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Original Article

Assessment of Toxic Metals and Physico-Chemical Parameters of Spring, Borehole and Well Water in Hong Local Government Area, Adamawa State, Nigeria

Dangari Livinus Linus[1], Fwangle Ishaya Istifanus[2]

[1]*Department of Physics, Faculty of Physical Sciences, Modibbo Adama University, Yola, Adamawa State, Nigeria.*
[2]*Department of Physical Sciences Education, Faculty Education, Modibbo Adama University, Yola, Adamawa State, Nigeria.*

[1]*Corresponding Author : livinuslinus1@gmail.com*

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Abstract *- The research assessed water sources from springs, boreholes and wells in the Hong Local Government Area of Adamawa State to establish their appropriateness for drinking and household purposes. Researchers gathered 19 water samples, including 3 from springs and 8 from both boreholes and wells, using GPS to ensure exact location records. Atomic Absorption Spectroscopy (AAS) enabled testing of these water samples to detect toxic metals and key physicochemical properties. Parameter analysis revealed differences in pH levels, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), fluoride content, and water hardness. The temperature and EC measurements from the borehole and well water sources surpassed the NSDWQ established thresholds and elevated TDS levels. The concentration of Pb in these water sources exceeded the WHO acceptable safety limits. The health risk assessments utilizing Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Total Hazard Index (THI) demonstrated potential health risks, especially to children. The Water Quality Index (WQI) results showed that spring water had excellent quality levels, while borehole water was rated between good and moderate and well water needed potential treatment despite being generally good. The outcome emphasizes the essential need for systematic water quality assessments and effective treatment interventions to protect public health, especially in geneti cally and immunologically sensitive individuals.*

Keywords - *Hong LGA, Physicochemical parameters, Toxic metals, Water quality index, Waterborne health risk.*

1. Introduction

Water is indispensable to human existence and daily activities, serving numerous purposes that underpin both individual health and societal development. Chemically consisting of hydrogen and oxygen (H_2O), it is a colorless, tasteless, and odorless fluid essential for biological processes and ecosystem balance [9]. Maintaining steady access to clean, safe water is essential to public health and a major deterrent against waterborne illnesses [32]. Globally, water serves diverse functions ranging from irrigation in agriculture to household consumption and power generation. As highlighted by [49], the provision of safe drinking water hinges on regular surveillance, efficient purification methods, and strategic management systems, reinforcing its status as a core necessity for human life.

Despite its critical role, groundwater sources like wells, boreholes, and natural springs are frequently at risk of contamination. This is primarily due to fluctuating physicochemical conditions and the infiltration of hazardous substances, particularly heavy metals, which pose both immediate and long-term health and ecological risks. Many marginalized or rural communities continue to depend on these sources, often without proper safeguards, exposing them to pollutants that may accumulate in the body over time and potentially interfere with hereditary health patterns [39].

Sustained access to potable water is vital for health preservation. According to [38], each individual requires between 50 and 100 liters of water per day for personal hygiene and domestic activities. This water must be not only accessible and cost-effective but also meet safety and quality standards. Ideally, water designated for household usage should be free from turbidity, pathogenic organisms, and chemical contaminants. Although water drawn from natural sources like springs and boreholes is generally presumed to be of higher quality, it is not immune to pollution, especially where poor sanitary practices and temperature fluctuations compromise source integrity.

Before using water for domestic, agricultural, or industrial purposes, prior analysis of its physicochemical properties is mandatory. These parameters serve as fundamental indicators of water quality and its effects on human life and the environment. The following factors must be deeply tested: pH level, electrical conductivity, total turbidity, temperature, total dissolved solids, and hardness [28].

The contamination of water supplies with harmful metals is a major concern for people's health on a global scale. Even in minimal concentrations, substances such as arsenic, lead, chromium, and mercury are biologically damaging by being capable of inflicting organ damage over time and causing epigenetic changes [22]. The aforementioned metals, which have a place in the periodic table as certain Transition Elements, Lanthanides, Actinides, and some Metalloids, are constituents of diverse groups. Their occurrence in water sources comes from both natural activities like mineral weathering and volcanic eruptions, as well as anthropogenic activities like industrial discharge, mining, agricultural activities, and even atmospheric fallout [13]. After these contaminants are introduced to the environment, they can persist and bioaccumulate, leading to cross-generational health complications among genetically predisposed populations.

Worsening pollution of water sources is closely associated with the increased prevalence of illnesses that come from mismanagement of industrial and agricultural waste [15, 21]. Prolonged exposure to these metals can damage some internal body organs, as well as have an impact on the blood and neurological systems [10, 36]. In addition to chemical toxicity, some of these metals pose radiological risks, potentially leading to genetic mutations, chromosomal abnormalities, and even fatal health conditions [1]. Industrial effluents and mining residues are among the leading contributors to the contamination of natural water bodies [14]. Notably, arsenic (As) stands out as one of the most hazardous toxic metals; it is highly poisonous and classified as a carcinogen when found in drinking water [26].

Water is essential for all living organisms, playing a vital role in cellular metabolism and overall survival. The continued existence of humans on Earth is heavily reliant on the availability of clean, high-quality water. However, field observations in several communities within the Hong Local Government Area, such as Pella, Dzuma, Gashaka, and Dilchidama, reveal a concerning trend of yellowish or brownish discolouration of teeth. Similarly, residents of Kwakwa and Garaha are reportedly experiencing health challenges like goitre, which are probably caused by unclean drinking water in these areas [42].

Research conducted by [29] in Pella revealed that the pH value of the well and borehole water sources is both acidic, with values falling around 6.30, which is lower than the WHO minimum standard. Such acidic conditions contribute to dental discoloration and encourage the growth of chromogenic bacteria like Streptococcus mutans, which produce pigments that stain teeth and may lead to other health issues. However, this study did not explore the potential health impacts of these harmful metals present in the water.

Further investigation by [48] in nearby local government (Michika) found that certain heavy metals, including Fe, Co, Pb, Cr, and Cd, exceeded the safe limits. Water is indispensable to human existence and daily activities, serving numerous purposes that underpin both individual health and societal development. Given that Hong Local Government lies just about 50 kilometres from Michika and shares similar geological features within the Upper Benue Trough, there is a high likelihood that toxic metals may also be present in Hong's groundwater. These metals may naturally leach into water supplies due to the region's extensive granite rock formations.

There is a growing concern in rural communities about the portability of water for consumption; up to now, little is known regarding the actual concentration and possible adverse health effects of toxic metals in the water sources in Hong Kong. This gap in knowledge is particularly worrisome, given the crucial role that basic water-related parameters, such as physical and chemical properties, play in determining how these metals dissolve and move within the water system. These physicochemical properties can either increase or reduce the likelihood that harmful substances will be absorbed into the human body. This lack of clean water has been strongly linked to various health problems, including recurring headaches, joint pain such as arthritis, digestive issues like heartburn, and infectious diseases such as typhoid fever, dysentery, and cholera. These illnesses not only affect individual well-being but also burden families and strain already limited healthcare resources.

Across the African continent, millions of lives are impacted each year by waterborne diseases. Statistics reveal that over 3.4 million deaths annually are caused by illnesses related to water that is polluted, insufficient cleanliness, or poor hygiene [50]. The study aims to assess the presence of various physicochemical parameters and metals that are toxic in water obtained from springs, boreholes, and well in Adamawa State, Hong Local Government Area with the following objectives to determine the physical and chemical properties of the collected water samples, the concentrations of toxic metals present in these samples, potential hazards to health, and to calculate the Water Quality Index (WQI) for all he sources.

This research is vital for identifying communities that are most at risk of facing the negative consequences of low water quality, including exposure to waterborne diseases. The findings can help reduce health risks and mortality rates linked to contaminated water. Additionally, the study provides critical information for NGOs involved in WASH (Water, Sanitation, and Hygiene) initiatives, enabling them to design effective intervention programs, advocate for policy reforms, and secure funding to increase the availability of safe drinking water. The study also assists public sector institutions by providing information that can help design policies, rules, and public health initiatives grounded on scientific research, thereby aiding in sustainable development and respect for the environment.

This study is limited to the examination of toxic metals and physical and chemical characteristics of the water found in the water sources within the Hong Local Government Area of Adamawa State. As a result, its findings may not be representative of conditions in other rural communities within the state or the country as a whole. The investigation focuses exclusively on springs, boreholes, and well water potentially affected by natural and human-induced contamination, excluding other water sources such as rivers, lakes, or rainwater.

The use of Atomic Absorption Spectroscopy (AAS) for detecting toxic metals and evaluating physicochemical parameters may also have limitations, particularly regarding the detection sensitivity for certain substances. Moreover, the timing of sample collection may not reflect seasonal variations, which can influence water quality.

2. Concept of Water

Water is essential for sustaining life, supporting economic progress, and maintaining ecological balance. It is a clear, tasteless, and odorless liquid with a chemical formula H_2O. Water possesses distinct physical attributes, such as a standard density of 1 g/cm^3, a freezing point of 0°C (32°F), and a boiling temperature of 100°C (212°F) [2, 16]. It occurs in various natural forms, including freshwater from rivers, lakes, and aquifers, seawater, alkaline and acidic water (depending on pH), mineral-rich water, and distilled types [47]. This indispensable resource plays a critical role in daily human needs, ranging from drinking and food preparation to hygiene, agriculture, and sanitation. The main sources of surface water and their ground counterparts are utilized for water that people would typically use in their day-to-day living. Routine water quality examination must become a priority in the fight for good hygiene and public health.

Moreover, there is a higher chance of chronic exposure since pollutants like metals can linger in water systems and accumulate over time. Such an environmental trauma may be associated with harmful health effects, including possible disturbances of inherited biological systems through generations. Consistent monitoring, therefore, not only plays a key role in the prevention of immediate health threats but also in the preservation of the inherent health conditions of the members of the families in the vulnerable population.

2.1. Groundwater

Groundwater is fairly well exploited as a source of potable water and may account for approximately 50% of the total global potable water [4]. It is usually developed and put in use by manual wells, mechanized boreholes, or natural springs [37]. High-rise buildings have boreholes that are usually powered by submersible pumps, while in rural settings, rainwater, which is collected from rooftops at the start of the rainy season, is stored in underground tanks for domestic use. When borehole water becomes inaccessible or inadequate, residents usually rely on hand-dug wells. In addition to domestic use, groundwater also supports irrigation and various industrial processes [25]. While often considered safe due to the natural filtration provided by soil layers, groundwater can still become contaminated through natural geological processes and human activities [24]. Common sources of contamination include poorly managed industrial waste, agricultural runoff, and soil erosion, all of which can carry the infiltration of harmful substances into underground water systems, which is a growing concern, particularly in developing nations like Nigeria [3].

The extent of groundwater contamination is impacted by a number of variables, including the chemical nature and concentration of pollutants, the depth of the aquifer, and the structural and compositional attributes of the soil through which these substances migrate [24]. Borehole water is widely utilized as the main source of drinkable water in Nigeria's remote and semi-rural regions, which are increasingly scrutinized for their potential to contain hazardous metals, especially in sub-Saharan Africa [20]. In a recent investigation by [29], water samples from three water sources (boreholes, wells, and streams) were analyzed in the dry season in Hong LGA. Nine samples were selected and analyzed for heavy metals and their physicochemical attributes using an AAS machine. The results showed that water was slightly basic, but most of the data points were within the WHO and NAFDAC safe levels.

2.2. Physical and Chemical Parameters of Water

Water factors, such as physical and chemical, are the properties that determine the content of basic elements, their volume, and their physical condition. Such parameters are crucial in the qualitative determination of water for various purposes such as drinking, irrigation, and industrial processes [7]. Monitoring these indicators helps water managers and public health officials assess water quality and take corrective actions when necessary. To improve water treatment system efficiency and guarantee that water satisfies set safety standards, these factors must be routinely evaluated [44]. In Mubi North, Adamawa State, a study looked at the quality of drinking water that came from various locations. The outcomes demonstrated that all the parameters measured fell within the safe limit established by the BIS and the WHO [51]. This suggests that the water was suitable for daily household activities and consumption.

2.3. Toxic Metals

Toxic or heavy metals are metallic substances that can pose a threat to the human body system and the environment when their concentrations are significant. These metals linger in natural ecosystems and accumulate in living organisms over time. When this bioaccumulation occurs, it can interfere with metabolic activities, cause long-term health issues, and even alter genetic material and influence gene expression. People may be exposed to these harmful metals through eating and drinking contaminated food and water, breathing in metal-laden dust particles, or skin contact with polluted water or soil. When exposure exceeds the amount that the body system can detoxify, these metals build up in body tissues, which may lead to serious and sometimes irreversible health problems that can persist across generations. In Ifo, Ogun State, a study investigated the quality of groundwater by testing 22 well water samples. The findings revealed significantly elevated concentrations of toxic metals, particularly cadmium and lead, posing substantial risks to public health [45]. Based on these findings, the researchers advocated for effective water treatment interventions to mitigate these risks. Similarly, research was carried out in Michika, Adamawa State, to determine the presence of toxic metals in borehole and well water. Certain metals were found within acceptable limits, some were found to be high, such as chromium, lead, cadmium, cobalt, and iron, were found to be high. These exceeded the safety limits recommended by the WHO, USEPA, and NSDWQ [48]. Given that the Hong Local Government Area is geographically and geologically similar to Michika, a strong scientific basis exists for conducting a similar assessment in Hong. Evaluating toxic metal concentrations in the water sources of Hong is essential for identifying potential health threats and ensuring that residents have access to water that is free of impurities.

Table 2.1. Health Implications of Toxic Metals in Contaminated Water

Metals	Associated Health effects
Lead	Causes damage to the brain and liver. Increases the risk of miscarriage in women. It can be fatal in severe cases. It disrupts the functioning of the kidney and damages the nervous system. Harms the reproductive organs.
Chromium	Damage to the kidneys, liver, and blood cells occurs through oxidative stress. May lead to hemolysis and eventual organ failure. Triggers nerve and circulatory issues. Leads to skin irritation, respiratory complications (e.g., asthma, nasal ulcers), and increases cancer risk.
Cadmium	Impairs liver and kidney function. Causes bone demineralization, leading to skeletal disorders.
Cobalt	Linked to a higher risk of goitre. Causes nausea, vomiting, and potential damage to the eyes, cardiovascular system, and thyroid.
Manganese	Inhibits the absorption of dietary iron, potentially resulting in anaemia. Associated with neurological impairments.
Copper	Short-term effects include abdominal cramps, vomiting, nausea, diarrhoea, dizziness, and headaches. Prolonged exposure has been linked to numerous health conditions, including anaemia, acne, adrenal gland dysfunction, allergies, hair loss, arthritis, developmental issues, autism, cancer, fatigue, high blood pressure, infections, cardiovascular disorders, gastrointestinal problems, and mental health challenges such as depression and anxiety attacks.
Zinc	Excessive intake may cause digestive discomfort, especially diarrhoea.
Iron	Can contribute to metabolic and inherited diseases. Inhalation of iron particles over time may cause siderosis, a non-cancerous lung condition.
Mercury	Extremely dangerous conditions can lead to respiratory failure and brain damage. Especially harmful to unborn babies and the developing nervous system. Symptoms of exposure include mood swings, tremors, vision or hearing problems, memory loss, high blood pressure, digestive issues, and skin or eye irritation. Can result in kidney failure, respiratory tract damage, gastrointestinal disorders, and overall neurotoxicity.
Nickel	Toxic and potentially cancer-causing. Exposure may lead to stomach upset, skin rashes, lung damage, and kidney dysfunction. Known to cause multiple organ toxicities, including damage to the immune system, nervous system, reproductive organs, liver, kidneys, and lungs.

Izah and Srivastav (2015)

2.4. Health Impact of Toxic Metals in Water on Human

The contamination of water sources by toxic metals poses serious risks to human health. People can be exposed to these metals through everyday activities such as drinking, cooking, or bathing. Once in the body, these metals tend to accumulate over time, potentially leading to long-term health issues. The extent to which it can cause harm to human health depends on which type and the amount being ingested, how long the exposure lasts, and an individual's susceptibility, such as age, health status, or genetic vulnerability to metal toxicity [46][35].

3. Materials and Methods

3.1. Materials Used to Determine Toxic Metals

- Plastic bottles were used to collect and store the water samples.
- Disposable hand gloves were worn during sampling to prevent contamination from metals that may be present on the skin.
- A handheld GPS was used during the sample collection to record the geographical coordinates of each sampling location.
- Distilled water was employed to rinse the polyethene bottles before use, minimizing the risk of introducing foreign substances.
- The Atomic Absorption Spectrometer (AAS) was the instrument used to detect and measure trace levels of toxic metals in the water samples.
- A thermometer was used on-site to obtain the temperature at the time of sampling.

3.2. Study Area

The location of Hong Local Government Area is approximately 10.38°N and longitude 12.35°E, in the northeastern part of Adamawa State, Nigeria [29]. Gombi to the south, Mubi North and Mubi South to the west, and Michika to the north are its surrounding neighbors. It covers an area of about 2,419 square kilometres. The 2011 National Population Census estimated that there were 195,580 people living in the Hong LGA.

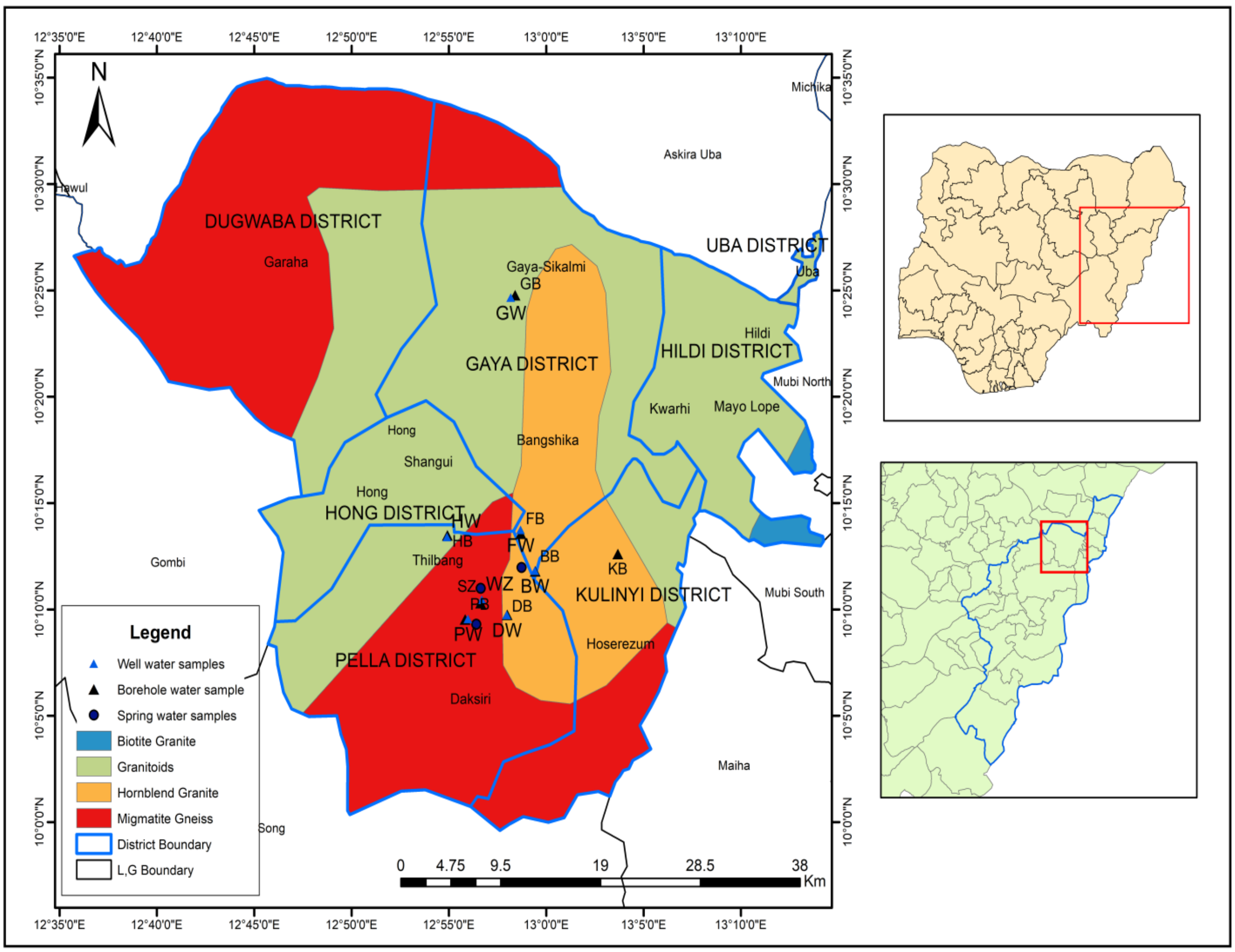

Fig. 3.1. A map of the study area of the Hong Local Government

The landscape is predominantly rugged, featuring a mix of mountains, valleys, and rivers, with the Hawul and Kuliyi rivers standing out as major water bodies. The administrative headquarters is located in Hong Town, which is considered the largest urban settlement in the LGA.

According to [17], Hong Town qualifies as a third-order core urban center within Adamawa State. The Local Government Area is subdivided into seven districts: Hong, Dugwaba, Pella, Kulinyi, Hildi, Gaya, and Uba.

3.3. Method of Water Sample Collection for Toxic Metals and Physicochemical Parameters

Nineteen (19) water samples were systematically collected from different communities within the Hong Local Government Area, Adamawa State.

These included three (3) spring water samples drawn from the areas of Pella, Dzuma, and Banshika, and sixteen (16) water samples collected from boreholes and dug wells in regions such as Hong, Pella, Fadama Reke, Banshika, Dzuma, Dilchidama, Kwakwa, and Gaya Garsanu. To ensure geographic precision and facilitate spatial tracking in longitudinal studies, each sampling point was geotagged using a GPS device.

Collection was performed using sterilized 75 cl polyethene containers, which were pre-washed with detergent, followed by multiple rinses using both distilled water and the specific water sample from each location. This multi-stage cleaning approach minimized cross-contamination risks and adhered strictly to the standardized sampling protocols outlined by [6].

Immediately after field collection, all specimens were transported under controlled conditions to the laboratory for the detection of physicochemical and toxic metals.

3.4. Measurement of Toxic Metals Concentration and Physicochemical Parameters

The quantification of toxic metals in the water samples was performed using Atomic Absorption Spectrophotometry, in the Soil Science Laboratory of the Department of Crop Science, Adamawa State University, Mubi.

3.5. Analysis of Physicochemical Parameters

An ordinary mercury-in-glass thermometer was used to take temperature readings at each location during sampling. The rest of the parameters were analyzed at the same Adamawa State University, Mubi laboratory.

3.6. Analytical Techniques for Data Evaluation

3.6.1. Risk Assessments and Human Health Impact

To estimate the risk to human health through more than one toxic metal, first, the daily exposure of an individual is calculated using equation 1 [41].

$$CDI = \frac{C_w \ X \ IR \ X \ EF}{BW X \ AT} \ X \ ED \quad (1)$$

Where CDI refers to the chronic daily intake calculated in mg/kg/day; C_w indicates the amount of toxic metal present in the water sample (mg/L); IR stands for the daily water intake rate (L/day); EF denotes how frequently exposure occurs; ED represents the total length of exposure; BW refers to the individual's body weight in kilograms (kg); and AT is the average period of exposure expressed in days.

The Hazard Quotient (HQ) is used. It is calculated using the formula shown in Equation (2) [19, 40].

$$HQ = \frac{CDI}{RfD} \quad (2)$$

Where RfD is the reference dose measured in (mg/kg/d), identify as the maximum acceptable daily exposure level.

Hazard Index (HI) represents the overall risks from exposure to multiple toxic metals, which is calculated using Equation (3) [33].

$$THI = \sum HQ_{Pb} + HQ_{As} + HQ_{Cr} + HQ_{Cd} + HQ_{Hg} \quad (3)$$

Equation (3) assumes that the total harm from multiple metal exposures is proportional to the sum of individual exposures with similar mechanisms of toxicity impacting the target organ.

3.6.2. Water Quality Index (WQI)

The WQI serves as an effective method for expressing the entire WQ into a single, comprehensive value. It integrates multiple factors like the individual metals and the physical and chemical variables detected in the water.

In this research, the Weighted Arithmetic Water Quality Index (WAWQI) approach was applied to determine the WQI values, using Equation (4) [12].

$$\text{WAWQI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (4)$$

Where W_i Represent the weight attribute assigned to each parameter i, Q_i represents the Quality rating of the i_{th} value among a total of "n" parameters considered, S_i Is the standard permissible limit for the specific element? Q_i Represents the quality rating for each parameter given by equation (5).

$$Q_i = \sum_{i=1}^{n} 100 \ X \ \frac{C_i}{S_i} \quad (5)$$

The WAWQI are often categorized into Excellence from 0 to 40, Good from 41 to 60, Moderate from 61 to 80 and Poor from 81 to 100.

4. Results and Discussion

4.1. Tables of Results

Table 4.1. Sample ID and coordinates of the Spring Water Sample Location

Sample ID	Longitude	Latitude
SZ	012° 56.640	10° 10.995
PS	012° 56.406	10° 09.303
BS	012° 58.734	10° 11.969

Table 4.2. Sample ID and coordinate of the Borehole Water Sample Location

Sample ID	Longitude	Latitude
BZ	012°56.639	10° 10.305
PB	012° 55.837	10° 09.538
BB	012° 59.437	10° 11.796
KB	013° 02.751	10° 11.206
FB	012° 58.706	10° 13.565
HB	012° 54.931	10° 13.487
DB	012° 57.996	10° 09.759
GB	012° 58.407	10° 24.778

Table 4.3. Sample ID and coordinates of the Well Water Sample Location

Sample ID	Longitude	Latitude
WZ	012° 56.699	10° 10.462
PW	012° 55.986	10° 09.559
BW	012° 59.423	10° 11.828
KW	013° 02.758	10° 11.174
FW	012° 58.689	10° 13.745
HW	012° 54.914	10° 13.411
DW	012° 57.987	10° 09.750
GW	012° 58.186	10° 24.669

Table 4.4. Physicochemical parameters of spring water

Sample ID	pH	Temp (^{0}C)	EC (µS/cm)	TDS(mg/L)	Turbidity(NTU)	Hardness (mg/L)	F(mg/L)
SZ	6.61	23	94.7	68.6	0.324	97.0	0.212
PS	7.04	21	143.8	106.0	0.272	68.0	0.126
BS	7.09	25	313.0	217.0	0.134	52.0	0.521
MEAN	**6.9**	**23**	**183.0**	**130.0**	**0.200**	**72.3**	**0.300**
MIN	**6.61**	**21**	**94.7**	**68.6**	**0.134**	**52.0**	**0.126**
MAX	**7.09**	**25**	**313.0**	**217.0**	**0.324**	**97.0**	**0.521**
NSDWQ	**6.5 - 8.5**	**10^0 - 30^0**	**1000.0**	**500.0**	**5.000**	**150.0**	**1.500**

Table 4.5. Physicochemical parameters of borehole water

Sample ID	pH	Temp (^{0}C)	EC (µS/cm)	TDS(mg/L)	Turbidity(NTU)	Hardness (mg/L)	F(mg/L)
BZ	6.54	33.0	358	255	0.112	73	0.341
PB	6.83	32.0	219	156	0.714	110	0.269
BB	6.72	31.0	643	454	0.121	67	0.053
KB	6.66	31.0	878	623	0.312	181	0.015
FB	6.89	29.0	647	452	0.492	105	0.191
HB	6.96	30.5	1743	1240	0.276	374	0.324
DB	6.87	31.0	399	399	0.027	120	0.057
GB	7.04	32.0	415	297	0.272	93	0.178
MEAN	**6.8**	**31.0**	**644**	**329**	**0.300**	**139**	**0.200**

MIN	**6.54**	**29.0**	**219**	**156**	**0.027**	**67**	**0.015**
MAX	**7.04**	**33.0**	**1743**	**1240**	**0.714**	**374**	**0.341**
NSDWQ	**6.5 - 8.5**	**10^0. - 30^0**	**1000**	**500**	**5.000**	**150**	**1.500**

Table 4.6. Physicochemical Parameters of Well Water

Sample ID	pH	Temp (^{0}C)	EC (µS/cm)	TDS(mg/L)	Turbidity(NTU)	Hardness (mg/L)	F(mg/L)
WZ	6.97	31.5	103.6	73.8	0.028	43.00	0.070
PW	7.22	30.5	265.0	190.0	0.034	109.00	0.026
BW	7.56	29.0	1065.0	742.0	0.781	152.00	0.052
KW	6.67	29.5	1305.0	912.0	0.293	196.00	0.479
FW	7.44	28.0	1328.0	929.0	0.079	115.00	0.125
HW	7.28	30.0	1542.0	1120.0	0.288	240.00	0.328
DW	7.54	29.0	497.0	356.0	0.623	72.00	0.038
GW	7.29	30.0	693.0	499.0	0.935	123.00	0.217
MEAN	**7.3**	**30.3**	**724.8**	**450.3**	**0.300**	**126.25**	**0.200**
MIN	**6.67**	**28.0**	**103.6**	**73.8**	**0.028**	**43.00**	**0.026**
MAX	**7.56**	**31.5**	**1542.0**	**1120.0**	**0.935**	**240.00**	**0.479**
NSDWQ	**6.5 - 8.5**	**10^0 - 30^0**	**1000.0**	**500.0**	**5.000**	**150.00**	**1.500**

Table 4.7. Toxic metals of spring water

Sample ID	Pb (mg/L)	As (mg/L)	Cr (mg/L)	Cd (mg/L)	Hg (mg/L)
SZ	0.0019	0.0031	0.0002	0.0004	-
PS	0.0027	0.0001	-	-	0.0001
BS	0.0139	0.0076	0.0042	0.0024	-
M / SD	**0.0062±0.0055**	**0.0036±0.00308**	**0.0022±0.0020**	**0.0014±0.0010**	**0.0001±0**
Range	**0.0019-0.0139**	**0.0001-0.0076**	**0.0002-0.0042**	**0.0004-0.0042**	**0-0**
WHO	**0.0100**	**0.0100**	**0.0500**	**0.0030**	**0.0010**

Table 4.7. Toxic Metals of Borehole Water

Sample ID	Pb (mg/L)	As (mg/L)	Cr (mg/L)	Cd (mg/L)	Hg (mg/L)
BZ	0.0256	-	0.0076	0.0001	-
PB	0.0314	0.0037	0.0011	0.0004	-
BB	0.0013	0.0026	0.0342	0.0014	0.0004
KB	0.0131	0.0041	0.0029	0.0024	-
FB	0.0217	0.0019	0.0012	0.0012	0.0001
HB	0.0268	0.0057	0.0231	0.0032	0.0003
DB	0.0043	0.0032	-	0.0003	0.0002
GB	0.0306	0.0020	0.0213	0.0005	-
M/SD	**0.01924±0.0109**	**0.00291±0.00162**	**0.0130±0.0115**	**0.0012±0.0010**	**0.0003±0.0001**
Rang	**0.0013-0.0314**	**0.0054-0.0057**	**0.0011-0.0342**	**0.0001-0.0032**	**0.0001-0.0004**
WHO	**0.0100**	**0.0100**	**0.0500**	**0.0030**	**0.0010**

Table 4.8. Toxic metals of well water

Sample ID	Pb (mg/L)	As (mg/L)	Cr (mg/L)	Cd (mg/L)	Hg (mg/L)
WZ	0.0038	0.0002	0.0004	0.0006	-
PW	0.0105	0.0015	0.0113	0.0012	-
BW	0.0211	0.0029	0.0051	0.0021	0.0002
KW	0.0126	0.0011	0.0321	-	-
FW	0.0112	0.0017	0.0011	-	-
HW	0.0057	0.0012	0.0055	0.0031	0.0001
DW	0.0203	0.0032	0.0029	0.0001	0.0001
GW	0.0035	0.0034	-	0.0026	-
M/SD	**0.0111±0.0053**	**0.0019±0.001**	**0.0083±0.0104**	**0.0016±0.0010**	**0.0001±0.0000**
Rang	**0.0035-0.0211**	**0.0002-0.0034**	**0.0004-0.0321**	**0.0001-0.0031**	**0.0001-0.0002**
WHO	**0.0100**	**0.0100**	**0.0500**	**0.0030**	**0.0010**

Table 4.9. Quantitative Evaluation of Human Health Risk of toxic metals in spring water samples

Toxic metals	RfD_{Ch} mg/kg/day	RfD_{Ad} mg/kg/day	CDI_{Ch} mg/kg/day	CDI_{Ad} mg/kg/day	HQ_{Ch}	HQ_{Ad}
Pb	0.0015	0.0035	0.00044400	0.0001690	0.29600	0.01900
As	0.0010	0.0015	0.00028000	0.0001070	0.28000	0.06700
Cr	0.0020	0.0030	0.00015800	0.0000603	0.07900	0.02000
Cd	0.0005	0.0008	0.00010100	0.0000384	0.20200	0.04800
Hg	0.0010	0.0020	0.00000719	0.00000274	0.00717	0.00137
THI					0.8600	0.15000

RfD_{Ad} [44] and RfD_{Ch} [41]

Table 4.10. Quantitative Evaluation of Human Health Risk of toxic metals in borehole water

Toxic metals	RfD_{Ch} mg/kg/day	RfD_{Ad} mg/kg/day	CDI_{Ch} mg/kg/day	CDI_{Ad} mg/kg/day	HQ_{Ch}	HQ_{Ad}
Pb	0.0015	0.0035	0.0012700	0.00048500	0.8470	0.13900
As	0.0010	0.0015	0.0002380	0.00009080	0.3280	0.06100
Cr	0.0020	0.0030	0.0009421	0.00035900	0.4708	0.11960
Cd	0.0005	0.0008	0.0000854	0.00003250	0.1710	0.04100
Hg	0.00100	0.0020	0.0001800	0.00000685	0.0179	0.00343
THI					1.8300	0.36000

RfD_{Ad} [44] and RfD_{Ch} [41]

Table 4.11. Quantitative Evaluation of Human Health Risk of toxic metals in well water samples

Toxic metals	RfD_{Ch} mg/kg/day	RfD_{Ad} mg/kg/day	CDI_{Ch} mg/kg/day	CDI_{Ad} mg/kg/day	HQ_{Ch}	HQ_{Ad}
Pb	0.0015	0.0035	0.00079700	0.0003040	0.53130	0.08690
As	0.0010	0.0015	0.00013700	0.0000521	0.13700	0.03470
Cr	0.0020	0.0030	0.00059900	0.0002280	0.29990	0.07600
Cd	0.0005	0.0008	0.00011700	0.0000444	0.23400	0.05550
Hg	0.0010	0.0020	0.00000957	0.0036400	0.00957	0.00182
THI					1.21000	0.25000

RfD_{Ad} [44] and RfD_{Ch} [41]

Table 4.12. Calculated weight of the attributes in the Spring Water

Parameter	C_i	S_i	W_i	Q_i	WQI_{Sub}
pH	6.9000	8.500	0.07	81.18	5.68
Temp.	31.0000	20.000	0.03	115.00	3.45
EC	644.0000	1000.000	0.07	18.30	1.28
TDS	329.0000	500.000	0.07	26.00	1.82
Turbidity	0.3000	5.000	0.07	4.00	0.28
Hardness	139.0000	500.000	0.03	14.46	0.43
F	0.2000	1.500	0.07	20.00	1.40
Pb	0.0060	0.010	0.13	62.00	8.06
As	0.0036	0.010	0.13	36.00	4.68
Cr	0.0022	0.050	0.10	4.40	0.44
Cd	0.0014	0.003	0.13	46.67	6.07
Hg	0.0010	0.001	0.13	10.00	1.30
WQI					34.89

Table 4.13. Calculated weight of the attributes in the Borehole Water

Parameter	C_i	S_i	W_i	Q_i	WQI_{Sub}
pH	6.8000	8.500	0.07	80.00	5.6
Temp.	31.0000	20.000	0.03	115.00	3.45
EC	644.0000	1000.000	0.07	64.40	4.51

TDS	329.0000	500.000	0.07	65.80	4.61
Turbidity	0.3000	5.0.000	0.07	6.00	0.42
Hardness	139.0000	500.000	0.03	27.80	0.83
F	0.2000	1.5.000	0.07	13.33	0.93
Pb	0.0192	0.010	0.13	192.40	25.01
As	0.0029	0.010	0.13	29.10	3.78
Cr	0.0130	0.050	0.10	26.00	2.60
Cd	0.0012	0.003	0.13	40.00	5.20
Hg	0.0003	0.001	0.13	30.00	3.90
WQI					60.85

Table 4.14. Calculated weight of the attributes in the Well Water

Parameter	C_i	S_i	W_i	Q_i	WQI_{Sub}
pH	7.3000	8.500	0.07	85.88	6.01
Temp.	30.3000	20.000	0.03	151.5	4.55
EC	724.8000	1000.000	0.07	72.48	5.07
TDS	450.3000	500.000	0.07	90.06	6.30
Turbidity	0.3000	5.000	0.07	6.00	0.42
Hardness	126.2500	500.000	0.03	25.25	0.76
F	0.2000	1.500	0.07	13.33	0.93
Pb	0.0111	0.010	0.13	111.00	14.43
As	0.0019	0.010	0.13	19.00	2.47
Cr	0.0083	0.050	0.10	16.60	1.66
Cd	0.0016	0.003	0.13	53.33	6.93
Hg	0.0001	0.001	0.13	10.00	1.30
WQI					50.84

4.2. Discussion

Longitude 012 ˚ 56.406 to 012˚ 58.734 and latitude 10˚ 09.303 to 10˚ 11.969 for spring, longitude 012˚ 54.931 to 01 ˚ 02.751 and latitude 10˚ 09.538 to 10˚ 13.565 for borehole, and longitude 012˚ 54.914 to 013˚ 02.758 and latitude 10˚ 09.559 to 010˚ 24.669 for well water are the coordinates of the different water samples, according to Tables 4.1 to 4.3.

Tables 4.4, 4.5, and 4.6 show the physicochemical properties of the three water sources. The spring water's pH values ranged from 6.61 to 7.09, with SZ having the lowest value and BS having the highest. While well water had a pH range of 6.67 to 7.56, borehole water had a pH range of 6.54 to 7.04. All recorded values for the water sources are within the standard range of 6.5–8.5 set by the NSDWQ for various water uses, including potable water.

Location-specific temperature readings were different. The spring water temperatures were between 21°C and 25°C, with BS having the hottest and PS having the lowest. While well water temperatures ranged from 28°C to 31.5°C, borehole temperatures were higher, ranging from 29°C to 33°C. The spring was naturally shielded from direct sunlight by the rocks and flora around it, but as [5] and [11] point out, high temperatures in wells and boreholes may have been caused by low water depth and increased solar exposure.

The EC values were between 94.7 and 313 µS/cm, 219 and 1743 µS/cm, and 103.6 and 1542 µS/cm, respectively, for water from springs, boreholes, and wells. The findings in all spring water samples were lower than the 1000 µS/cm NSDWQ standard.

However, the maximum EC (1743 µS/cm) was measured by drill sample HB, beyond the allowable limit. Well samples BW, KW, FW, and HW also exceeded the norm in a similar manner. These high EC levels, which indicate greater concentrations of dissolved particles that may affect taste and overall water appropriateness, might be caused by mineral leaching or agricultural runoff.

TDS levels range from 68.6 to 217 mg/L for spring water, 156 to 1240 mg/L for borehole water, and 73.8 to 1120 mg/L for well water. It is comparatively lower compared to the spring water's value to the NSDWQ's maximum value of 500 mg/L. This indicates that the water contains a small number of dissolved suspended solid particles. The limit was surpassed by well samples BW, KW, FW, and HW, as well as borehole samples KB and HB. This can change the water's color and smell. TDS does not directly damage health, but it can reveal the existence of dangerous elements like As and Pb that were found in the water [43].

The turbidity results in the spring source ranged from 0.134 NTU in BS to 0.324 NTU in SZ, while the well and borehole water values ranged from 0.028 to 0.935 NTU and 0.027 to 0.714 NTU, respectively. These samples were all extremely low, falling below the 5 NTU NSDWQ standard limit. Additionally, these outcomes were less than those of comparable research on streams and wells published by [29].

In spring water, the range of water hardness was 52 to 97 mg/L; in borehole water, it was 67 to 374 mg/L; and in well water, it was 43 to 240 mg/L. According to the results, the concentrations of HB from the borehole source, BW, KW, and HW from the well source are greater than 300 mg/L NSDWQ. Water that is overly hard can accumulate on water supply distribution pipes and, if consumed over an extended period of time, may increase the risk of kidney stones, some types of cancer, and cardiovascular issues [34].

All samples had fluoride amounts that were confirmed to be within safe limits; spring boreholes and wells had concentrations between 0.126 and 0.521 mg/L, 0.015 and 0.341 mg/L, and 0.026 and 0.479 mg/L, respectively, well below the 1.5 mg/L standard established by NSDWQ.

The concentrations and statistical summaries of toxic metals are detailed in Tables 4.13, 4.14, and 4.15. Traces of lead (Pb) and arsenic (As) were found in all spring and well water samples, while all borehole samples showed traces of lead (Pb) and cadmium (Cd).

Pb values in spring, borehole, and well water ranged from 0.0120 to 0.0139 mg/L, 0.0013 to 0.0314 mg/L, and 0.0035 to 0.0211 mg/L. 0.0111 ± 0.0053 mg/L (well), 0.0192 ± 0.0109 mg/L (borehole), and 0.0062 ± 0.0055 mg/L (spring) were the mean concentrations. Interestingly, the average Pb levels in well and borehole water were higher than the WHO-recommended threshold of 0.01 mg/L. In contrast to this finding, [29] found no detectable Pb in their research region. Because lead is poisonous, high levels of it, particularly in wells and boreholes, pose serious health risks. Long-term exposure can damage the cardiovascular system, kidneys, neurological system, and reproductive health, particularly in younger individuals and pregnant women [8].

A certain amount of As was found in every water sample. 0.0001 to 0.0076 mg/L with a mean value of 0.0036 ± 0.0031 mg/L, 0.0054 to 0.0057 mg/L with a mean value of 0.00291 ± 0.00162 mg/L, and 0.0002 to 0.0034 mg/L with a mean value of 0.0019 ± 0.001 mg/L were the concentrations discovered in spring, borehole, and well water. There is no acute health risk from As exposure in any of the water sources because these levels are beneath the WHO-recommended limit of 0.01 mg/L.

Cr was found in every kind of sample. In spring, it was between 0.0002 and 0.0042 mg/L; in borehole, it was between 0.0011 and 0.0342 mg/L; and in well water, it was between 0.0004 and 0.0321 mg/L. The mean levels were 0.0130 ± 0.0115 mg/L (borehole), 0.0083 ± 0.0104 mg/L (well), and 0.0022 ± 0.0020 mg/L (spring). All of these results stayed significantly below the WHO-recommended acceptable level of 0.05 mg/L.

The spring water has a mean of 0.0014 ± 0.0010 mg/L of Cd, ranging from 0.0004 to 0.0042 mg/L. 0.0001 to 0.0032 mg/L (mean: 0.0012 ± 0.0010 mg/L) were found in borehole water, whereas 0.0001 to 0.0031 mg/L (mean: 0.0016 ± 0.0010 mg/L) were found in well samples. The majority of the water samples in this area were below the 0.003 mg/L WHO safety guideline.

Generally, low levels of Hg were found in the water sources. It was largely undetectable in spring water, with an average concentration of 0.0001 ± 0.0000 mg/L. While well water ranged from 0.0001 to 0.0002 mg/L with a mean of 0.0001 ± 0.0000 mg/L, borehole water had slightly higher values, with a minimum and maximum range of 0.0001 to 0.0004 mg/L (mean: 0.0003 ± 0.0001 mg/L). Every Hg reading was much below the WHO-recommended acceptable limit of 0.001 mg/L.

Tables 4.10 to 4.12 provide an estimate and summary of the Hazard Quotients (HQ) and Daily Intake level (CDI) for hazardous metals in the portable water. The daily concentrations of lead (Pb) in spring water were 0.000169 and 0.000444 mg/kg for adults and children, 0.000485 and 0.00127 mg/kg for borehole water, and 0.000304 and 0.000797 mg/kg for well water. Children's exposure from boreholes and wells neared the RfD of 0.0015 mg/kg/day, which could pose a health risk with extended consumption, even though the adult levels stayed below the RfD of 0.0035 mg/kg/day.

The As in both adults and children had CDI values of 0.000107 and 0.000280 mg/kg/day (spring), 0.0000908 and 0.000238 mg/kg/day (borehole), and 0.0000521 and 0.000137 mg/kg/day (well), respectively. These levels, which were below the RfD of 0.001 mg/kg/day for children and 0.0015 mg/kg/day for adults, indicated no serious health issues.

Compared to the RfD of 0.003 mg/kg/day for adults and 0.002 mg/kg/day for children, the chromium CDI values for spring, borehole, and well were 0.0000603 to 0.000158 mg/kg/day, 0.000359 to 0.000942 mg/kg/day, and 0.000228 to 0.000599 mg/kg/day, respectively showing no potential risk.

A cadmium CDI of 0.0000384 and 0.000101 mg/kg/day was determined for the spring, 0.0000325 and 0.0000854 mg/kg/day for the borehole, and 0.0000444 and 0.000117 mg/kg/day for the well. These values showed no risk because they were below the RfDs of 0.0008 mg/kg/day for adults and 0.0005 mg/kg/day for children.

Additionally, the CDI values for well, borehole, and spring water for mercury were below the corresponding RfDs. 0.00000274 and 0.00000719 mg/kg/day were consumed by adults and children in the spring, 0.00000685 and 0.0000180 mg/kg/day in the borehole, and 0.00364 and 0.00000957 mg/kg/day in the well

Lead (Pb) Hazard Quotient (HQ) examination of spring water, borehole water, and well water revealed HQs of 0.019 and 0.296 for adults and children, 0.139 and 0.847 for borehole water, and 0.0869 and 0.5313 for well water. All HQ values stayed below the critical risk threshold, despite differences between sources, suggesting that non-carcinogenic health consequences are unlikely at the current exposure levels 1. However, results for children in well and borehole water indicate that prolonged exposure may have negative effects. HQ values of As for adults and children were 0.0347 and 0.137 (well), 0.067 and 0.280 (spring), and 0.061 and 0.328 (borehole), respectively, suggesting no health risk.

The HQ values for Cr were under unity and were 0.020 and 0.079 (spring), 0.1196 and 0.4708 (borehole), and 0.076 and 0.2999 (well). No substantial health risk was indicated by the Cd HQs of 0.048 and 0.202 (spring), 0.041 and 0.171 (borehole), and 0.0555 and 0.234 (well). Hg HQs were also low, falling below the danger threshold for adults and children at 0.00137 and 0.00717 (spring), 0.00343 and 0.0179 (borehole), and 0.00182 and 0.00957 (well), respectively.

The study's Total Hazardous Index (THI) for spring water is 0.15 and 0.86, borehole water is 0.36 and 1.83, and well water is 0.25 and 1.21 for both adults and children. The findings indicate that children's THI in well and borehole water is greater than one unit. This is consistent with the results of [27] and [23]. It may result in difficulties such as brain impairment, kidney problems, and developmental delays since the risk of non-carcinogenic consequences cannot be ignored, and the possibility of long-term health complications is still high [43].

The results are shown in Tables 4.13, 4.14, and 4.15. The Water Quality Index (WQI) was evaluated using the physicochemical characteristics and amounts of hazardous metals. The spring water received a score of 34.39, which is considered "excellent" based on the computed WQI values. This implies that the water is suitable for drinking, irrigation, and recreational purposes and that no health hazards are connected to it.

According to the computed value of 60.85 for the borehole water, the water quality is between good and moderate. Although it is still comparatively safe to drink and use in agriculture, there might be certain issues that need to be addressed. The presence of substantial amounts of mineral elements, such as lead, which exceeded the recommended value in the current study, was the primary cause of the decline in water quality [31, 30].

According to the well water value of 50.84, the water quality is good, meaning it is typically suitable for most uses, such as drinking and farming. However, in some circumstances, some preventative treatment may be required. Here, the primary cause of the decline in water quality is the EC, which was higher than the current study's suggested limit and is corroborated by [30].

5. Conclusion

This study evaluated the concentrations of toxic metals and important physicochemical characteristics in spring, borehole, and well water sources. The physicochemical assessment revealed significant differences among the water sources. Borehole and well samples had elevated levels of temperature, electrical conductivity (EC), and total dissolved solids (TDS), surpassing the threshold limit established by the NSDWQ. Hazardous metal analysis showed the presence of several metals, with Pb in borehole and well water exceeding WHO permissible limits. The health risk assessment indicated that children may be at risk due to cumulative metal exposure, as shown by the THI. WQI analysis classified spring water as excellent, borehole water as between good and moderate and well water as good for consumption. Nonetheless, borehole and well water may require some basic treatment measures like chlorination and boiling before use.

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