



Quality and Safety Assessment of Water Samples Collected from Wells in Four Emirate Zones of Kebbi State, Nigeria

T. Yahaya^{1*}, O. Ologe², C. Yaro³, L. Abdullahi¹, H. Abubakar², A. Gazal⁴, J. Abubakar⁵

¹ Department of Biological Sciences, Federal University Birnin Kebbi, Kebbi State, Nigeria

² Department of Geophysics, Federal University Birnin Kebbi, Kebbi State, Nigeria

³ Department of Animal and Environmental Biology, University of Uyo, Akwa Ibom State, Nigeria

⁴ Department of Geology, Federal University Birnin Kebbi, Kebbi State, Nigeria

⁵ Department of Biochemistry and Molecular Biology, Federal University Birnin Kebbi, Kebbi State, Nigeria

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ABSTRACT

The increasing prevalence of water-borne diseases necessitates periodic monitoring of domestic and drinking water sources. The current study assessed the safety of well water in the four emirate zones (Gwandu, Yauri, Argungu, and Zuru) of Kebbi State, Nigeria. Using normal procedures, samples of well water were examined for heavy metals, physicochemical characteristics, and microorganisms, and the results were compared to the World Health Organization (WHO) drinking water criteria. The heavy metals' chronic daily ingestion (CDI) and hazard quotient (HQ) were also determined. The results showed that well water in the four emirate zones had normal temperature, biochemical oxygen demand (BOD), dissolved oxygen (DO), total suspended solids (TSS), and zinc (Zn). However, non-permissible concentrations of lead (Pb), iron (Fe), cadmium (Cd), chromium (Cr), and pH (Gwandu and Argungu only) were detected in all the water samples. Except for Cd and Cr in children, the CDI and HQ of the heavy metals were normal. The microbiological examinations revealed that the water samples from the four zones had abnormal levels of *Bacillus species* (bacteria), *Escherichia coli* (bacteria), *Staphylococcus aureus* (bacteria), *Aspergillus niger* (fungi), *Mucor racemosa* (fungi), and *Paecilomyces variotti* (fungi). The results obtained suggest that well water in the four zones is not suitable for human consumption unless treated.

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INTRODUCTION

Water is an important component of the environment, which is necessary for life to exist. On Earth, 97.2% of the water is salty and 2.8% is fresh water, of which 20% is groundwater. Groundwater is the best source of fresh water for human use because it has a virtually balanced salt concentration [1]. In comparison to surface water, groundwater is cleaner and pollution-free in an ideal situation [2]. When properly managed, groundwater is cost-effective, safe, consistent in quality and quantity, and available to human.

However, groundwater quality can be compromised by anthropogenic activities such as industrialization,

population expansion, unplanned urbanization, and overuse of agrochemicals such as fertilizers and pesticides [3, 4]. The long-term discharge of industrial effluents, domestic sewage, and solid waste pollutes groundwater [5, 6]. Most of these water contaminants are laden with heavy metals such as mercury (Hg), copper (Cu), chromium (Cr), iron (Fe), lead (Pb), cadmium (Cd), zinc (Zn), and nickel (Ni), as well as microorganisms like bacteria, viruses, and protozoans [7]. Heavy metals can build up in the human body and deplete antioxidants, producing free radicals and health risks [8, 9]. Abnormal populations of microorganisms in water can predispose humans to cholera, dysentery, and typhoid fever [10]. According to Dohare et al. [11], water-borne diseases

*Corresponding Author Email: yahaya.tajudeen@fubk.edu.ng (T. Yahaya)

account for around 80% of all human diseases. Problems with groundwater quality are much more acute in densely populated and intensively industrialized areas with shallow groundwater tables [6]. Aside from human causes, natural causes may also contaminate groundwater. Groundwater flowing through sedimentary rocks and soils, for example, can absorb a variety of chemical compounds [12].

In Nigeria, particularly those in Kebbi State, many people depend on boreholes and wells for drinking water due to the country's inefficient and inadequate pipe-borne water system [13]. Moreover, practically all of Nigeria's surface water has been severely contaminated by natural sources, humans, and animals. Almost every household in Birnin Kebbi State has a well or borehole for drinking and domestic use. To avoid disease outbreaks and health hazards, continuous monitoring of groundwater throughout the state is required. As a result, this study assessed the safety of well water in Kebbi State's four emirate zones, i.e., Gwandu, Argungu, Yauri, and Zuru zones.

MATERIALS AND METHODS

Description of the study area

This study was carried out in Zuru, Yauri, Argungu, and Gwandu emirate zones, Kebbi State, Nigeria (see Figure 1). Kebbi State is in the north-west of Nigeria, between

latitudes of 10° N and 13° N and longitudes of 3° E and 6° E. It borders Sokoto State in the north, Niger State in the south, and Zamfara State in the east. It covers an area of 36,800 km². The natural vegetation of the state comprises Sudan Savanna in the north and Guinea Savanna in the south [14].

Zuru is the headquarters of the Zuru local government and the Zuru emirate. Zuru can be found at 11° 18.4056 N and 5° 54.7968 E. Zuru is in the south of Kebbi State, occupying about 9000 km² of land. Zuru is bordered in the north by Zamfara State and Niger State in the south. The language spoken by the people of Zuru is Dakarkari, and the majority of them engage in intense farming activities. Yauri is the headquarters of Yauri local government and Yauri emirate. Yauri is situated between latitude 10.9925 N and longitude 4.5212 E. Yauri occupies about 3,380 km². Yauri ethnic groups include the Shangawa, Gungawa, Dukkawa, Kambari, Hausa, Nupe, Yoruba, and Kanuri. Argungu lies along the Sokoto River. Its coordinates are 12.7333 N and 4.516667 E. Residents of Argungu are predominantly farmers and are known for the production of tobacco, peanuts, rice, millet, wheat, and sorghum, among others. The city also hosts a yearly international fishing festival. Birnin Kebbi is the capital of Kebbi State and the administrative center of the Gwandu emirate. It lies between 12° 27 '13" N and 4° 12 '1" E. The population of the city was estimated at 125,594 in 2007. Kebbi is predominantly Hausa and Fulani, with Islam being the predominant religion [15].

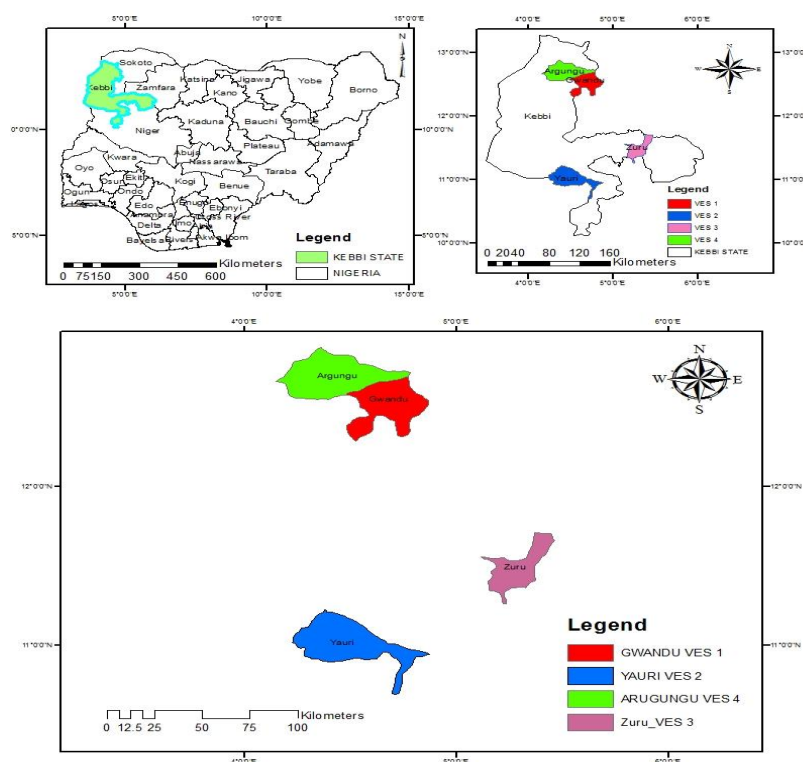


Figure 1. Map of the study area, showing Gwandu, Yauri, Argungu, and Zuru Emirates

Sample collection

Well water samples were collected from Gwandu, Argungu, Yauri, and Zuru emirate zones in Kebbi State in February 2021. The water samples were collected in 1000 mL pre-sterilized plastic containers, transported to the laboratory in polythene bags, and refrigerated at $\leq 6^\circ\text{C}$.

Determination of physicochemical parameters

The physicochemical parameters of the water samples were determined according to the American Public Health Association's criteria [16]. Temperature and pH were measured in-situ with a mercury-in-glass thermometer and a digital pH meter, respectively. In the laboratory, a 5500 Clark DO Sensor and a HM Digital TDS meter (model TDS-4) were used to measure dissolved oxygen (DO) and total suspended solids (TSS), respectively, while a SR2-16 HACH BOD incubator was used to measure biochemical oxygen demand (BOD).

Determination of heavy metals

A 100 mL well-mixed water sample was transferred into a beaker and 5mL of concentrated HNO_3 was added and covered tightly to prevent contamination. The mixture was heated slowly at 95°C until it evaporated to about 21 mL. The mixture was poured into a 100mL volumetric flask and filled up to the meniscus with distilled water. The solution was allowed to cool, after which it was analyzed for the presence of Pb, Fe, Cd, Cr, and Zn using a UNICAM atomic absorption spectrometer.

Quality control and assurance

All the reagents used were made from high-grade chemicals. Each reagent's container was washed in a detergent solution and rinsed thoroughly with water and the reagent. The background contamination of the samples was checked by testing blank samples after every five analyses to ensure the accuracy of the heavy metal analysis. Moreover, each heavy metal was analyzed thrice, and the results were reproducible at a 95% confidence level. So, the mean value of each heavy metal was used for further analysis.

Health Risk assessment

The health risk of daily consumption of the water by adults and children was determined from the chronic daily intake (CDI) [17] and hazard quotient (HQ) [18] of heavy metals in the water. These were evaluated using Equations (1) and (2).

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

In the equation above, *CDI* denotes a consumer's daily ingestion of heavy metals (mg/L), *CW* represents the concentration of heavy metals in water (mg/L), *IR* stands for the ingestion rate, *EF* represents exposure frequency, *ED* indicates exposure duration, *BW* denotes body

weight, and *AT* is the average time. Table 1 shows the standard values for the mentioned parameters.

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

In Equation (2), *CDI* stands for the daily ingestion of heavy metals (mg/L), while *RFD* represents the reference dose. The standard *RFD* value for each heavy metal is indicated in Table 2.

Microbiological analysis

The microbial populations (bacteria, coliforms, and fungi) in the water samples were estimated using the membrane filtering approach described by Brock [19]. A sterile cellulose filter was used to filter 100 mL of water, and the filter was incubated on a nutrient agar medium for 24 hours at 36°C . A colony counter was used to count the total number of bacteria that grew on the medium.

The two-step enrichment approach was used to estimate the coliform population in the water. The bacteria-infested filter was placed on a lauryl tryptose broth medium first, then M-Endo media, and incubated at 34°C for 3 hours and 22 hours, respectively. The coliforms that grew were then counted.

The nutrient agar was also used to estimate the fungal population, but an antibiotic was added to the medium to prevent bacterial growth [20].

RESULTS

Physicochemical parameters

Table 3 shows the physicochemical parameters of well water obtained from Gwandu, Argungu, Yauri, and Zuru

Table 1. Standard values for calculating average daily ingestion of heavy metals

Exposure factors	Units	Values
Exposure frequency (<i>Ef</i>)	Days/Years	365
Ingestion rate (<i>Ir</i>)	L/day	2
Exposure duration (<i>Ed</i>)	Years	55
Average body weight (<i>Bwt</i>)	Kg	65

Table 2. Oral reference doses (*RFD*) for Pb, Fe, Cd, Cr, and Zn in water

Heavy metal	Values
Pb	14
Fe	700
Cd	0.5
Cr	3.0
Zn	300

Table 3. Physicochemical parameters of well water samples collected in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Parameters	Emirate				Limit [21]
	Gwandu	Argungu	Yauri	Zuru	
pH	5.95±0.15	4.89±0.31	7.18±0.04	6.55±0.17	6.5-8.5
Temp (°C)	24.66±0.36	24.50±0.43	24.12±1.04	24.0±1.09	—
DO	7.13±0.05	7.27±0.09	7.09±0.13	7.21±0.08	7-14
BOD	50	8.79	1.8	30.77	60
TSS	360	140	460	100	NA

Values were expressed as mean ± SD and mg/L; NA= Not Available; DO= Dissolved Oxygen; BOD= Biochemical Oxygen Demand; TSS= Total Suspended Solid

emirates. The temperature, DO, BOD, and TSS of all the water samples were within the range of World Health Organization (WHO) acceptable limits. However, the pH of Gwandu and Argungu were above the acceptable limits.

Concentration of heavy metals in the water samples

Table 4 shows the levels of heavy metals in the well water obtained from Gwandu, Argungu, Yauri, and Zuru emirates. All the water samples had abnormal levels of all the heavy metals, with the exception of Zn.

Health risk assessment of daily ingestion of the water

The *CDI* of heavy metals per person for adults and children in Birnin Kebbi, Argungu, Yauri and Zuru are presented in Tables 5 and 6, respectively. The *CDI* of all the heavy metals was normal in adults. However, in children, the *CDI* of Cd and Cr was higher than the recommended limit, while other heavy metals were within the recommended limits.

Table 4. Levels of heavy metals in well water samples collected in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Emirate	Pb	Cd	Cr	Zn	Fe
Gwandu	1.315±0.00200	0.959±0.00100	4.507±0.00100	1.284±0.00100	1.358±0.00100
Argungu	0.937±0.00200	0.965±0.00100	4.552±0.00200	1.295±0.00100	1.176±0.00200
Yauri	0.886±0.00100	0.959±0.00100	4.650±0.00100	1.277±0.00100	0.940±0.00100
Zuru	1.315±0.00400	1.001±0.00100	4.800±0.00200	1.333±0.00153	1.303±0.00200
Limit [21]	≤ 0.01	≤ 0.003	≤ 0.05	≤ 3.00	≤ 0.3

Values were expressed as mean± SD and mg/L

Table 5. Chronic daily ingestion of heavy metals per person for adults in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Emirate	Pb	Cd	Cr	Zn	Fe
Gwandu	0.0405	0.0295	0.139	0.0395	0.0418
Argungu	0.0288	0.0297	0.140	0.0398	0.0362
Yauri	0.0273	0.0295	0.143	0.0393	0.0289
Zuru	0.0405	0.0308	0.148	0.0410	0.0401
RDI	0.21	0.06	0.20	3.0	0.30

Values expressed as mg/day; RDI: recommended daily intake

Table 6. Chronic daily ingestion of heavy metals per person for children in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Emirate	Pb	Cd	Cr	Zn	Fe
Gwandu	0.088	0.064	0.30	0.086	0.091
Argungu	0.062	0.064	0.31	0.086	0.078
Yauri	0.059	0.064	0.31	0.085	0.063
Zuru	0.088	0.067	0.32	0.089	0.087
RDI	0.21	0.06	0.20	3.0	0.3

Values expressed as mg/day; RDI: recommended daily intake

The *HQ* of the heavy metals for both adults and children is shown in Tables 7 and 8, in which the *HQ* of the heavy metals in all the water samples was less than 1, for both adults and children.

Table 7. Hazard quotient of heavy metals via ingestion by adults in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Emirate	Pb	Cd	Cr	Zn	Fe
Gwandu	0.00289	0.059	0.0463	0.0001316	0.000059
Argungu	0.00206	0.0594	0.0467	0.0001326	0.000051
Yauri	0.00195	0.059	0.0477	0.000131	0.000041
Zuru	0.00289	0.0616	0.0493	0.000136	0.000057

Table 8. Hazard quotient of heavy metals via ingestion by children in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Zone	Pb	Cd	Cr	Zn	Fe
Gwandu	0.0063	0.128	0.10	0.0029	0.00013
Argungu	0.0044	0.128	0.103	0.0029	0.00011
Yauri	0.0042	0.128	0.103	0.0028	0.00009
Zuru	0.0063	0.134	0.12	0.003	0.00012

Loads and microorganism species in the water samples

In Table 9, the loads and species of total bacteria, fungi, and coliforms found in the water samples are presented. The water samples had abnormal counts of total bacteria, total fungi, and coliform bacteria, except in Yauri, where coliform was not detected. Total bacteria had the highest count of all the microorganisms detected, with 29.5×10^6 in Yauri, 28.5×10^6 in Zuru, and 4.3×10^6 in Argungu. The lowest total bacteria count was observed in Gwandu, which was too few to count. The biochemical tests of the isolates revealed that all the water samples contained *Bacillus species* (bacteria), *Staphylococcus aureus* (bacteria), *Escherichia coli* (bacteria), *Mucor racemosa* (fungi), *Paecilomyces variotti* (fungi), and *Aspergillus niger* (fungi).

DISCUSSION

This study evaluated the safety of well water in Gwandu, Argungu, Yauri, and Zuru Emirate zones in Kebbi State, Nigeria. Table 3 shows that the physicochemical parameters of the water samples from the four zones were normal, except for the pH of Gwandu and Argungu, which are slightly acidic. This result is consistent with most of the studies that analyzed the physicochemical parameters of groundwater in the state. Notably, Elinge et

al. [23] and Wali et al. [24] reported a decrease in the pH of groundwater in Birnin Kebbi and Bunza in Kebbi State. Aliyu et al. [25] also observed normal physicochemical parameters in well water obtained from Argungu in Kebbi State. The reduced pH of well water from Gwandu and Argungu may not pose a serious health risk to consumers because pH has no direct adverse effects on health [26]. However, in sensitive individuals, gastrointestinal irritation as well as redness and irritation of the eyes may occur [27].

The heavy metal analysis shows that the water samples from the four zones contained abnormal concentrations of Cd, Cr, Pb, and Fe (Table 2). Elinge et al. [23] found abnormal levels of some heavy metals in well water samples obtained from Bunza, Kebbi State. Shabanda et al. [28] detected abnormal quantities of several heavy metals in boreholes and wells in Aliero, Kebbi State. These findings show that well water in Kebbi State may be grossly contaminated with heavy metals and so may not be suitable for consumption unless treated. A cadmium overdose may cause diarrhea, lung and kidney damage, vomiting, stomach irritation, and bone weakness [29]. Lead exposure may cause cancer, vitamin D deficiency, high blood pressure, brain damage, infertility, and mental impairment in children [30]. An erythropoietin effect, such as a swollen goiter, can be induced by excessive chromium ions in water [31]. Water with high levels of iron can cause fatigue, heart and liver disease, and diabetes mellitus [32].

The *CDI* of the individual heavy metals by adults was within the permissible limits, and the same goes for children, except for Cd and Cr (Tables 5 and 6). This shows that children could be at an increased risk of Cd and Cr toxicities. However, the *HQ* of the individual heavy metals for adults and children is less than one (Tables 7 and 8), which is the upper limit at which a substance can be considered non-toxic. This suggests that the water may not pose a serious health risk to adults and children. But in strict environmental terms, there is no safe level for heavy metals. Furthermore, heavy metals may combine additively and increase the risk of daily consumption of a substance.

Table 9 reveals that the well water samples from the four zones had abnormal bacteria, coliform, and fungal counts, which again proved that the water may predispose consumers to health hazards. *Bacillus species* (bacteria) were detected in the water, which can induce toxins in humans [33]. The presence of *Escherichia coli* (coliform) indicates that the water has been contaminated by fecal matter and may cause diarrhea [34]. *Staphylococcus aureus* (bacteria) seen in the water can cause boils, furuncles, cellulitis, blood infections, and pneumonia [35]. *Aspergillus niger* (fungus) was also found in the water, which may cause allergic reactions and opportunistic invasive infections [36]. *Mucor racemosa* (fungus) observed in the water can cause vascular invasion, resulting in thrombosis, infarction, and tissue

Table 9. Levels and species of microorganisms isolated from well water samples collected in Gwandu, Argungu, Yauri, and Zuru Emirates in Kebbi State, Nigeria

Zone	TBC	TFC	TCC		Species isolated
	10 ⁶	10 ⁵	MPN	EMB	
Gwandu	TFTC	9.4	79	26	<i>Aspergillus niger</i> , <i>Escherichia coli</i> , <i>Bacillus sp.</i> , <i>Candida albicans</i>
Argungu	4.3	4.1	17	19	<i>Aspergillus niger</i> , <i>Paecilomyces variotti</i> , <i>Staphylococcus aureus</i> , <i>Bacillus sp.</i> , <i>Escherichia coli</i>
Yauri	29.7	4.5	6	ND	<i>Aspergillus niger</i> , <i>Staphylococcus aureus</i> , <i>Bacillus sp.</i>
Zuru	28.5	TNTC	33	94	<i>Aspergillus niger</i> , <i>Mucor racemosa</i> , <i>Staphylococcus aureus</i> , <i>Bacillus sp.</i> , <i>Escherichia coli</i>
Limit [22]	≤100 CFU/mL	≤50 CFU/mL	0	0	

TBC= Total Bacteria Count; TFC= Total Fungi Count; TCC= Total Coliform Count; EMB= Eosin Methylene Blue MPN= Most Probable Number; TFTC= Too Few to Count; TNTC= Too Numerous to Count; ND: Not Detected

necrosis [37]. The water also contained *Paecilomyces variotti* (fungus), which often causes peritonitis, cutaneous and disseminated infections [38]. Almost all previous microbiological studies of groundwater in Kebbi State reported the presence of heavy microbial populations. Importantly, Shemishere et al. [39] detected abnormal levels of some microorganisms in borehole water in Birnin Kebbi and Kalgo. Ola-Buraimo et al. [40] reported abnormal populations of some microorganisms in well water in several parts of Kebbi State. Elinge et al. [41] reported non-permissible levels of certain microbial species in borehole water from Aliero, Kebbi State. Bashir et al. [42] detected abnormal levels of bacteria and coliform in Sokoto, a neighboring state.

CONCLUSION

It can be concluded from the results that well water in Kebbi State is grossly contaminated. Non-permissible levels of Pb, Fe, Cd, and Cr were detected in well water samples from all the four emirate zones (Gwandu, Argungu, Zuru, and Yauri) of the state. In addition, the well water from Gwandu and Argungu zones had a reduced pH and was thus slightly acidic. The CDI of Cd and Cr by children in all the four zones was above the normal limit, suggesting that children might be at an increased risk of Cd and Cr toxicities. The water samples also contained abnormal levels of bacteria, fungi, and coliform species, which further proved the non-suitability of the water for consumption.

RECOMMENDATIONS

The following are suggestions based on the current study's findings:

- Residents should consider water purification before consuming it.
- Members of the communities should engage in environmental sanitation.
- There is an urgent need for public enlightenment in the state regarding the risks of consuming contaminated water.
- The wells should be capped and the well casings should be water tight.
- Governments should ensure clean and safe water in the state.
- Periodic monitoring of water quality in the state is advised.

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CONFLICT OF INTEREST

The authors declare that they hold no competing interests.

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Persian Abstract

چکیده

شیوع روزافزون بیماری‌های انتقال یافته از طریق آب، نظارت دوره‌ای بر منابع آب خانگی و آشامیدنی را ضروری می‌کند. مطالعه حاضر ایمنی آب چاه را در چهار منطقه امارت (گواندو، یاوری، آرگونگو و زورو) در ایالت کبی، نیجریه ارزیابی کرد. با استفاده از روش‌های معمول، نمونه‌های آب چاه از نظر فلزات سنگین، ویژگی‌های فیزیکی و شیمیایی و میکروارگانیسم‌ها مورد بررسی قرار گرفت و نتایج با معیارهای آب آشامیدنی سازمان جهانی بهداشت (WHO) مقایسه شد. مصرف مزمن روزانه فلزات سنگین (CDI) و ضریب خطر (HQ) نیز تعیین شد. نتایج نشان داد که آب چاه در چهار منطقه امارت دارای دمای نرمال، نیاز اکسیژن بیوشیمیایی (BOD)، اکسیژن محلول (DO)، کل جامدات معلق (TSS) و روی (روی) است. اما غلظت‌های غیرمجاز سرب (Pb)، آهن (Fe)، کادمیوم (Cd)، کروم (Cr) و pH فقط گواندو و آرگونگو) در تمام نمونه‌های آب شناسایی شد. به جز Cr و Cd در کودکان، CDI و HQ فلزات سنگین نرمال بود. بررسی‌های میکروبیولوژیکی نشان داد که نمونه‌های آب از چهار منطقه دارای سطوح غیرعادی گونه‌های باسیلوس (باکتری)، اشریشیا کلی (باکتری)، استافیلوکوکوس اورئوس (باکتری)، اسپرزیلوس نایجر (قارچ)، موکور راسموزا (قارچ) و پسیلومایسس واریوتی (قارچ) بودند. نتایج به‌دست‌آمده نشان می‌دهد که آب چاه در چهار منطقه برای مصرف انسان مناسب نیست مگر اینکه تصفیه شود.