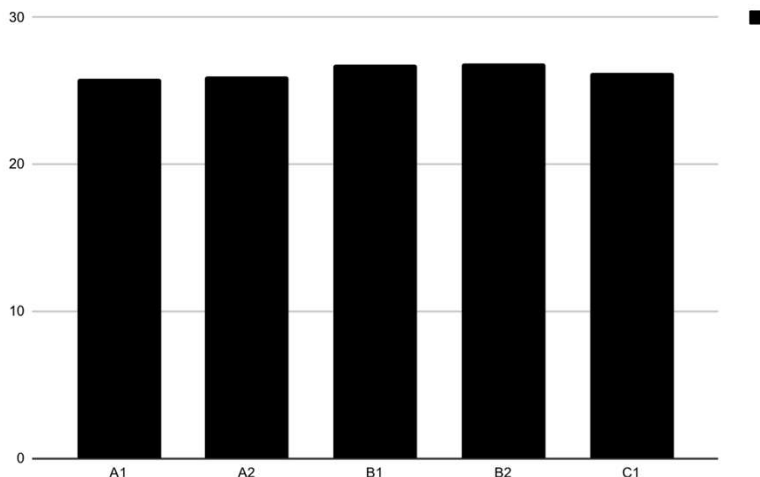


Figure 3. Temperature Value

4.2.5 Total Hardness

Water hardness is primarily caused by the presence of calcium and magnesium ions in water. The hardness values obtained from the samples ranged between 28.33 mg/L and 113.72 mg/L, which are well below the recommended limit of 500 mg/L set by the World Health Organization.

This indicates that the water samples are moderately soft and suitable for drinking and domestic use. Low hardness levels also reduce the likelihood of scaling in pipes and household appliances.

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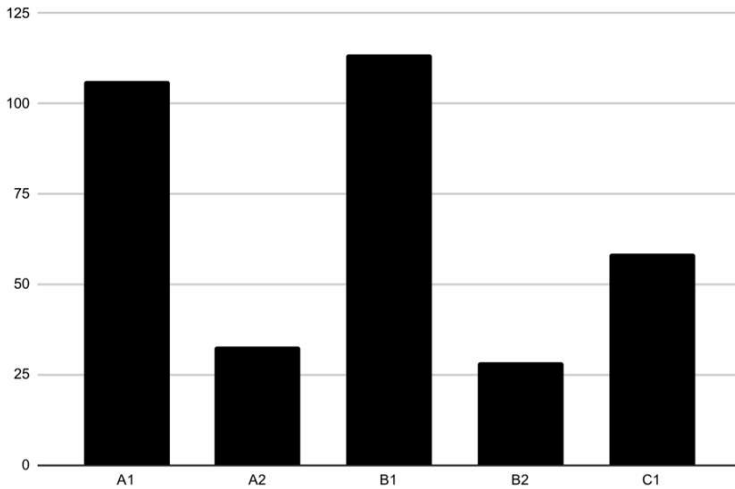
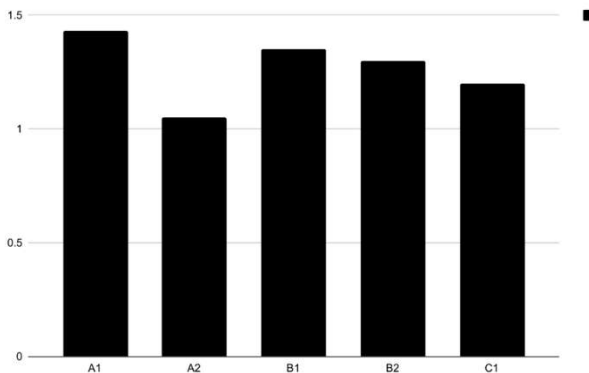


Figure 4. Total Hardness Value

4.2.6 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) measures the amount of oxygen required to chemically oxidize organic and inorganic substances in water. High COD values often indicate pollution from organic matter such as industrial or agricultural waste.

The COD values obtained for the samples ranged from 1.05 to 1.43 mg/L, which are well within the acceptable limits. This suggests that the water sources are not significantly contaminated with oxidizable organic pollutants.



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Figure 5. Chemical Oxygen Demand Value

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4.2.7 Total Solid (TS)

Total solids represent the combined amount of dissolved and suspended materials present in water. High levels of total solids can reduce water quality and affect its taste and suitability for consumption.

The results showed total solid values of 305.6 mg/L, 401.1 mg/L, 503.6 mg/L, 601.7 mg/L, and 312.0 mg/L for samples A₁, A₂, B₁, B₂, and C₁ respectively. While most samples fall within acceptable limits, B₁ and B₂ exceed the WHO recommended limit of 500 mg/L, indicating possible contamination from environmental or human activities around those locations.

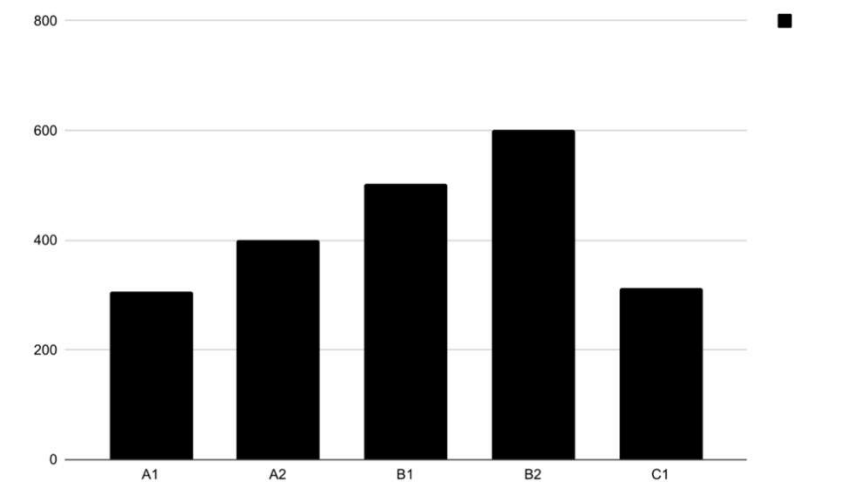


Figure 6. Total Solid

4.2.8 Total Dissolved Solid (TDS)

Total dissolved solids represent the concentration of dissolved minerals, salts, and organic matter in water. Excessive TDS can affect water taste and may make it unsuitable for certain uses.

The values obtained ranged from 179.3 mg/L to 320.8 mg/L, which fall within the acceptable limits recommended by the World Health Organization. These results indicate that the water samples contain moderate levels of dissolved substances and are generally suitable for drinking.

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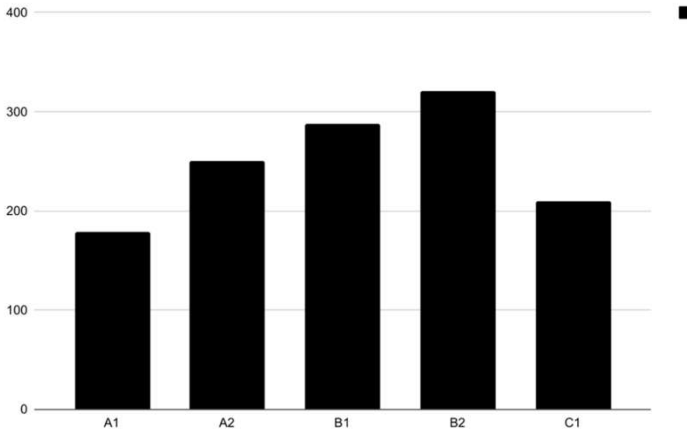
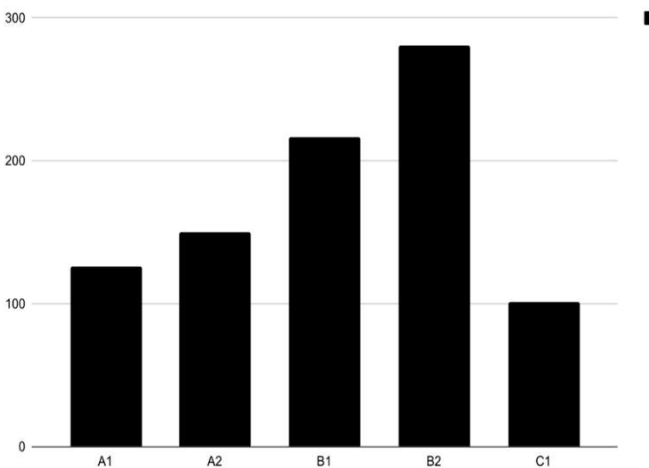


Figure 7. Total Dissolved Solid

4.2.9 Total Suspended Solid (TSS)

Total suspended solids refer to particles suspended in water that do not dissolve. High TSS levels can reduce water clarity and may carry pollutants such as heavy metals and microorganisms.

The TSS values recorded ranged from 101.5 mg/L to 280.9 mg/L, which are within acceptable limits. This indicates that the water samples contain relatively low levels of suspended materials.



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Figure 8. Total Suspended Solid

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4.2.10 Alkalinity

Alkalinity represents the ability of water to neutralize acids and resist changes in pH. It is mainly influenced by the presence of bicarbonates, carbonates, and hydroxides.

Most samples recorded alkalinity values within the acceptable range; however, sample C₁ recorded a value of 1000 mg/L, which is significantly higher than the recommended limit. This may be attributed to geological factors or environmental activities around the sampling location.

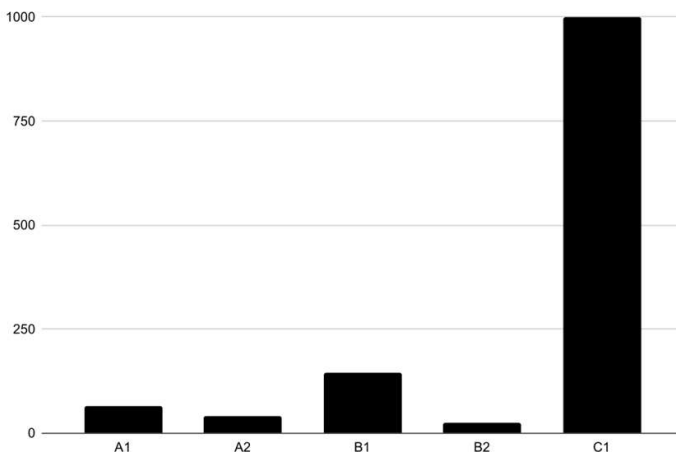


Figure 9. Alkalinity Value

4.2.11 Determination of Calcium

Calcium is a major component of water hardness and contributes to the buffering capacity of water. The calcium concentrations in the samples ranged from 30 mg/L to 175 mg/L, which fall within the acceptable limits for drinking water.

This suggests that the water samples contain moderate levels of calcium and are not likely to cause health problems associated with excessive mineral intake.

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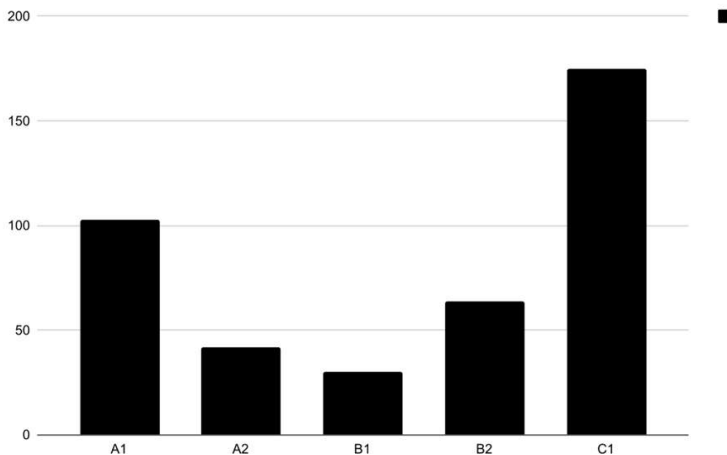


Figure 10. Calcium Value

Results and Discussion

The results indicate that most water samples fall within acceptable WHO limits. Turbidity values ranged from 1.5 to 4.1 NTU, indicating relatively clear water. Conductivity values were low, suggesting minimal dissolved salts.

However, pH values were slightly acidic (below 6.5), which may affect water taste and corrosion potential. Total solids exceeded recommended limits in some samples, indicating possible contamination.

Alkalinity was significantly high in one location, suggesting geological or environmental influence. Despite these variations, most samples showed acceptable hardness, calcium, and COD levels.

Public Health Implications

Water with high total solids or abnormal pH can lead to:

- Gastrointestinal issues
- Long-term exposure risks
- Reduced water acceptability

This highlights the need for treatment and monitoring.

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CONCLUSION

This study evaluated the physicochemical characteristics of borehole and well water sources in Kazaure Town, Jigawa State, Nigeria. The results obtained indicate that most of the analyzed parameters fall within the recommended limits established by the World Health Organization (WHO) for drinking water. However, variations were observed among the sampling locations.

Specifically, the Baya Gida Siasa borehole and Sabuwan Jowa well recorded total solid values that exceeded the recommended WHO limits, indicating possible contamination or the presence of excessive dissolved and suspended materials. In addition, the Sabuwan Jowa borehole showed relatively high alkalinity values, which may affect the chemical stability and suitability of the water for certain domestic uses.

Conversely, water samples obtained from Shagari Quarters borehole and Guru well exhibited physicochemical parameters within acceptable WHO standards, suggesting that these water sources are suitable for human consumption and domestic use without significant health risks.

Overall, the findings highlight the importance of continuous monitoring of groundwater sources in Kazaure to ensure water safety and protect public health. Where elevated parameter levels were detected, appropriate water treatment methods such as coagulation, flocculation, sedimentation, and filtration should be implemented to improve water quality. Furthermore, community awareness and proper environmental management practices are essential in preventing contamination and ensuring the long-term sustainability of groundwater resources in the region.

Recommendations

- Establish an integrated water quality management program that involves collaboration among local authorities, environmental agencies, and community stakeholders. This initiative should include regular monitoring, targeted interventions, and community awareness campaigns to address specific water quality challenges observed in the study.

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- Collaborate with urban planners to implement and enforce land use planning and zoning regulations that mitigate potential contaminants entering water sources. Emphasize sustainable land management practices to prevent adverse impacts on water quality in both urban and peri-urban areas.
- Launch community-based environmental education programs aimed at raising awareness about the impact of individual and community activities on water quality. Empower residents with knowledge on proper waste disposal, agricultural practices, and the importance of preserving water sources.
- Institute a long-term monitoring program to track changes in water quality over extended periods. This will provide valuable insights into seasonal variations, trends, and emerging challenges. Regular data collection will enable proactive measures and a deeper understanding of the dynamics influencing water quality in Kazaure Town.

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