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Research article

Evaluation of groundwater quality in communities near Sokoban Wood Village

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ABSTRACT

Groundwater is vital for drinking, agriculture, and domestic use in Sokoban Wood Village, Ghana, but concerns exist about its quality. This study assessed the suitability of 20 groundwater samples for domestic purposes. The study was carried out in 2023. We collected samples from boreholes and hand-dug wells using standard methods, analyzing them for various physicochemical parameters (pH, electrical conductivity, turbidity, nitrates, fluorides, and heavy metals). The microbiological analysis assessed fecal coliforms and *E. Coli* to identify microbial contamination. Established methodologies were used to evaluate potential health risks (carcinogenic and non-carcinogenic) associated with heavy metals. The Water Quality Index (WQI), Hazard Potential Index (HPI), and Heavy Metal Evaluation Index (HEI) provided a comprehensive water quality evaluation. The results revealed that the water fell below the recommended WHO pH range for drinking water. While most other parameters and heavy metals fell within WHO guidelines, 25 % of the samples contained fecal coliforms and *E. Coli*, indicating ongoing microbial contamination. The overall cancer risk was low for all age groups. Although some parameters met WHO standards, the WQI classified 20 % of the samples as not of good quality. Despite this, the HPI and HEI (−4.62 and 0.001) suggested generally good water quality based on heavy metal content. In conclusion, despite some positive indicators, acidic water and microbial contamination raise concerns. Regular monitoring and potential treatment measures are crucial to ensure safe drinking water for the Sokoban Wood Village community.

1. Introduction

Water is indispensable for enhancing living conditions, promoting health, and maintaining children's and adults' well-being [1], [2]; [3]. Clean and safe water plays a pivotal role in achieving these objectives, as recognized by [4], who emphasizes safe drinking water as a fundamental human right for health and well-being. Despite numerous pledges by governments to enhance access to clean drinking water and basic sanitation, as outlined in the Millennium Development Goals (MDGs) with a target deadline of 2015, challenges persist in ensuring the safety of various water sources. This research investigated the safety and quality of groundwater

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sources and their impact on public health and well-being.

Water quality profoundly influences health, as highlighted by the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) (UNICEF, 2019; [5]). Contaminated water sources are linked to the spread of infectious diseases such as dysentery, cholera, diarrhea, hepatitis A, polio, and typhoid [6]. Groundwater, surface water, and rainfall are the primary drinking water sources, each with varying degrees of safety and accessibility [7].

Groundwater, formed through natural processes as water seeps through soil and rocks, is typically considered safer due to natural purification mechanisms [8]. However, contamination can occur, mainly from dumpsite leachate and malfunctioning sanitation systems. Consequently, surface water treatment becomes imperative to ensure its suitability for consumption [9,10]. Investigating the safety and quality of water sources is crucial for public health and is a vital aspect of environmental contamination research [11].

Various factors contribute to residential water contamination, including the source of water, its quantity, accessibility, availability, and the type of sanitation facility used and storage conditions [12]. Despite progress, challenges remain, with approximately 844 million people lacking access to clean drinking water and an estimated 3.4 billion individuals at risk due to acute water shortages, primarily affecting populations in low-income countries [13,14]. Addressing these disparities, particularly between rural and urban areas, remains critical in achieving universal access to safe drinking water.

Groundwater sources can become contaminated with heavy metals, posing significant health risks [15–18]. These contaminants can accumulate in the body and cause various health problems, including cancer, neurological issues, and cardiovascular problems. Exposure to heavy metals like cadmium, nickel, and chromium can lead to cancer, which is a major risk to human health. Certain heavy metals accumulate in the environment and are found challenging to recycle or degrade, significantly increasing the risk to human health [19]. While previous studies have documented heavy metal pollution of groundwater in Ghana [12,20–25], a comprehensive assessment of groundwater quality and its potential health implications in Sokoban Wood Village, Ghana, is lacking. This study aims to evaluate the suitability of groundwater in this area for domestic purposes by analyzing various physicochemical parameters and heavy metal concentrations. We further assess the potential health risks associated with the detected contaminants using established indices like the Water Quality Index (WQI), Hazard Potential Index (HPI), and Heavy Metal Evaluation Index (HEI).

2. Materials and methods

2.1. Study area

Sokoban Wood Village is a community situated on the outskirts of Kumasi, the capital of Ghana's Ashanti Region. It is known for housing a significant portion of the country's wood products manufacturing industry (Fig. 1). While the area initially boasted modern infrastructure like good roads, electricity, and clean water, these features have undergone some degradation as the population has

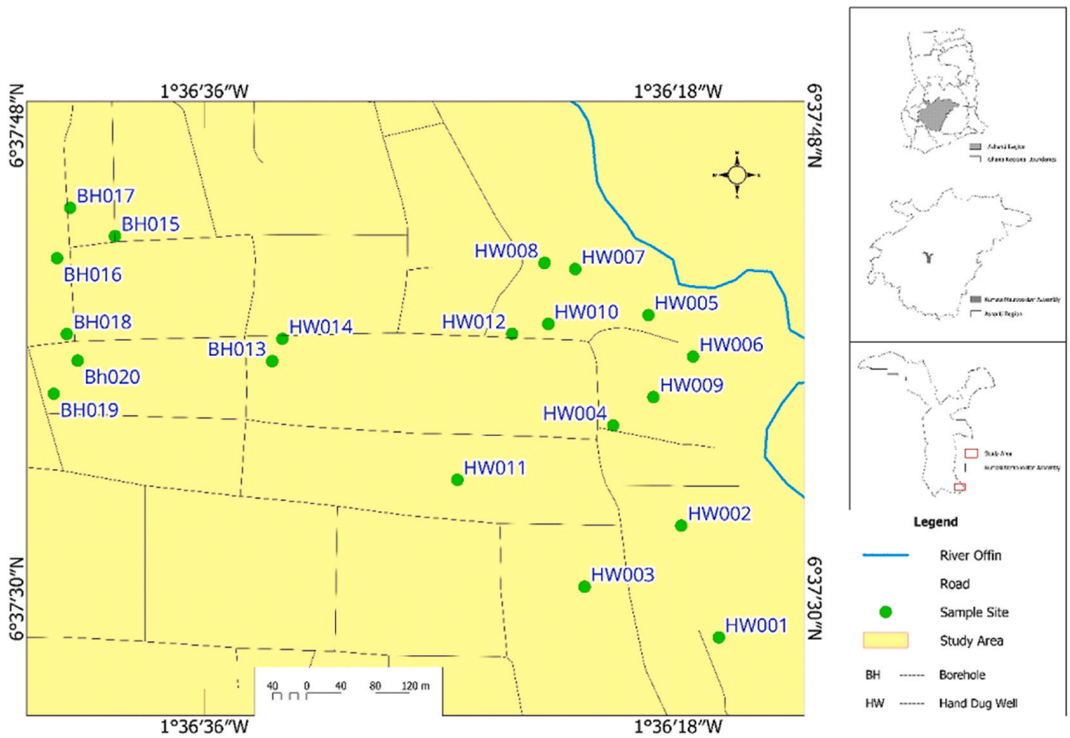

Fig. 1. Map of study area.

grown.

Sokoban Wood Village is geographically located at 6.5917° N latitude and −1.6227° W longitude. Neighboring communities include Kaase, Atonsu, Kuwait, and Daban. Industrial activity is present nearby, with companies like the Bulk Oil Storage and Transportation Company Limited (BOST), Guinness Brewery, Twellium Industrial Company, and Kumasi and Oti landfill bordering the area. Industrial and commercial activities in Sokoban Wood Village, such as sawdust burning, charcoal production, and animal hide roasting, contribute to environmental smoke and dust.

2.2. Sampling

A total of 20 water sources, comprising 13 hand-dug wells and 7 boreholes, were sampled from Sokoban Wood Village. Each borehole yielded three samples designated for physicochemical, heavy metals, and bacteriological analysis. Groundwater samples were collected using Polyethylene 500 mL bottles, pre-treated by rinsing with the respective source water to ensure cleanliness.

On-site measurements of total dissolved solids (TDS), electrical conductivity (EC), and pH were conducted using a portable multi-parameter meter [2,11]. For heavy metal analysis, groundwater samples were immediately acidified with 50 % HNO_3 to achieve a pH below 2 during sampling [18]. All samples were meticulously labeled to ensure proper identification throughout the analysis process.

Microbial determination required sterile conditions; water samples were collected in sterilized 500 mL plastic bottles [2,26]. Following sampling, all water samples were promptly placed in an icebox to maintain their integrity and transported to the laboratory for further analysis.

2.3. Determination of heavy metals

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) was utilized to determine the presence of heavy metals in samples. Specifically, 100 mL of the sample was mixed with 10 mL of HNO_3. The mixture was heated gradually to 150–200 °C until nitrite fumes were no longer emitted. Heating continued until the volume reduced to 3–4 mL and the solution turned colorless. After cooling, the mixture was diluted to 50 mL with distilled water. The final solution was then analyzed using ICP-OES to quantify heavy metals.

2.4. Water quality index (WQI)

The Water Quality Index (WQI) formula, as described by Equations (1) and (2), was utilized to assess the suitability of sampled groundwater from the research area in Sokoban Wood Village for specific users. This method involved determining the purity of water quality grades by analyzing commonly calculated water quality indicators. Equation (3) was employed to calculate the relative weight (Wi) based on maximum recommended limits reported in previous studies Akoto et al., 2021; [8,27]. Each component was assigned a weight ranging from 1 to 5, depending on its impact on human health, as detailed in Table 1. The water quality index consists of five categorized sections: excellent water (<25), good water (25–50), poor water (50–75), very poor water (75–100), and groundwater unsuitable for human consumption (>100) [28].

$$\mathrm{WQI} = \sum_{i}^{n} (W_i q_i) \tag{1}$$

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

$$W_i = \frac{w_i}{\sum w_i} \tag{3}$$

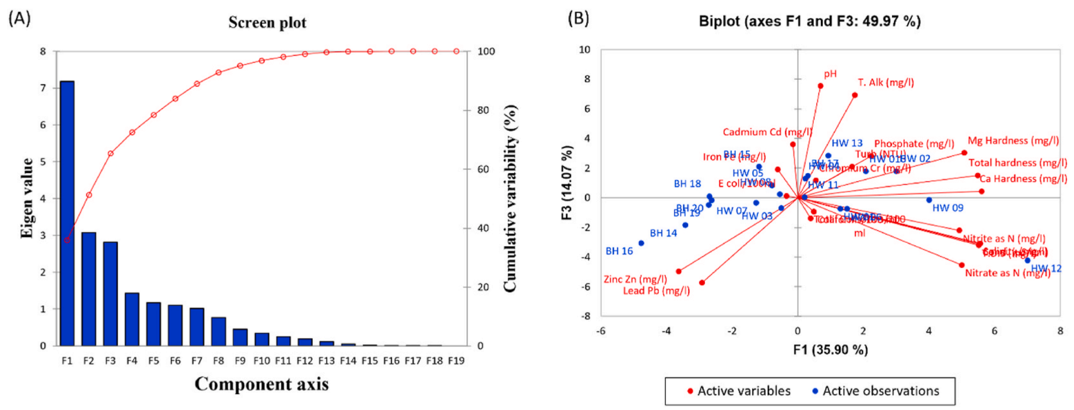

Fig. 2. (A) Screen plot of PCA and (b) PCA factor observations and Variable loadings Biplot.

Table 1
Standard limits, assigned weight and relative weight of each parameter.

Parameter	Standard Si	Assigned Weightage (wi)	Relative Weight (Wi)
pH	8.5	4	0.0588
Cond. (μS/cm)	400	2	0.0294
Turb (NTU)	1	4	0.0588
T.D.S (mgl^{-1})	500	4	0.0588
Nitrite, NO_2^- (mgl^{-1})	3	5	0.0735
Total Alkalinity (mgl^{-1})	120	3	0.0441
Salinity (mgl^{-1})	600	3	0.0441
Phosphate (mgl^{-1})	2.5	4	0.0588
Nitrate NO_3^- (mgl^{-1})	50	5	0.0735
Total hardness (mgl^{-1})	100	3	0.0441
Ca hardness (mgl^{-1})	75	4	0.0588
Mg Hardness (mgl^{-1})	50	2	0.0294
Cadmium Cd (mgl^{-1})	0.003	5	0.0735
Chromium Cr (mgl^{-1})	0.05	5	0.0735
Lead Pb (mgl^{-1})	0.01	5	0.0735
Zinc Zn (mgl^{-1})	3	5	0.0735
Iron Fe (mgl^{-1})	0.3	5	0.0735

where WQI is the Water quality index, qi stands for quality rating, Wi stands for relative weight, and wi for the weights given to each parameter. Ci stands for each parameter's concentration, while Si stands for each parameter's drinking water standards limit, and n is number of parameters.

2.5. Health risk evaluation

The health risk analysis calculates the likelihood that an unpleasant or harmful health effect of a certain magnitude of various substances will occur over a certain time in human health [29]. Consumers may be exposed to the health risks from toxic metals in drinking water largely through ingestion [30]. For this purpose, Cd, Cr, Fe, Zn, and Pb were evaluated for their carcinogenic and non-carcinogenic potential health effects on humans. The chronic daily intake (CDI) *via* the ingestion pathway of the US Environmental Protection Agency was modified, as reported earlier [29,31].

$$\mathrm{CDI} = \frac{CW \times IR \times EF \times ED}{BW \times AT} \tag{4}$$

Table 2 defines all of the parameters used in Eqn. (4), with values based on the assumption that residents in the Sokoban community drink from boreholes and well water samples.

Additionally, the hazard quotient (HQ) computed establishes possible no risk of cancer. If the HQ value is greater than one or less than 1, there is thought to be no chance of harmful non-cancerous impacts on the state of people's health. The HQ was assessed using Eqn (5).

$$\mathrm{HQ} = \frac{\boldsymbol{CDI}}{\boldsymbol{RfD}} \tag{5}$$

Table 3 provides the heavy metals' oral reference doses (RfD) in mg/kg/day [32].

The total of all determined HQs for each substance, HI, was determined to evaluate the overall risk of impacts of many heavy metals that aren't cancer-causing but are still harmful (T [12]):

$$\mathrm{HI} = \Sigma\,(\mathrm{HQ}_1 + \mathrm{HQ}_2 + \mathrm{HQ}_3 \ldots \ldots \ldots \ldots + \mathrm{HQn}) \tag{6}$$

If HI is less than 1, there are no non-carcinogenic concerns at the sampling location. Non-carcinogenic health hazards are indicated by HI > 1.

The probability that a person may get cancer of any kind while exposed to cancer risks throughout their lifetime is known as the carcinogenic risk (CR) Akoto et al., 2021. The slope factor (SF) translates the chronic daily intake (CDI) of pollutants directly to cancer risk.

Table 2
Input parameters to characterize chronic daily Intake (CDI).

Exposure parameters	Symbols	Units	Adults Value	Children Value
Ingestion Rate	IR	L/day	2.2	1
Average Time	AT	Days	25,550	3650
Exposure Duration	ED	Years	70	10
Exposure frequency	EF	days per year	365	365
Body Weight	BW	Kg	70	15

Table 3
Heavy metal toxicity responses as Slope factor (SF) and oral reference dosage (RfD).

Heavy Metals	Oral Rfd (mg/kg/day)	Oral SF (mg/kg/day)
Fe	0.7	–
Cd	5×10^{-4}	–
Zn	0.3	–
Cr	1.5	0.5
Pb	3.5×10^{-3}	8.5×10^{-3}

Using equation (7), it was possible to determine the likelihood of CR related to groundwater consumption in the Sokoban community.

$$CR = CDI \text{ x } SF \tag{7}$$

Heavy Metal Pollution Assessment

Making use of the Heavy Metal Pollution Index (HPI) and Heavy Metal Evaluation Index (HEI), the level of heavy metals pollution in groundwater was assessed.

Index of Heavy Metal Pollution (HPI)

The HPI was determined using Qi and Wi as follows:
Qi is the quality rating for element i and Wi is the relative weight for element i [28,33].

$$HPI = \frac{\sum_{i=1}^{n} (|W_i Q_i|)}{\sum_{i=1}^{n} Q_i} \tag{8}$$

$$Qi = \frac{Mi - Ii}{Si - Ii} \tag{9}$$

Mi is the concentration obtained from element (i) in a sample, and Ii is the ideal maximum concentration for i. Si is the standard permissible limit, and Ii is the acceptable limit (Boum-Nkot, S. N. et al. (2023). The number of samples taken into consideration is n. The HPI readings are divided into three categories to determine the level of pollutants.

There are three levels of pollution: minimal (HPI value less than 100), threshold (HPI value equal to 100), and inappropriate (HPI value greater than 100). (Boum-Nkot, S. N. et al. (2023).

2.6. Heavy Metal Evaluation Index (HEI)

HMEI is determined as

$$HMEI = \sum_{i=1}^{n} \frac{Mi}{MACi} \tag{10}$$

where Mi stands for regulated value, and MACi stands for maximum permissible concentration for the ith heavy metal. The HMEI categorizes groundwater quality into three groups: low (5 or less), moderate (5–10), and high (10 or more) Akoto et al., 2021; [33].

2.7. Data analysis

XLSTAT software was used to analyze the data. Triplicate analyses were computed for each parameter and sample, with means and standard deviations as the results. The correlations between parameters were scrutinized using Pearson's correlation at a ($p = 0.05$), 95 % confidence level. Principal Component Analysis is a multivariate statistical technique (PCA) that created a relationship between variables, categorized important elements, and determines the common pollution sources responsible for groundwater quality. Varimax Rotation under Kaiser normalization of principal components results was carried out. A measurement's link to a sample of people or things is investigated in multivariate data analysis.

3. Results and discussion

The results of the physicochemical properties and heavy metals concentrations of the groundwater samples are shown in Table 4. The pH, Electrical Conductivity (E.C) (μS/cm), Total Dissolved Solids (T.D.S) (mg/L), Calcium hardness (mg/L), Magnesium hardness (mg/L), Alkalinity (mg/L), Salinity (mg/L), Nitrite as N (mg/L), Nitrate as N (mg/L), and Phosphate (mg/L) levels observed in both the hand-dug wells and boreholes of the water samples fell within the guidelines set by the World Health Organization (WHO) for drinking water quality. The water temperature ranged from 24.2 to 25.1 °C, with hand-dug wells varying from 24.2 to 25.1 °C and boreholes

Table 4
Physicochemical parameters of the water samples.

Sample	pH	Temp(°C)	Elec.Cond.(μS/cm)	Turb.NTU)	T.D.S(**mg/L**)	Tot.Hardness(**mg/L**)	Cahardness(**mg/L**)	Mghardness(**mg/L**)	Alk(**mg/L**)	Salinity(**mg/L**)	Nitrite(**mg/L**)	Nitrate(**mg/L**)	Phosphate(**mg/L**)	Cadmium(**mg/L**)	Chromium(**mg/L**)	Lead(**mg/L**)	Zinc(**mg/L**)	Iron(**mg/L**)
HW 01	4.9	25.0	290	9.67	213	44	26	18	24	177.0	1.7×10^{-3}	3.30	0.28	BDL	6.9×10^{-3}	6.0×10^{-4}	1.0×10^{-2}	BDL
HW 02	6.1	24.7	300	4.00	220	94	54	40	102	183.0	1.5×10^{-2}	3.70	0.20	BDL	BDL	BDL	7.0×10^{-4}	BDL
HW 03	5.6	24.5	190	6.00	140	34	20	14	18	105.0	1.3×10^{-2}	2.40	0.18	BDL	2.2×10^{-3}	BDL	8.1×10^{-2}	BDL
HW 04	5.7	24.4	150	2.00	113	54	30	24	58	94.4	1.1×10^{-2}	2.20	0.16	BDL	2.4×10^{-2}	BDL	6.6×10^{-3}	BDL
HW 05	5.4	24.6	100	6.00	077	42	24	18	20	71.8	1.2×10^{-2}	2.10	0.15	BDL	7.2×10^{-3}	BDL	1.7×10^{-2}	2.6×10^{-1}
HW 06	5.0	24.4	240	4.00	177	66	36	30	16	170.0	1.9×10^{-2}	3.00	0.16	BDL	6.7×10^{-3}	4.0×10^{-4}	7.4×10^{-3}	BDL
HW 07	5.5	24.2	140	4.00	106	20	12	08	12	44.5	1.4×10^{-2}	2.70	0.05	BDL	BDL	BDL	2.2×10^{-3}	BDL
HW 08	5.1	24.3	060	2.00	054	46	22	24	28	93.2	1.6×10^{-2}	2.40	0.03	0.0002	5.2×10^{-3}	7.0×10^{-4}	5.8×10^{-3}	BDL
HW 09	5.6	24.4	380	4.00	275	116	68	48	20	250.0	1.9×10^{-2}	3.80	0.15	BDL	2.3×10^{-3}	BDL	6.7×10^{-3}	BDL
HW 010	5.9	24.4	310	2.00	225	62	36	26	64	192.0	1.5×10^{-2}	2.70	0.75	0.0003	5.5×10^{-3}	5.0×10^{-4}	7.2×10^{-3}	BDL
HW 11	5.7	24.3	070	2.00	059	56	32	24	28	51.9	1.8×10^{-2}	3.50	0.15	BDL	BDL	BDL	BDL	BDL
HW 12	4.4	24.4	810	4.00	583	104	70	34	08	496.0	2.6×10^{-2}	10.8	0.21	BDL	2.8×10^{-3}	0.0037	0.0211	BDL
HW 13	7.8	24.6	140	10.00	107	66	34	32	46	99.5	1.0×10^{-2}	2.50	0.19	BDL	BDL	BDL	BDL	BDL
BH 14	4.8	24.8	020	2.00	026	20	10	10	08	25.0	5.0×10^{-3}	1.40	0.04	BDL	3.8×10^{-3}	9.1×10^{-3}	1.3×10^{-1}	BDL
BH 15	5.6	24.9	090	4.00	074	44	24	20	48	76.2	4.0×10^{-3}	1.0	0.24	0.0006	3.9×10^{-3}	1.7×10^{-3}	3.5×10^{-2}	8.4×10^{-2}
BH 16	4.9	25.0	010	0.00	017	08	06	02	08	22.9	3.0×10^{-3}	1.2	0.09	BDL	1.9×10^{-3}	1.49×10^{-2}	2.4×10^{-1}	BDL
BH 17	5.7	24.7	150	2.00	113	84	48	36	82	101.0	2.0×10^{-3}	1.1	0.13	BDL	1.3×10^{-3}	2.6×10^{-2}	5.0×10^{-2}	BDL
BH 18	5.2	24.9	030	2.00	030	18	10	08	20	30.6	3.0×10^{-3}	0.8	0.09	BDL	8.0×10^{-4}	1.1×10^{-3}	1.6×10^{-2}	6.6×10^{-3}
BH 19	5.0	24.9	030	6.00	029	20	14	06	18	31.2	4.0×10^{-3}	1.2	0.21	BDL	BDL	3.4×10^{-3}	9.4×10^{-2}	BDL
BH 20	5.3	25.1	040	2.00	037	24	16	08	16	36.8	2.0×10^{-3}	1.0	0.1	BDL	4.0×10^{-4}	2.4×10^{-3}	3.9×10^{-2}	BDL
WHO LIMIT	6.5–8.5	25	400	1	0	100	75	50	120	600	3	50	0.1–1	0.003	0.0500	0.0100	3.0000	0.3000

from 24.7 to 25.1 °C. The highest temperature was recorded for BH 20. The average temperature observed in this study favors the potential growth of microbes, as they tend to thrive at room temperature. However, compared to established water temperature guidelines such as the Dutch Drinking Water Act, only BH20 exceeded the threshold of 25 °C.

Turbidity levels in the 20 water samples ranged from 0 to 10 Nephelometric Turbidity Units (NTU). Turbidity in hand-dug wells ranged from 2 to 10 NTU, with an average of 4.8 NTU, while in boreholes, it varied from 0 to 6 NTU, with an average of 2.7 NTU. Thus, the turbidity of hand-dug wells in this study was 1.8 times higher than that of boreholes. The WHO standard for turbidity in potable and drinking water is 1 NTU, with maximum permissible values up to 5 NTU. BH16 recorded turbidity less than 1 NTU, while HW1, HW4, HW5, HW13, and BH19 had turbidity levels greater than 5 NTU (6–10 NTU), indicating turbid waters exceeding the WHO threshold. These waters are less transparent and more colored due to dissolved materials such as organic dyes, particulate matter, or algae, making them potential breeding grounds for waterborne pathogens [34].

3.1. Heavy metals concentration

The cadmium, zinc, and iron levels in the water samples were below the guideline values set by the World Health Organization (WHO). Chromium levels in 16 water samples ranged from 0.0004 to 0.024 mg/L, with an average concentration of 0.004 mg/L across all 20 samples. These concentrations were below the WHO standard for chromium in drinking water, which is 0.05 mg/L. Notably, HW4 exhibited the highest cadmium level among the samples analyzed.

Lead concentrations varied from 0.0004 to 0.015 mg/L in twelve water samples, with the highest amount detected in BH16. All the samples, except BH16, were within the WHO standard for lead in drinking water of 0.01 mg/L.

The analysis revealed encouraging results for most heavy metals tested. Cadmium, zinc, and iron concentrations in all water samples were below the WHO guideline values for drinking water. This indicates minimal risk associated with these metals in the water supply.

Chromium levels were slightly elevated in some samples (16 out of 20), ranging from 0.0004 mg/L to 0.024 mg/L. However, the average concentration across all samples (0.004 mg/L) remained well below the WHO standard of 0.05 mg/L. This suggests that chromium contamination is unlikely to pose a significant health threat in this area. While chromium has an essential form (trivalent chromium), the form typically found in contaminated water (hexavalent chromium) is a carcinogen and can cause respiratory problems, skin irritation, and stomach ulcers [35].

One sample, HW4, exhibited a higher cadmium level than the others. While still potentially a result of natural variations or localized contamination sources, further investigation into this specific well might be warranted. Chronic exposure to high cadmium levels can damage the kidneys, bones, and lungs. It can also increase the risk of certain cancers [35].

Lead contamination was detected in twelve samples, ranging from 0.0004 mg/L to 0.015 mg/L. It is important to note that all samples except BH16 fell within the WHO's acceptable limit of 0.01 mg/L for lead in drinking water. However, the presence of lead in some samples, particularly the elevated level in BH16, necessitates further attention. Lead exposure, especially in children, can impair cognitive development, cause learning disabilities, and damage the nervous system. It can also lead to anemia, high blood pressure, and kidney problems [35].

Table 5
Microbial levels of the water samples.

Sample	Total Coliforms/100 ml	Coliforms/100 ml	*E coli*/100 ml
HW 01	1.5×10^7	2.1×10^6	NIL
HW 02	NIL	NIL	NIL
HW 03	2.3×10^6	2.1×10^6	2.3×10^5
HW 04	NIL	NIL	NIL
HW 05	2.9×10^6	9.3×10^5	2.3×10^5
HW 06	9.3×10^6	2.1×10^6	NIL
HW 07	NIL	NIL	NIL
HW 08	NIL	NIL	NIL
HW 09	NIL	NIL	NIL
HW 10	NIL	NIL	NIL
HW 11	1.5×10^7	4.3×10^6	2.3×10^5
HW 12	NIL	NIL	NIL
HW 13	NIL	NIL	NIL
B H14	NIL	NIL	NIL
BH 15	NIL	NIL	NIL
BH 16	NIL	NIL	NIL
BH 17	NIL	NIL	NIL
BH 18	NIL	NIL	NIL
BH 19	NIL	NIL	NIL
BH 20	NIL	NIL	NIL
WHO LIMIT	NIL	NIL	NIL
% ABOVE WHO	25	25	15

3.2. Microbiological concentration

Total coliforms were detected in samples HW1, HW3, HW5, HW6, and HW11 from the hand-dug wells, with concentrations ranging from 2.3×10^6 to 1.5×10^7 cfu/100 ml. These concentrations exceeded the World Health Organization (WHO) standard of 0 cfu/100 ml for total coliforms in water.

Fecal coliform contamination was observed in five water samples, with concentrations ranging from 9.3×10^5 to 4.3×10^6 cfu/100 ml. Additionally, *E. Coli* contamination was found in three water samples, with similar concentrations of 2.3×10^5 *E. Coli*/100 ml cfu.

Detailed microbiological concentration results can be found in the data provided in Table 5.

The analysis revealed concerning levels of fecal contamination in some of the hand-dug wells (HW1, HW3, HW5, HW6, and HW11). These samples exceeded the WHO guideline of 0 cfu/100 ml for total coliforms, indicating the presence of fecal indicator bacteria. Furthermore, the detection of fecal coliforms and *E. Coli* in several samples confirm the presence of fecal matter in the water, posing a significant health risk.

Microbial contamination from fecal matter can introduce various disease-causing pathogens like bacteria, viruses, and parasites into the water supply. Consuming such contaminated water can lead to gastrointestinal illnesses like diarrhea, vomiting, and cramps. These illnesses can be particularly severe for vulnerable populations like children and immunocompromised individuals [36,37].

The presence of fecal coliforms and *E. Coli* suggests human or animal waste contamination. Potential sources could include the lack of proper toilets or latrines near the wells, which can allow human waste to seep into the groundwater, livestock manure from nearby farms or improper waste management practices that can also contribute to fecal contamination and inadequate well construction or sealing that may allow contaminated surface water to infiltrate the groundwater source.

3.3. Water quality index (WQI)

The Water Quality Index (WQI) values for the groundwater samples varied from excellent water quality, with a minimum value of 17.274, to inferior water quality, with a maximum value of 77.232. Specifically, the WQI values for the hand-dug well (HW) and borehole (BH) samples ranged from 25.499 to 77.232 and 17.274 to 45.950, respectively.

Notably, the BH samples exhibited excellent and good quality, while some HW samples ranged from good to very poor quality. This highlights water quality variations between the two sources [38].

3.4. Principal Component Analysis (PCA)

Table 6 presents the varimax rotated factor loadings, percentage variability, and cumulative explanation for each factor and component. Fig. 2 (A) shows the screen plot of PCA and (b) PCA factor observations and Variable loadings Biplot. Negative factor loadings indicate that the groundwater samples exhibit parallel or non-point characteristics, originate from diverse sources, or are influenced by geochemical transport mechanisms within the Sokoban environments.

The first factor (F1) provides insight into ion exchange, water-rock mineralization, and saline water intrusion, mainly due to the intensive pumping of fresh rock groundwater. This process may lead to saline water intrusion into freshwater, impacting salinity and

Table 6
Principal Component Analysis of the quality of groundwater.

Parameters	F1	F2	F3
pH	−0.192	0.081	**0.762**
Conductivity (μS/cm)	**0.974**	−0.032	0.047
Turbidity (NTU)	0.138	0.457	0.277
T.D.S (mgL⁻)	**0.975**	−0.036	0.041
Nitrite as N (mgL⁻)	**0.814**	0.399	0.071
Alkalinity (mgL⁻)	0.015	−0.241	**0.790**
Salinity (mgL⁻)	**0.979**	−0.065	0.055
Phosphate (mgL⁻)	0.236	−0.026	0.411
Nitrate as N (mgL⁻)	**0.939**	0.083	−0.128
Total hardness (mgL⁻)	**0.790**	−0.057	0.493
Ca hardness (mgL⁻)	**0.851**	−0.073	0.398
Mg Hardness (mgL⁻)	**0.666**	−0.031	**0.610**
Cadmium Cd (mgL⁻)	−0.146	−0.236	0.352
Chromium Cr (mgL⁻)	0.039	0.000	0.147
Lead Pb (mgL⁻)	−0.192	−0.483	−0.703
Zinc Zn (mgL⁻)	−0.343	−0.307	−0.685
Iron Fe (mgL⁻)	−0.190	0.280	0.127
Total Coliforms/100 ml	0.050	**0.864**	−0.163
Coliforms/100 ml	0.048	**0.872**	−0.115
E coli/100 ml	−0.118	**0.826**	−0.062
Eigenvalue	7.180	**3.073**	2.814
Variability (%)	32.682	**15.537**	17.116
Cumulative (%)	32.682	**48.220**	65.335

conductivity levels. Additionally, chemical fertilizer applications, lithology, geological activities, soil erosion, and dissolved minerals contribute to factors such as total dissolved solids (TDS), nitrate, nitrite, and alkaline earth elements like total hardness (Mg^{2+} and Ca^{2+}).

The negative loading of phosphate ions (PO_4^{3-}), microbial contaminants, and heavy metals in the first factor suggests non-point sources of pollution, including organic pollutants from nearby streams and extensive agricultural activities. Industrial wastes also play a significant role in this scenario.

The second factor (F2) is characterized by strong positive loadings of fecal coliforms, total coliforms, and *E. Coli* bacteria, indicating potential fecal pollution and environmental contamination from nearby washrooms and animal excretion. This factor shows weak or negative loadings for heavy metals and physicochemical parameters, accounting for 15.54 % of the total variability.

The third factor (F3), contributing to 17.12 % of the total variability and a cumulative percentage of 65.34 %, demonstrates strong loadings on pH and total alkalinity, with moderate loadings on Mg^{2+}. The high pH loadings suggest a natural accumulation of hydrogen ions in the groundwater, possibly influenced by basic carbonates from sources like wood ash runoff in the study area.

3.5. *Health risk assessment of heavy metals*

Non-carcinogenic and carcinogenic risk assessments for humans via the oral pathway were conducted, with (HQ) representing non-carcinogenic risk and (HI) representing carcinogenic risk. The non-carcinogenic risk (HQ) was evaluated for both children and adults through oral consumption, specifically ingestion.

Except for Fe in groundwater samples HW05, HW15, and HW18, both the HQ and HI values for all metals in all samples were below the permissible limit of one ($HQ < 1$) for adults. This indicates that these metals do not expose adults to non-cancer and cancer-related health effects.

3.6. *Heavy Metal Pollution Index (HPI)*

The analysis of the 20 groundwater samples from the Sokoban Wood Village region indicates that the water is safe for drinking. An HPI value of −4.62 was obtained. This indicates excellent water quality, which is consistent with the findings of the WQI analysis. The low HPI readings validate the minimal metal concentrations observed in the borehole samples, which fall below the WHO benchmarks.

The negligible HPI readings likely result from the dilution of metals due to rainfall rather than the absence of heavy metal pollution [39].

3.7. *Heavy Metal Evaluation Index (HEI)*

The HEI for the 20 samples were 0.001. This value indicates low pollution of heavy metals in these sources and, hence, is suitable for drinking purposes. The low HEI may be due to the dilution of heavy metals by rainwater and the low influence of human activities on the contamination of groundwater [12,28].

4. Conclusion

This study reveals that groundwater in Sokoban tends to be acidic and falls below the WHO-recommended pH levels for safe human consumption, posing potential health risks to residents. However, the physicochemical parameters of the water samples generally fall within safe levels. Similarly, chemical contaminants such as nitrite, phosphate, nitrate, and heavy metals were within acceptable limits for consumption.

The observed pH and electrical conductivity variations across the study area suggest potential influences from different geological formations. Lead (Pb) and chromium (Cr) were the primary heavy metals exceeding WHO drinking water guidelines, potentially posing health risks. These findings align with previous studies in nearby regions reporting similar heavy metal contamination linked to agricultural practices using metal-based pesticides or historical mining activities. However, the limited sample size in our study restricts the generalizability of this association. Future research should focus on identifying specific Pb and Cr contamination sources through isotope analysis or source tracing techniques. Additionally, investigating the implementation of effective water treatment methods like reverse osmosis or exploring remediation strategies for affected aquifers would be crucial in safeguarding public health and the surrounding environment.

Microbial contamination found in some samples renders them unfit for human consumption. Tools like the Water Quality Index (WQI) and Principal Component Analysis (PCA) were employed to assess overall water quality. These analyses suggest that the groundwater in Sokoban generally exhibits good quality.

Carcinogenic and non-cancer risks in both children and adults were generally low, with exceptions noted for elevated levels of iron in certain samples, indicating potential non-cancer health effects in adults.

The observed low levels of HPI and HEI may be attributed to significant rainfall during the sampling period, which could have diluted contaminants.

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Data availability

Supplementary data will be available from the corresponding author upon request.

CRediT authorship contribution statement

Bernice Amponsah: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Nathaniel Owusu Boadi:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Selina Ama Saah:** Writing – review & editing, Data curation. **Patrick Opare Sakyi:** Writing – review & editing, Resources, Methodology. **Eric Selorm Agorku:** Writing – review & editing, Resources, Methodology. **Harry Okyere:** Writing – review & editing, Resources, Methodology. **Andrew Nyamful:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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