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Research Article

An Analysis of Fertilizer Application on Surface and Groundwater Quality in Giwa Lga Kaduna

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Abstract

This study examines water quality parameters in surface and groundwater sources alongside fertilizer usage patterns in an agricultural region. Five (5) samples were randomly collected from rivers. The parameters analyzed include pH, temperature, turbidity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Electrical Conductivity, Total Dissolved Solids (TDS), Alkalinity, Total Hardness, Sulphate, Nitrate and Phosphate. The results reveal significant differences between surface and groundwater quality, reflecting the influence of agricultural practices, particularly fertilizer application. The dominance of synthetic fertilizers, such as Nitrogen Phosphorous Potassium (NPK) (43.3%) and urea (33.7%), underscores their role in enhancing crop productivity but raises concerns about water pollution and sustainability. The findings contribute valuable insights into the relationship between agricultural practices and water quality, offering a basis for developing strategies to ensure sustainable water resources in the study area.

Introduction

Agriculture remains the cornerstone of economic activity in Giwa Local Government Area (LGA) of Kaduna State, Nigeria, supporting the livelihoods of a significant proportion of the population. The region's fertile soil, coupled with a favorable climate, makes it an ideal location for both crop and livestock farming. However, intensive agricultural practices, especially the use of chemical fertilizers, have posed significant challenges to environmental sustainability. Fertilizer application is critical for improving soil fertility and ensuring high crop yields, especially in regions like Giwa LGA, where soil degradation and nutrient deficiencies are common [1,2]. Among the most commonly applied fertilizers are Nitrogen Phosphorous Potassium (NPK), urea, livestock manure, and agricultural waste, all of which aim to replenish essential nutrients that crops require for growth. Despite the apparent benefits of fertilizer usage, indiscriminate and excessive use of these chemicals has raised concerns regarding their negative effects on water quality, both on the surface and in groundwater systems [3]. Excessive fertilizer runoff from agricultural fields can lead to nutrient loading in local water bodies, resulting in eutrophication, algal blooms, and other ecological imbalances that affect aquatic life and human health [4]. This is particularly problematic in Giwa LGA, where surface water bodies such as rivers and streams receive substantial runoff from farmlands, and groundwater is increasingly being relied upon for drinking water. Fertilizer runoff from agricultural activities contaminates these water sources, threatening the health of local populations and ecosystems [5,6].

In addition to their agricultural role, fertilizers introduce high levels of nutrients—particularly nitrates and phosphates—into both surface and groundwater systems. These contaminants can leach through the soil and infiltrate underground aquifers, posing a long-term threat to water quality [7,8]. Nitrates, which are a primary component of synthetic fertilizers, can contaminate drinking water sources and have been linked to methemoglobinemia, or "blue baby syndrome," in infants, as well as other health issues in humans and animals [9]. On the other hand, excessive phosphate concentrations in surface water can lead to eutrophication, which promotes the growth of aquatic plants and algae, depleting oxygen levels and ultimately diminishing water quality [10,11]. In Giwa LGA, the

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impact of fertilizer application on water quality has become increasingly apparent as both surface and groundwater sources exhibit signs of nutrient contamination [12,13]. While surface water systems experience direct fertilizer runoff, groundwater is more susceptible to gradual infiltration processes, where contaminants slowly accumulate over time, resulting in long-term contamination risks [14]. The intensification of fertilizer use in recent decades has been driven by the need to boost agricultural productivity to meet the growing demands of the population [15]. However, this has come at the expense of sustainable water management practices, highlighting the need for integrated nutrient management strategies that take into account the delicate balance between maximizing agricultural productivity and safeguarding water quality [16]. This study seeks to evaluate the impact of fertilizer application on the physico-chemical properties of both surface and groundwater quality in Giwa LGA, with the objective of understanding the extent to which fertilizers contribute to water pollution and the broader environmental implications of such practices. The findings of this research aim to contribute to the development of effective policies that promote sustainable farming practices and better water management, ultimately ensuring the long-term health and welfare of the local population and ecosystems [17,18].

Aim of the study

This study aims to assess the effect of fertilizer application on groundwater quality in Giwa Local Government Area.

Objectives of the study

1. **The objectives of the study are to**To determine the physico-chemical properties of groundwater in the study area?
2. To determine the difference between the physico-chemical characteristics of the groundwater in the study area?
3. What is the correlation and extent of interaction among these parameters?

Study area

Giwa LGA is one of the 23 LGAs in Kaduna State; it was created out of Igabi LGA on the 15th of September, 1991 by the General Ibrahim Badamasi Babangida's administration. The local government has eleven wards that are Giwa, Yakawada, Gangara, Dan Mahawayi, Kadage, Shika, Kidandan, Galadimawa, Idasu, Kakangi and Fan Hauya. Giwa ward is the administrative headquarters for the LGA.

Location and size

Giwa LGA lies between Latitudes 10° 35′N and 11°24′N, Longitudes 7°00′E and 7°49′E as presented in Figure 1. It has an area of 2,066km^2 and it is bounded in the North by Funtua LGA in Katsina State, while in the south, it is bounded by Igabi Local Government Area. In the west, it is bounded by Birnin Gwari LGA while in the east; it is bounded by Zaria LGA and Sabon-Gari LGA.

Methodology

A multi-stage sampling technique was employed in selecting the respondents and sampling points for this study. In the first stage, wards within Giwa Local Government Area (LGA) were systematically selected. The wards were arranged alphabetically, and those with even-numbered positions were chosen, resulting in the selection of five wards: Galadimawa, Giwa, Kadage, Kidandan, and Shika. Due to prevailing security challenges in the region, including frequent incidents of kidnapping, armed banditry, and recurring conflicts between farmers and Fulani herders, accessibility to certain locations was significantly restricted. These security concerns necessitated the adoption of a pragmatic and safety-conscious approach to sampling. Consequently, five surface water and five groundwater samples were collected from relatively secure and accessible areas within the selected wards. This approach ensured the safety of field personnel while still allowing for a representative assessment of water quality parameters across the LGA. The following parameters were analyzed pH, temperature, turbidity, Electrical Conductivity (EC), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS), Alkalinity, Chlorides, Total Hardness (TH), sulfate, nitrate, and phosphate.

Fertilizer types and application rates

Fertilizers used in Nigeria are broadly categorized into organic and inorganic types, each playing a critical role in enhancing crop yields. Organic fertilizers, such as compost and manure, enrich soil health and support microbial activity, while inorganic (synthetic) fertilizers offer immediate nutrient availability but can lead to soil degradation and environmental pollution if misused. Inorganic fertilizers are widely used due to their cost-effectiveness and quick results, with nitrogen-based (e.g., urea, ammonium nitrate), phosphorus-based (e.g., DAP, TSP), and potassium-based (e.g., KCl, K_2SO_4) being the most common. Compound fertilizers (NPK), secondary nutrient fertilizers (like those containing sulfur, magnesium, and calcium), and micronutrient formulations (e.g., zinc, boron, iron) are also used to meet specific crop and soil needs. Recent advancements in precision agriculture have enabled more efficient fertilizer application, balancing productivity with sustainability [19].

However, inorganic fertilizers, particularly phosphate-based types, may introduce contaminants such as cadmium (Cd), lead (Pb), arsenic (As), and uranium (U) into the soil because they are derived from phosphate rock. These heavy metals can accumulate over time, adversely affecting soil health, plant growth, and water quality through leaching and runoff. The risk of environmental contamination increases with excessive and continuous fertilizer use. Consequently, the integration of organic fertilizers, proper nutrient management, and environmentally friendly practices is becoming essential in Nigerian agriculture to ensure long-term soil fertility and reduce ecological harm [20].

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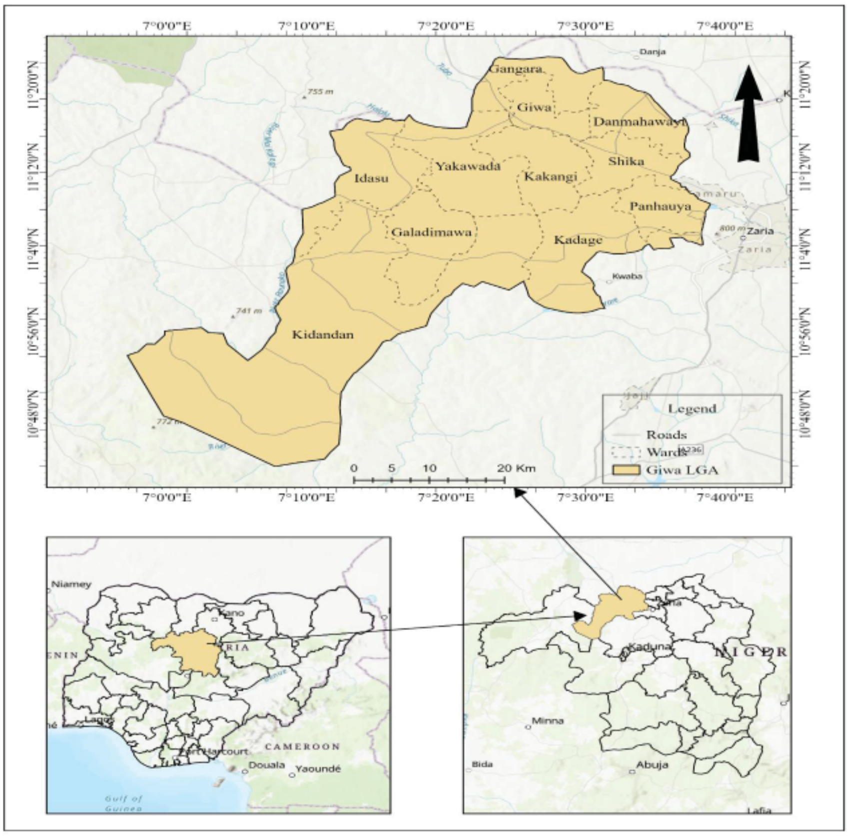

Figure 1: The Study Area.
Source: Adapted from map of Giwa LGA (2023).

Results

The prevalence of NPK (43.3%) and urea (33.7%) correlates with elevated nutrient concentrations, particularly nitrates and phosphates, in surface water. These nutrients, while essential for crops, can contribute to eutrophication in aquatic ecosystems when present in excess [21]. The minimal use of agricultural and industrial waste fertilizers further underscores the limited integration of sustainable practices that could mitigate such impacts. Incorporating organic fertilizers like livestock manure (15.9%) and agricultural waste (3.7%) could address both soil fertility and water quality challenges. Livestock manure significantly enhances Soil Organic Carbon (SOC) levels, improving soil structure and fertility while reducing the dependency on synthetic chemical inputs. In addition, the recycling of agricultural waste into organic amendments such as compost and biochar not only minimizes nutrient leaching but also aligns with circular economy principles by promoting resource efficiency and environmental sustainability [22] (Table 1).

Table 1: Most commonly used Fertilizer in the Study Area.

Fertilizer	Frequency	Percentage
Nitrogen Phosphorous Potassium NPK)	153	43.3
Livestock Manure	56	15.9
Agric-waste	13	3.7
Urea	119	33.7
Industrial waste	12	3.4
Total	353	100

In addition to fertilizer use, several other significant sources contribute to water pollution in Giwa Local Government Area (LGA), Kaduna State. One major contributor is domestic wastewater. In many Nigerian communities, including Giwa, the absence of adequate sewage treatment infrastructure results in the direct discharge of untreated household wastewater into nearby water bodies (Ado, 2023). This wastewater often contains organic matter, pathogens, and various chemicals from detergents and other household products, which degrade water quality and pose health risks to the population. Improper solid waste disposal is another contributor. Uncontrolled refuse dumps, typically located near residential areas and water sources, allow leachates from organic and inorganic waste including plastics and hazardous substances to seep into surface and groundwater systems (Public Health Nigeria, 2023). These pollutants can significantly deteriorate water quality and threaten both human health and aquatic ecosystems.

Sample collection

The collection of water samples from both wells and rivers within the study area of Giwa Local Government Area (LGA) was carried out following standard procedures to ensure that the samples were representative of the water quality and free from contamination. The process aimed to capture both **surface**

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water (from rivers and streams) and **groundwater** (from wells) to evaluate the impact of fertilizer application on water quality. The following steps outline the methodology for collecting the 10 samples (5 from rivers and 5 from wells) (Tables 2-4).

Discussion of results

The comparison between surface and groundwater parameters reveals distinct trends. Surface water exhibited higher turbidity and electrical conductivity, potentially influenced by direct agricultural runoff containing fertilizers and other pollutants. Conversely, groundwater showed more stable pH and lower turbidity, reflecting its filtration through soil layers. However, elevated nitrate levels in both sources point to fertilizer leaching, a known issue in intensive agricultural regions [23].

Surface water and groundwater systems are influenced by diverse natural and anthropogenic factors, which result in distinct physicochemical profiles. From the datasets, surface water generally exhibits higher variability in parameters such as turbidity (mean: 9.9 NTU *vs.* 2.04 NTU in groundwater) and electrical conductivity (mean: 372.8 µs/cm *vs.* 175.7 µs/cm). This is primarily due to surface water's direct exposure to environmental inputs such as runoff, which carries sediments, organic matter, and pollutants. Groundwater, which percolates through soil strata, tends to exhibit lower turbidity and conductivity but exhibits elevated stability in parameters such as pH and temperature. This aligns with findings in hydrogeological studies indicating that surface water responds more dynamically to seasonal and external changes compared to groundwater (Tebbutt, 1998).

In comparison to regulatory standards such as the WHO and NSDWQ, both water types exhibit parameters within acceptable limits for most categories. However, some critical differences are noteworthy. For instance, turbidity in surface water exceeds the permissible limit of 5 NTU in several locations (e.g., Galadimawa and Giwa Rivers), making it less suitable for direct consumption without treatment. Similarly, total dissolved solids (TDS) in surface water (mean: 253.9 mg/L) are significantly higher than in groundwater (98.7 mg/L), reflecting greater solute load from runoff and anthropogenic activities. Conversely, groundwater demonstrates concerning nitrate levels (mean: 7.34 mg/L), potentially linked to agricultural leachates or septic systems, as identified in global water quality studies [24]. These trends underscore the necessity of tailored treatment strategies based on water source type.

The ecological and human influences on surface water and groundwater differ markedly. Surface water sources such as rivers are subject to sediment transport, algal growth, and point-source pollution, as evidenced by elevated biochemical oxygen demand (BOD) in areas like Shika River (0.8 mg/L). Groundwater, on the other hand, benefits from natural filtration, but its electrical conductivity and chloride levels in areas such as Shika (642 µs/cm and 36.49 mg/L, respectively) suggest localized contamination, possibly from saline intrusion or anthropogenic activity. This contrast aligns with findings from previous studies on land use impacts and climate on water resources [25]. Proper land management and pollution

Table 2: Latitude and longitude of samples collected in the study area.

Sample Areas	Latitude	Longitude	Name	Type
Galadimawa	11.28005	7.417779	Resident well	Well
Galadimawa	11.29083	7.404211	Galma river	River
Giwa	11.05623	7.332673	Kwakure well	Well
Giwa	11.05232	7.322516	Kubi river	River
Kidandan	11.02304	7.451443	Well	Well
Kidandan	11.02441	7.449311	River rakuma	River
Kadage	11.05321	7.198465	Resident well	Well
Kadage	11.05225	7.193976	Tsohon river	River
Shika	11.20384	7.609994	Resident well	Well
Shika	11.20092	7.608484	Shika river	River

Table 3: Physico-chemical Properties Surface water in the Study area with standards.

S/N	Parameter	Unit	GAL. R	GWA.R	KAD.R	KID.R	SHK.R	Mean	SD	Who Standard	NSDWQ
1	Ph	-	6.92	6.64	6.87	6.63	6.83	6.8	0.13	6.5-8.5	6.5-8.5
2	Temperature	˚C	24.9	25.9	25.8	26.4	26	25.8	0.55	30	Ambient
3	Colour	Hazen	10	10	10	5	5	8.0	1.6	15	15
4	Turbidity	NTU	13.5	15.8	11.9	5.6	2.8	9.9	5.49	5	5
5	Electrical conductivity	µs/CM	312	413	115.8	178	845	372.8	288.2	400	1000
6	DO	Mg/L	1.3	1.1	1.2	1.1	1.3	1.2	0.1	4-6	4-6
7	BOD	Mg/L	0.7	0.6	0.2	0.5	0.8	0.56	0.23	0.8-5.0	0.8-5.0
8	Total dissolved solids	Mg/L	178	205	58.5	356	472	253.9	161.5	1000	500
9	Alkalinity	Mg/L	64	43	11	74	86	55.6	29.5	100	100
10	Chloride	Mg/L	52.4	18.48	6	45.67	49.98	34.5	21.2	200-300	250
11	Total hardness	Mg/L	132.41	151.51	80.81	147.06	101.01	122.6	30.5	60-120	150
12	Sulphate	Mg/L	142	105	103	109	208	133.4	44.6	<250	100
13	Nitrate	Mg/L	12	8	15	17	4	11.2	5.26	10	50
14	Phosphate	Mg/L	0.041	0.023	0.014	0.033	1.02	0.22	0.44	200	250

Key: GAL. R: Galadimawa River; GWA.R: Giwa River; KAD.R: Kadage River; KID. R: Kidandan River; SHK.R: Shika River

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Table 4: Physico-chemical Properties Groundwater in the Study area with standards.

S/N	Parameter	Unit	GAL. W	GWA. PHW	KAD.W	KID. W	SHK.W	Mean	SD	Who Standard	NSDWQ
1	Ph	-	6.54	6.5	6.72	6.63	6.33	6.5	0.14	6.5-8.5	6.5-8.5
2	Temperature	˚C	25.5	25.3	25.8	25.6	25.8	25.6	0.21	30	Ambient
3	Colour	HAZEN	5	5	5	5	5	8.0	1.6	15	15
4	Turbidity	NTU	2.3	1.1	3.4	1.4	2	2.04	0.8	5	5
5	Electrical conductivity	µs/CM	63.7	47.4	57.6	67.8	642	175.7	260.8	400	1000
6	DO	Mg/L	1.2	1.1	1.4	1.1	1.3	1.2	0.12	4-6	4-6
7	BOD	Mg/L	0.5	0.4	0.6	0.4	0.6	0.5	0.1	0.8-5.0	0.8-5.0
8	Total dissolved solids	Mg/L	21.3	23.6	28.9	27.6	321	98.7	148.23	1000	500
9	Alkalinity	Mg/L	11	8	9	14	48	18	16.9	100	100
10	Chloride	Mg/L	7.92	5.5	5	31.67	36.49	34.5	21.2	200-300	250
11	Total hardness	Mg/L	67.45	40.4	50.5	54.64	121.21	66.84	31.9	60-120	150
12	Sulphate	Mg/L	124	104	2	43	203	95.2	77.3	<250	100
13	Nitrate	Mg/L	5.8	9	4.5	9.4	8	7.34	2.11	10	50
14	Phosphate	Mg/L	0.012	0.01	0.01	0.011	0.005	0.0096	0.0027	200	250

Key: GAL. W: Galadimawa Well; GWA.W: Giwa Well; KAD.W: Kadage Well; KID. W: Kidandan Well; SHK.W: Shika Well

control measures are essential for maintaining water quality in both systems.

The high turbidity and TDS levels in surface water necessitate robust treatment infrastructure, particularly for urban and peri-urban populations reliant on rivers for drinking water. Meanwhile, groundwater requires monitoring for contaminants such as nitrates and sulfates, which could pose long-term health risks. Additionally, sustainable practices such as protecting recharge zones and minimizing agricultural runoff are critical for groundwater conservation. These measures align with global recommendations for integrated water resource management, emphasizing the protection of both surface and subsurface water to meet growing demand sustainably [26].

Discussion of water quality parameters in surface and groundwater samples

The correlation matrix reveals complex interrelationships among the measured water quality parameters in both surface and groundwater samples, including pH, temperature, turbidity, Electrical Conductivity (EC), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), alkalinity, chlorides, total hardness (TH), sulphate, and nitrate. These correlations are crucial in understanding the dynamics of aquatic environments and assessing water quality for ecological and human consumption purposes.

Firstly, a strong negative correlation exists between temperature and pH (-0.741), indicating that as temperature increases, pH tends to decrease. This relationship can be attributed to the increased ionization of water at higher temperatures, which reduces pH levels [27]. This effect is often more pronounced in surface waters due to direct exposure to solar radiation compared to groundwater, which generally experiences more stable thermal conditions [28]. Furthermore, temperature shows negative correlations with turbidity (-0.661) and EC (-0.548), suggesting that higher temperatures may lead to decreased suspended particles and ionic concentrations, possibly due to sediment settling in surface water and reduced solubility of certain salts in both water types.

The positive correlation between turbidity and EC (0.951) is particularly significant. This indicates that areas with higher turbidity also contain elevated ionic concentrations, likely due to the dissolution of minerals and pollutants attached to particulates [29]. Additionally, turbidity correlates negatively with DO (-2.027), implying that increased suspended solids, more common in surface water, may hinder oxygen diffusion, reducing DO levels, which is critical for aquatic life.

Dissolved oxygen shows strong positive correlations with pH (0.893) and sulphate (0.762), while negatively correlating with temperature (-0.646) and nitrate (-0.428). High dissolved oxygen levels are typically associated with cooler, well-aerated surface waters that support aerobic biological processes, which can increase pH and promote sulphate stability [30]. In contrast, groundwater typically exhibits lower DO due to limited atmospheric exchange. The negative correlation with nitrate suggests that areas with high nitrate pollution, common in agricultural runoff affecting both surface and groundwater, may experience oxygen depletion due to eutrophication and microbial oxygen consumption [31].

Biological Oxygen Demand (BOD) correlates positively with alkalinity (0.843) and chlorides (0.787), indicating that higher organic pollution levels are associated with increased buffering capacity and chloride concentrations. This relationship may reflect anthropogenic influences, such as agricultural runoff and wastewater discharge, which contribute both organic matter and salts to surface waters, and leaching into groundwater [32]. Conversely, BOD's negative correlation with nitrate (-0.714) may highlight the role of nitrification processes in reducing oxygen levels in both water types.

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TDS shows strong positive correlations with alkalinity (0.903) and chlorides (0.703), reinforcing the connection between dissolved solids and ionic content in water. High TDS levels can affect water taste, health, and ecosystem stability [33]. Groundwater often has higher TDS due to prolonged rock-water interactions, while surface water TDS levels may fluctuate due to seasonal changes and runoff events. The negative correlation between TDS and DO (0.138) suggests that waters with high dissolved solids may have reduced oxygen availability, potentially stressing aquatic organisms, especially in surface waters.

Furthermore, nitrate exhibits predominantly negative correlations with most parameters, notably with sulphate (-0.741) and BOD (-0.714). This pattern suggests that nitrate pollution, common from agricultural runoff and septic systems, often occurs in environments with reduced sulphate and organic matter processing, possibly due to altered microbial activity or nutrient imbalances in both surface and groundwater systems [34]. Understanding these interrelationships helps in designing effective water management strategies and mitigating pollution impacts in diverse aquatic environments.

Summary

The physico-chemical analysis of surface and groundwater samples from Galadimawa, Giwa, Kadage, Kidandan, and Shika revealed varying water quality parameters when compared to WHO and NSDWQ standards. The pH levels for both surface (6.63–6.92) and groundwater (6.33–6.72) samples were within the acceptable range of 6.5–8.5, indicating slightly acidic to neutral conditions. Surface water temperatures ranged from 24.9°C to 26.4°C, slightly higher than groundwater temperatures (25.3°C–25.8°C), reflecting ambient environmental influences. Both water sources showed color values within permissible limits, However, turbidity levels... exceeded the recommended 5 NTU in surface water (mean = 9.9 NTU), suggesting the presence of suspended particles.

Electrical Conductivity (EC) values varied significantly, with surface water averaging 372.8 µS/cm, higher than groundwater (175.7 µS/cm). Surface water samples from Shika River recorded the highest EC (845 µS/cm), indicating increased dissolved ionic content. Total Dissolved Solids (TDS) exhibited a similar trend, with surface water exhibiting higher concentrations (mean = 253.9 mg/L) compared to groundwater (98.7 mg/L). Despite these variations, TDS levels remained below the 1000 mg/L WHO guideline. Dissolved Oxygen (DO) levels were critically low in both water sources, averaging 1.2 mg/L, far below the optimal range of 4–6 mg/L, which could impair aquatic life and may indicate the presence of organic pollution.

Biochemical Oxygen Demand (BOD) levels in both surface and groundwater were relatively low (0.56 mg/L and 0.5 mg/L, respectively), falling within the permissible range (0.8–5.0 mg/L). However, low DO combined with low BOD levels may reflect limited microbial activity or potential contamination that inhibits biological degradation. Alkalinity values in surface water (mean = 55.6 mg/L) were significantly higher than in groundwater (18 mg/L), reflecting the buffering capacity against pH changes. Chloride concentrations in both water types remained below the maximum limits, though Shika groundwater showed elevated levels (36.49 mg/L), potentially from anthropogenic sources.

Nutrient analysis revealed nitrate concentrations slightly exceeding the WHO guideline of 10 mg/L in surface water (mean = 11.2 mg/L), while groundwater levels were within safe limits (7.34 mg/L). High nitrate levels in surface water, especially from agricultural runoff, could pose health risks, such as methemoglobinemia. Phosphate concentrations were notably higher in surface water (mean = 0.22 mg/L) compared to groundwater (0.0096 mg/L), indicating possible eutrophication risks in surface water bodies due to nutrient enrichment.

Correlation analysis among the parameters indicated strong positive relationships between certain variables, such as EC and turbidity (r = 0.951), and alkalinity with chloride (r = 0.931), suggesting common pollution sources or geochemical interactions. Negative correlations, such as between nitrate and sulphate (r = -0.741), might reflect different contamination pathways. Overall, while most parameters were within regulatory limits, issues like high turbidity, low DO, and elevated nitrate levels in surface waters highlight potential environmental and public health concerns requiring mitigation efforts.

Conclusion

The results showed variability in the water quality of both surface and groundwater samples. Parameters such as pH, turbidity, and nutrient levels often exceeded the recommended limits for safe drinking water. This variability can be attributed to both anthropogenic activities and natural factors that influence water quality.

Surface water samples showed generally higher contamination levels of contamination compared to groundwater. This is likely due to the direct exposure of surface water to pollutants such as agricultural runoff, industrial discharges, and domestic waste. These pollutants can significantly alter the composition of surface water, making it less suitable for consumption and other uses.

In contrast, groundwater samples tended to have lower contamination levels overall. However, wells located near industrial or agricultural areas recorded elevated levels of contaminants, highlighting the risks posed by localized pollution sources. This suggests that even groundwater resources are not immune to contamination, and greater vigilance is needed in areas where land use practices may impact water quality.

These findings underscore the importance of regular monitoring of both surface and groundwater sources to ensure compliance with water quality standards. Regular monitoring is essential to protect public health and prevent long-term environmental degradation. It is particularly important to identify sources of contamination early to mitigate their effects on water resources.

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In light of these findings, it is recommended that efforts be made to reduce pollution from nearby industrial and agricultural activities, and that sustainable water management practices be adopted. Regular treatment of surface and groundwater, along with increased public awareness, can significantly improve water quality. Ultimately, integrated water quality management strategies are essential to protect water resources, safeguard public health, and ensure environmental sustainability.

Recommendation

To address the water quality issues identified in this study, enhanced monitoring and data collection are crucial. Implementing a more frequent and systematic water quality monitoring program for both surface and groundwater will help track changes in water parameters and detect contamination early. Implementing real-time monitoring systems may provide timely alerts to contamination risks to ensure more accurate and timely data, enabling faster responses to water quality degradation and contamination risks.

Pollution source control is equally vital. Efforts should focus on reducing agricultural runoff, industrial discharges, and domestic waste that contribute to water contamination. Sustainable agricultural practices, waste management improvements, and stronger enforcement of environmental regulations on industrial emissions will help mitigate pollution. Establishing buffer zones around water bodies can also limit the impact of human activities on water quality.

Investment in water treatment infrastructure is necessary to ensure the safety of water for consumption, particularly in areas with high contamination levels. Installing effective filtration, disinfection, and treatment systems for both surface and groundwater will significantly reduce health risks associated with unsafe water. Additionally, raising community awareness on water conservation and pollution prevention can promote healthier behaviors and support long-term improvements in water quality.

Furthermore, promoting sustainable land use practices and enhancing infrastructure development are essential steps in maintaining water quality. Reducing the use of harmful agricultural chemicals, encouraging soil erosion control, and reforestation efforts will help protect water sources from further contamination. Enhancing waste management and investing in sewage treatment infrastructure will reduce the amount of untreated wastewater entering water bodies, further safeguarding water quality. Collaboration among government agencies, the private sector, and local communities will ensure these strategies are effectively implemented.

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