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Article

# Hydrogeochemistry of groundwater in Lalan and its environs, Gusau Zamfara State Nigeria

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## Abstract

The study area (Lalan and its environs) Gusau town forms part of the North-Western Nigerian Basement Complex of Precambrian age. The geology of the area comprises the crystalline basement made of coarse-medium grained granite and lenses of banded gneiss. Five water samples were collected from different locations around Lalan and its environs, Gusau Zamfara, Northwestern Nigeria, to carry out hydro geochemical study to determine the quality of drinking water within the study area. AAS (Atomic Absorption Spectrometer) to determine the heavy metals. Others include Flame emission spectrometry where the sample solution is nebulized and introduced into the flame, where it is rapidly dissolved, vaporized, and atomized. The concentration of the analyzed metals in the study area shows that, Na2+, (1.4 mg/L to 30.8 mg/L, average 12.04 mg/L), Ni (0.0012 mg/L to 0.0094 mg/L, average 0.00496 mg/L), Cl (,0.2mg/L to 18.7mg/L, average 9.864 mg/L) NO3,- Mg2+ ,Fl-, Pb2+, SO4, Ca2+ are all within WHO (2022) safe limit. Physical parameters like TDS, pH and Temperature are within the NSDWQ (2020) safe limit. While Electrical Conductivity (EC) have values that are above the WHO (2022) recommended limits. Electrical Conductivity (EC) in water is a measure of the water's ability to pass an electric current, which is directly related to the concentration of dissolved ions in the water. Conductivity increases as the concentration of dissolved ions such as chlorides, alkalis, and salts increases in the water. Pure water has very low conductivity, while seawater has very high conductivity.

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Hydrogeochemical study, precambrian age, flame emission spectrometry, atomic absorption spectrometer (AAS), pH

## Introduction

Water is known to be the most essential commodity in sustaining human life as the human body is composed of approximately 70% water by mass. The importance of water varies from medical, to domestic to industrial uses, depending on the chemical composition of the water. The quality and chemical composition of groundwater is influenced by factors such as the composition of precipitation, the nature of the aquifers, climate, and topography (which is the sloppy nature of the environment. And anthropogenic activities, these factors can combine to create diverse water types that change in composition spatially and temporarily. The overall implication of this is that hydrogeochemical facies of groundwater change in response to its flow path. This also implies that mineralogical composition can exert important control on the final water chemistry. So, the quality of water is likely to change day by day as it remains in

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an aquifer and is supplied from different sources, (Ishaku J.M, 2012). Surface water is open to several kinds of abuse which renders it more contaminated than groundwater though the two sources are interdependent as surface water in most cases recharges the groundwater, (Joyce, 2017).

The availability of clean and safe water supply has a direct influence on the economic well-being, health, and quality of life of any society. Understanding the quality of groundwater with its temporal and seasonal variation is important because it is the factor that determines the suitability for drinking, domestic, agricultural, and industrial purposes (Shuaibu et al., 2020) The suitability of particular groundwater for certain utilities such as public water supply, irrigation, industrial application, cooling, heating, and power generation largely depends on sediments, lithologic content, temperature, possible temporal variations caused by climatic conditions as well as water quality. The chemistry of groundwater is due to several processes like soil/rock–water interaction during recharge and groundwater flow, prolonged storage in the aquifer, and dissolution of mineral species. These processes are related to the weathering of minerals which generally exerts an important control on groundwater chemistry. This process generally dominates the concentration of the major cations (Odukoya, 2015).

Water for human consumption and agriculture is stored as groundwater, which is the world's largest liquid freshwater supply (Eyankware, 2018; Eyankware, et al., 2020a). Despite the fact that climate change has caused significant spatial-temporal precipitation variability and has affected reservoir storage volume, groundwater remains an important and reliable source of water; however, pollutants do occasionally reach the aquifer as a result of natural or human factors. Inadequate waste disposal sites, which have an impact on all natural resources, are one of the major threats to the quality of groundwater designated for human use (Akakuru, et al., 2021; Agidi, et al., 2022). This has a big influence on the environment and on people's health, when maintained incorrectly, landfills represent a serious threat to groundwater quality (Wasiu et al,. 2022). The geology of the area studied comprises the crystalline basement made of coarse-medium-grained granite and lenses of banded gneiss (Chinwuko, et al., 2018). Groundwater in the crystalline basement rocks is localized in pockets and patches of weathered rock and fractures. Wells usually encounter water at shallow depths but yields are often low and subject to seasonal fluctuations (Shuaibu et al., 2020).

## Location and Geological Setting of the Study Area

The study area (Lalan and its environs) Gusau town forms part of the North-Western Nigerian Basement Complex of Precambrian age. Generally, the Basement rocks of Nigeria are distinguished into three lithological units; the migmatite, gneiss, and quartzite complex, the schist belts, and the older granites. The study area comprises area so-called "Older Granites" in Northwest Nigeria. The pan-African Orogeny during which the Older Granites were placed as a result of interaction between the magma and the pre-existing rocks, produced a variety of migmatite and gneissic rocks with a dominantly NNE-SSW trending foliation, Migmatite, and gneissic occur outside the study area and shortly before and beyond Lalan area along Zaria road. The end of the orogeny was marked by faulting and fracturing (Gandu et al., 1986; Olayinka, 1992). The geology of the area studied comprises the crystalline basement made of coarse-medium-grained granite and lenses of banded gneiss (Chinwuko, et al., 2018). Groundwater in the crystalline basement rocks is localized in pockets and patches of weathered rock and fractures. Wells usually encounter water at shallow depths but yields are often low and subject to seasonal fluctuations (Shuaibu et al., 2020).

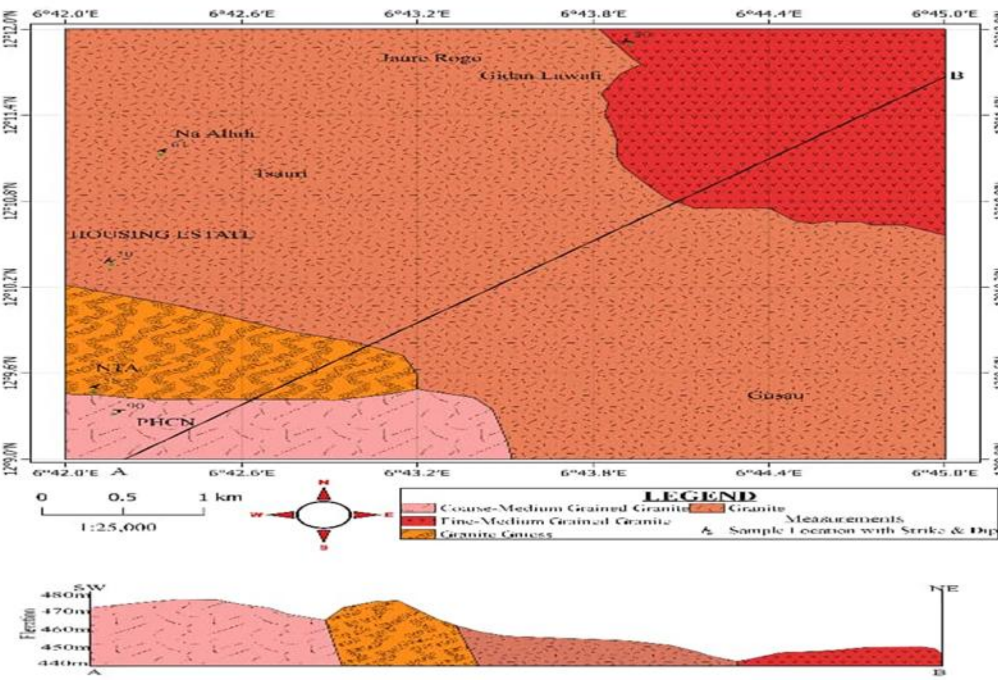


**Figure 1.** Geological cross-section of the study area

## Location and Accessibility of The Study Area

The Lalan area is located along the Zaria road in Local Government area of Zamfara state. It forms part of Gusau sheet 54SE covering an area of about 28.2km$^2$, itis located between latitude 12$^{o}$9′30″ N and longitude 6$^{0}$42′0E, and rise to the height of approximately 430m above mean sea level in some areas, (figure 1). However, the area is mainly accessible through the Zaria-Sokoto road and some un-tarred roads with other major and minor footpaths linking hamlet to hamlet and hamlets to farm lands within the area. The study area is situated in Gusau local government, Zamfara State. Major town in the study area is Gusau; while other built up settlements include: NTA, PHCN, Housing Estate, Tsauri, kureja, Jaure Rogo, Gidan Lawali and Gidan na Allah.

**Table 1.** Locations and settlement in the study area

| S/N | Settlement | Location |
|---|---|---|
| 1 | NTA | 12$^{O}$ 9$^{I}$ 30$^{II}$N, 06$^{o}$ 42$^{I}$ 0$^{II}$E |
| 2 | PHCN | 12$^{O}$ 9$^{I}$ 0$^{II}$N, 06$^{o}$ 42$^{I}$ 30$^{II}$E |
| 3 | Housing Estate | 12$^{O}$ 10$^{I}$ 0$^{II}$N, 06$^{o}$ 42$^{I}$ 30$^{II}$E |
| 4 | Tsauri | 12$^{O}$ 10$^{I}$ 30$^{I}$N, 06$^{o}$ 43$^{I}$ 0$^{II}$E |
| 5 | G Na allah | 12$^{O}$ 11$^{I}$ 0$^{II}$N, 06$^{o}$ 42$^{I}$ 30$^{II}$E |
| 6 | Kureja | 12$^{O}$ 11$^{I}$ 0$^{II}$N, 06$^{o}$ 43$^{I}$ 30$^{II}$E |
| 7 | GidanLawali | 12$^{O}$ 11$^{I}$ 30$^{II}$N, 06$^{o}$ 43$^{I}$ 30$^{II}$E |
| 8 | JaureRogo | 12$^{0}$ 11' 30''N, 06$^{0}$ 43' 0''E |

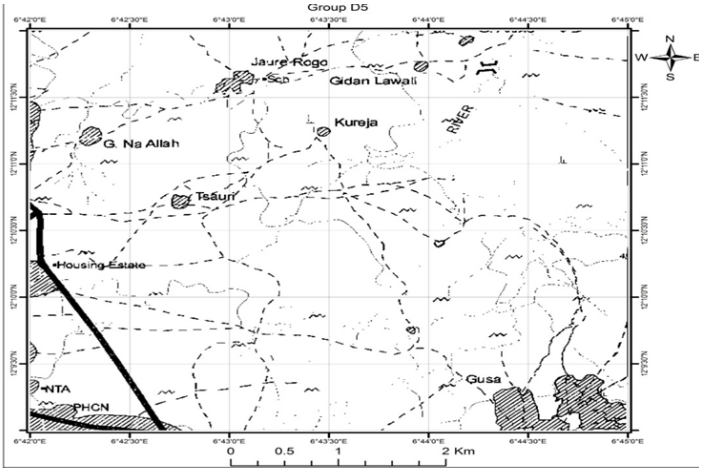


**Figure 2.** Topographic map of the study area

## Relief and Drainage

The relief observed in these areas is relatively characterized mainly by flat terrains, undulating farmlands, relative to the most conspicuous high features such as pendent low lying outcrops and other exposure of river channels. The settlers are mainly farmers and local miners that rely on wells, boreholes and river channels for their domestic activities.

## Climate and Vegetation

The study area falls within the tropical continental climate of Nigeria, the general weather is hot and dry, and temperature is very high during the daytime and low in the night. The climate is influenced by two major seasons of wet and dry season. Savannah vegetation form the vegetation cover with sparsely distributed trees shrubs and grasses that are of semi- arid in nature. The climate condition of Zamfara is tropical with temperatures rising up to 38 °C (100.4 °F) and above between March and May. Rainy season starts in late May to September while the mild season known as Harmattan lasts from December to April. The hottest months in Zamfara are March and April that is just before the first rains. The onset of the rains brings a cooling effect with temperature dropping.

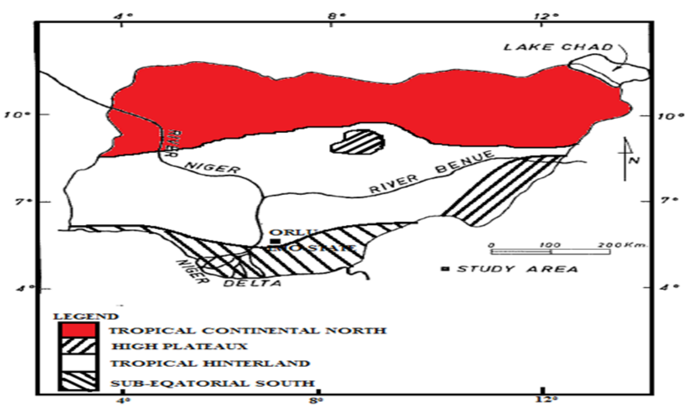


**Figure 3.** Map of Nigeria showing the climatic regions

## Rainfall

Rainfall is generally low; the average annual rainfall ranges from 600mm to 1000mm across the entire state. Much of the rain, falls between the months of May to September, while months of October to April experienced little or no rainfall. Evaporation is high ranging from 80mm in July to 210mm in April to May (NiMET, 2020). A monthly average evapo-transpiration range of about 140mm represent 30 of monthly average precipitation into the catchment.

## Temperature

Temperatures are generally extreme with average daily minimum of 18°C, during cool months of December and January while the hottest months of April to June, an average maximum of 38°C and minimum of 24°C temperatures are recorded (NiMET, 2020).

## Settlement and Land Use

The Lalan area is located in the Gusau Local Government Area of Zamfara State, Nigeria. The area is predominantly inhabited by the Hausa and Fulani ethnic groups, which are the two major ethnic groups in the region. The settlement pattern within the Lalan area is fairly sparse with hamlets that are sparsely distributed and the rest of the land is mainly used for farming i.e. the land is mainly used for residential and agrarian purposes with no industrial use. Most of the inhabitants of this area are farmers with few cattle breeders. The cultural significance of the Lalan area is reflected in its traditional practices and occupations, including builders, thatches, butchers, blacksmiths, drummers, and praise singers. The area's cultural heritage is also reflected in its agricultural and commercial activities, with cotton ginning, weaving, and dyeing being long-established local activities. Additionally, Gusau, where Lalan is located, is a major trade center for livestock and crops and has a significant textile industry. The area's cultural significance is further highlighted by its role as a medical center for the region, with hospitals, health offices, dispensaries, and maternity clinics.

# Method

A Geological field mapping was carried out using a topographic map and other geological tools like a hammer, and compass, to measure and record the attitude of beds to produce a geological map of the area.

## Geological Mapping

Geological mapping of the study area was done on approximately a scale of 1:25,000 using necessary and suitable field equipment such as the field notebook, GPS, compass clinometers measuring tape, and so on. Traversing was done using footpaths and roads available within the study area. A topographical map was used as a base map for the field work and sampling, coordinates were taken using the GPS (Global Positioning System), which was recorded in the field notebook and on the map for easy location and traversing.

## Water Sampling

Five (5) groundwater samples were taken mainly from a borehole, wells, and stream from the study area. The samples were collected from different residential areas within the topographic map in other to have a wider coverage of sampling. Three (3) groundwater samples were taken from a borehole while two (2) samples were taken from an Artisan well. The water samples were collected in sample bottles that had been thoroughly washed, rinsed with distilled water, and later on rinsed three times with the water that was to be sampled, so as to avoid contaminating the samples before filling the bottles. Two separate water samples were collected at each sampling location; one was for the determination of major cations and anions while the other was for the determination of heavy metals. The samples collected for heavy metals determination were acidified with concentrated nitric acid ( 〖HNO〗 _3) to a pH of approximately 2. This is done to reduce the adsorption of nearly all ions and also in order to prevent precipitation of the water or formation of bonds between the sample bottle and ions.

At each sampling point, some physical parameters such as Electrical conductivity (EC), Total dissolved solids, (TDS), Temperature, and pH were measured in situ using 3 in 1 Herod head conductivity portable pH meter, which can also be used for measuring temperature, and total dissolved solid meter. The in-situ measurements are necessary because the values of the parameters might change before being taken to the laboratory for analysis. Readings are measured; location name and number were all recorded on the field notebook and inputted on the map. The locations of each well where all samples were collected were taken using a G.P.S. and all sampled water were stored using ice perked container or coolers and transported to the laboratory for analysis.

**Table 2.** Location of sampling point along with their coordinates

| Sample No | Location | Coordinates | Water Source |
|---|---|---|---|
| 1. | Power Holding Company of Nigeria. (PHCN) | $12^0$ 9' 29''N<br>$6^0$ 42' 1''E | Borehole |
| 2. | Nigeria Television Authority (NTA) | $12^0$ 8' 47''N<br>$6^0$ 42' 13''E | Borehole |
| 3. | Housing Estate | $12^0$ 10' 23''N<br>$6^0$ 42' 09''E | Borehole |
| 4. | Tsauni | $12^0$ 10' 48''N<br>$6^0$ 43' 08''E | Well |
| 5. | Gidan Lawali | $12^0$ 11' 55' N<br>$6^0$ 43' 55''E | Well |

## Laboratory Analysis (Hydrogeochemical)

Five (5) samples were collected and taken to National Water Resources Institute Mando, Kaduna for further analysis of major and minor elements and oxides analysis using AAS (Atomic Absorption Spectrometer). The chemical study was carried out on the five (5) water samples, with the intent of determining the quality of the water sources such as borehole, well and river/stream used for drinking and domestic purposes; to determine the causes, sources of the pollutants and suggest solutions towards solving the problem. The five (5) water samples were analyzed for major elements and important anions. The cations Ca2+, and Mg2+ were determined using atomic absorption spectrometer at the laboratory in National Water Resources Institute (NWRI) and Na+ was analyzed using a flame photometer. The anions Cl-, and NO3- were determined using titrimetric. Water samples collected from the locations undergo laboratory tests. The sodium or alkali hazard of the water samples was also investigated; The Irrigation water containing high sodium is hazardous. The results were compared with recommended standards to determine the water geochemistry and its quality for drinking and domestic purposes.

## Standard Preparation

5ml of the stock solution is placed in 100 ml volumetric flasks. One of the solutions should have an iron concentration of 5.0 g/ml. This solution is used to test the instrument's performance. Make one stock solution (0.1000g/1000 ml) and dilute aliquots of it to make the five standard solutions. After cleaning the iron wire with an emery cloth, dissolve it in a small amount of a 1:1 v/v mixture of concentrated nitric acid and water. While heating is required, avoid boiling during the dissolving process. When the iron wire has been dissolved, briefly boil the solution to remove nitrogen oxides. Transfer the solution in a 1000-ml volumetric flask and dilute with distilled water to volume. Take aliquots of the stock solution using the volumetric pipettes provided. Transfer the aliquots to 100-ml volumetric flasks and dilute with distilled water to volume.

## Atomic Absorption Spectrophotometer (AAS) Principles for Elemental Analysis

The atomic absorption spectrophotometer (AAS) principle is founded on the notion that atoms of an element can absorb electromagnetic wavelengths. This happens when the element is atomized, and the wavelength of light absorbed by each element is unique. An atomizing device, a light source (a cathode lamp), and a detector comprise the atomic absorption spectrophotometer. A decrease in reaction in the detector caused by atomic absorption during atomization of the sample in a light beam can be adjusted and is responsive at the mg/l level. The sample was prepared in solution before being aspirated through a nebulizer and atomized in an acetylene-nitrous oxide flame.

**Figure 4.** Atomic Absorption Spectrometer (AA 900 series)

## Flame Emission Analysis for Na+

In flame emission spectrometry, the sample solution is nebulized (made into a fine aerosol) and introduced into the flame, where it is rapidly dissolved, vaporized, and atomized. Following that, atoms and molecules are excited by thermal collisions with the constituents of the partially burned flame gases. When they return to an electronic state that is lower or grounded. Excited atoms and molecules emit radiation that is unique to the sample components. The emitted radiation is passed through a monochromator, which isolates the desired wavelength for analysis. The radiant power of the selected radiation is measured by the photodetector, which then amplifies it and sends it to a readout device, meter, recorder, or microcomputer system. The most common sampling method is to nebulize a liquid sample in order to provide a steady flow of aerosol into a flame. The sample solution is introduced into a high-velocity gas jet, usually the oxidant, through an orifice. The pressure differential created by the high-velocity gas stream passing over the sample orifice draws liquid through the sample capillary. The analyte within the aerosol was converted into free analyte atoms in the ground state for flame emission analysis during the atomization step. To handle a large number of samples, flame emission analysis can be easily automated. Array detectors connected to a microcomputer system allow for the simultaneous analysis of multiple elements in a single sample. The majority of flame emission analysis applications have been in the determination of trace metals, particularly in liquid samples. It should be noted that flame emission analysis is a simple, low-cost, and sensitive method for detecting common metals such as alkali and alkaline earths.

## Results and Discussion

The analysis carried out on the Five (5) samples which include Physical Parameters, major and minor elements and oxides are displayed in the Table 2, 3, 4 and 5. The physical parameters were measured in-situ at the point of sampling, while the analysis for the major elements and oxides, and the minor elements were carried out in the laboratory. The chemistry of water can lead to adverse effects either if there is an absence of necessary constituents or, more commonly, if there is an excess of a harmful chemical in the water. Table 2 displays the physical parameters of the water samples being investigated. While the major elements and oxides are shown in Table 3.

**Table 3.** The physical parameters of the water samples as measured on the field

| Sample No. | EC | TDS | Ph | Temperature |
|---|---|---|---|---|
| PHCN | 771 | 381 | 7.48 | 28.2 |
| NTA | 539/751 | 296/374 | 7.74 | 28.2 |
| Housing Estate | 729 | 364 | 8.14 | 28.4 |
| Tsauni | 527 | 363 | 8.26 | 28.3 |
| Gidan Lawali | 668 | 334 | 8.13 | 28.1 |
| **Average** | **646.8** | **347.6** | **7.95** | **28.24** |

**Table 4.** The major elements and oxides measured for the water samples in the laboratory

| Sample | Na (Mg/L) | Fl (Mg/L) | Ca (Mg/L) | Mg (Mg/L) | Cl (Mg/L) | $CO_3$ (Mg/L) | $SO_4$ (Mg/L) | $NO_3$ (Mg/L) | Total Alkalinity |
|---|---|---|---|---|---|---|---|---|---|
| PHCN | 1.4 | 0.95 | 235 | 2.1 | 0.02 | NIL | 58 | 0.00 | 92 |
| NTA | 4.2 | 0.42 | 180 | 0.76 | 11 | NIL | 0 | 4.40 | 92 |
| Housing Estate | 1.8 | 0.76 | 340 | 0.31 | 3.4 | NIL | 59 | 4.03 | 27 |
| Tsauni | 22 | 0.02 | 112 | 0.76 | 16.2 | NIL | 46 | 112 | 270 |
| Gidan Lawali | 30.8 | 0.53 | 175 | 0.25 | 18.7 | NIL | 14 | 2.30 | 88 |
| Average | 12.04 | 0.536 | 254 | 0.836 | 9.864 | | 35.4 | 2.37 | 113.8 |
| WHO | 200 | 12 | 300 | 20 | 250 | | 250 | 50 | 500 |

Results for minor elements measured for the water samples being investigated in the laboratory is displayed in Table 4 while the WHO and NWSDQ recommended limit of measured parameters in groundwater is shown in Table 5.

**Table 5.** The major elements and oxides measured for the water samples in the laboratory

| Sample | Cd Mg/L | Co Mg/L | Cr Mg/L | Fe Mg/L | Ni Mg/L | Pb Mg/L |
|---|---|---|---|---|---|---|
| PHCN | 0.0008 | 0.0047 | 0.0062 | 0.052 | 0.0043 | 0.0049 |
| NTA | 0.0001 | 0.0017 | 0.0124 | 0.021 | 0.0040 | 0.0110 |
| H. Estate | 0.0003 | 0.0023 | 0.0232 | 0.001 | 0.0094 | 0.0005 |
| G. Lawali | 0.0002 | 0.0017 | 0.0319 | 0.00 | 0.0059 | 0.0117 |
| Tsauni | 0.0031 | 0.0001 | 0.0051 | 0.006 | 0.0012 | 0.0011 |
| **Average** | **0.0009** | **0.0021** | **0.0157** | **0.016** | **0.00496** | **0.00584** |
| **WHO** | **0.003** | **0.07** | **0.05** | **0.3** | **0.02** | **0.01** |

**Table 6.** WHO and NWSDQ Recommended limit of measured parameters in groundwater

| Parameter | WHO Recommended Limit (2022) | NWSDQ Recommended Limit (2020) |
|---|---|---|
| Temperature | 15°C-25°C | 15°C-25°C |
| Ph | 6.5-8.5 | 6.5-9.5 |
| Electrical conductivity | 250 µS/cm | 250 µS/cm |
| Total dissolved solids | 500 mg/L | 500 mg/L |
| Turbidity | 5 NTU | 5 NTU |
| Color | 15 TCU | 15 TCU |
| Calcium | 20-300 mg/L | 20-300 mg/L |
| Magnesium | 10-150 mg/L | 10-150 mg/L |
| Sodium | 200 mg/L | 200 mg/L |
| Potassium | 12 mg/L | 12 mg/L |
| Chloride | 250 mg/L | 250 mg/L |
| Sulfate | 250 mg/L | 250 mg/L |
| Bicarbonate | 300 mg/L | 300 mg/L |
| Phosphate ($PO_4$) | 4 mg/L | 4 mg/L |
| Ammonia ($NH_3$) | 0.5 mg/L | 0.5 mg/L |
| Nitrate ($NO_3$) | 50 mg/L | 50 mg/L |
| Dissolved oxygen (DO) | 5 mg/L | 5 mg/L |
| Biochemical oxygen demand (BOD) | 5 mg/L | 5 mg/L |
| Cadmium (Cd) | 0.003 mg/L | 0.003 mg/L |
| Chromium (Cr) | 0.05 mg/L | 0.05 mg/L |
| Cobalt (Co) | 0.07 mg/L | 0.07 mg/L |
| Iron (Fe) | 0.3 mg/L | 0.3 mg/L |
| Nickel (Ni) | 0.02 mg/L | 0.02 mg/L |
| Lead (Pb) | 0.01 mg/L | 0.01 g/L |

## Interpretation

### *Physical Parameters*

pH values range from 7.48 to 8.26 with an average value of 7.95 which corresponds to the weakly basic medium compare to NSDWQ standard limit (6.5-9.5). Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. However, acidity in water may cause gastrointestinal problems for humans. The

Total Dissolved Solids (TDS) NSDWQ (2020) value is 500 mg/l. In all four water samples analyzed, the TDS ranges from 296 to 381 with an average value of 347.6 which is within the (NSDWQ, 2020) set standard limit value. This indicates the water in the study area is good for consumption and does not have a health impact on humans. TDS in drinking water originates from natural sources and urban runoff. Reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking water may be objectionable to consumers (WHO guidelines for drinking water quality, 2022). The electrical conductivity (EC) of the five water samples, ranging from 527 to 771 with average value of 646.8 exceeds the acceptable safe limits of 250 ;µS/cm. EC designated the enrichment of salt in groundwater, and this varies with changing water in the semi-arid climate, nutrient constituents, and evaporation (Islam et al. 2018).

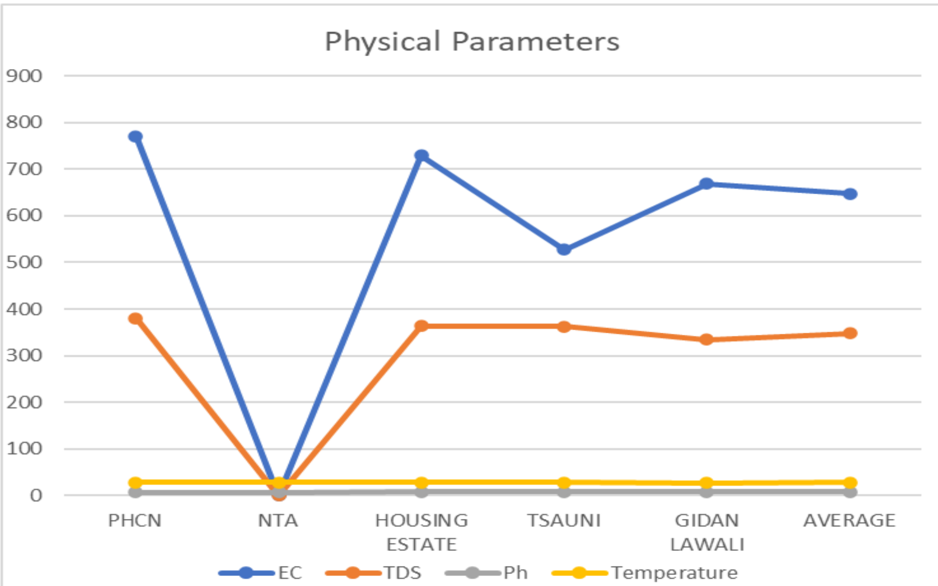


**Figure 5.** Physical parameters compared to WHO Standard limit

### *Major Elements*

**Magnesium ion (Mg2+).** Magnesium in water appears as hydrated ions, which are more easily absorbed than magnesium in food. The contribution of water magnesium among person who drink water with high magnesium levels could thus be crucial in the prevention of magnesium deficiency. According to World Health Organization standard, the permissible limit for Mg in water is 10 Mg/L to 150mg/L. Base on the results from the analysis, the concentration of Mg in the study area ranges between 0.25 mg/L to 2.1 mg/L with an average of 0.836 mg/L which is found to be below the permissible limits given by WHO in all water samples. The probable source of Mg in the groundwater is the decomposition of clay minerals, gypsum and other minerals from the aquifer materials into the groundwater. The World Health Organization (WHO) sets the permissible limit for magnesium in drinking water between 10 mg/L and 150 mg/L. However, recent analyses indicate that the concentration of magnesium in certain groundwater sources ranges from 0.25 mg/L to 2.1 mg/L, with an average of 0.836 mg/L, which is well below the WHO's recommended limits. This low concentration suggests that while drinking water can contribute to magnesium intake, it may not be sufficient for those at risk of deficiency.

**Chloride ion (Cl-).** Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salt. Thus increasing levels of metal in drinking water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion. The concentration of chloride found in the study area is within the range of 0.2mg/L to 18.7mg/L with an average concentration of 9.864 mg/L which is below the permissible limit for drinking water given by World Health Organization at 250 mg/L. All sampled groundwater for Cl- concentration falls within the acceptable limit of the WHO. While current chloride levels in the study area are within safe limits according to WHO guidelines, continuous monitoring is essential due to the potential for increased corrosion rates associated with higher concentrations of chloride. The presence of chloride not only raises concerns about drinking water quality but also poses risks for infrastructure integrity through enhanced corrosion processes in metal pipes.

**Sodium ion (Na+).** Sodium is mostly found in less concentration in water and it is naturally occurring element found in Feldspar, Halite etc. Elevated drinking water levels of Na+ may cause hypertension. Similarly, high Na+ may cause vomiting, muscular twisting, rigidity etc. The measured concentration of sodium in groundwater in the study area reveals that all the samples which ranges between 1.4 mg/L to 30.8 mg/L with an average of 12.04 mg/L, hence, all sampled groundwater are below World Health Organization criteria of 200 mg/L for good quality drinking water. The measured sodium concentrations in the groundwater samples are well within safe limits according to international standards. Nonetheless, monitoring and managing sodium levels remain crucial for public health, especially for vulnerable populations such as those with existing health conditions related to sodium intake.

**Carbonate ion (CO32-).** The World Health Organization (WHO) does not have specific recommended limits or National Water Quality Standards Division (NWSDQ) values for carbonate in drinking water. This is because carbonate itself is not a harmful substance and can actually be beneficial for human health, contributing to bone health and maintaining the pH balance in the body. However, high levels of carbonate can lead to scaling and other problems in water distribution systems. The World Health Organization (WHO) does not establish specific limits for carbonate in drinking water because it is generally considered non-harmful and can even be beneficial for health, particularly in supporting bone health and maintaining pH balance in the body. However, excessive levels of carbonate can lead to scaling issues in water distribution systems, prompting regulatory bodies to focus instead on total alkalinity, which encompasses the concentrations of carbonate, bicarbonate, and hydroxide ions. Therefore, the WHO and other regulatory agencies focus on the total alkalinity of water, which is a measure of the combined concentration of carbonate, bicarbonate, and hydroxide ions. The WHO's guideline value for total alkalinity in drinking water is 500 mg/L (milligrams per liter). This value is based on taste considerations, as higher alkalinity can give water an unpleasant taste. In Nigeria, the Nigerian Standard for Drinking Water Quality (NSDWQ) also does not have a specific limit for carbonate but sets a limit of 500 mg/L for total alkalinity. This standard is aligned with the WHO's guideline value.

**Flouride ion (Fl-).** The concentration of flouride in the water samples analyzed ranges between 0.02mg/L to 0.95mg/L with an average of 0.536mg/L which is below the World Health Organization permissible limit of 5mg/L in drinking water. Fluoride is commonly added to drinking water to prevent dental caries, but excessive concentrations can lead to health issues such as dental and skeletal fluorosis. The WHO recommends a fluoride concentration limit of 1.5 mg/L to mitigate these risks, with some countries setting lower limits to protect against dental fluorosis, particularly in vulnerable populations like children The observed fluoride levels in the analyzed samples suggest that they are within a safe range for public health, as they fall well below both the WHO's recommended limits and those enforced in various countries.

**Nitrate ion (NO3-).** Nitrate is essential plant nutrients but in excess amounts they can cause significant water quality problems. Together with phosphorous, nitrates in excess amount can accelerate eutrophication, causing dramatic increases in aquatic plants growth and changes in the types of plants and animals that live in the stream. World Health Organization standard limit for Nitrate in drinking water is 50 mg/L. The result gotten from the analyses carried out on the water samples indicate that Nitrate are within the limit of WHO standard for drinking water whichh is between 0.00mg/L to 2.30mg/L with an average of 2.37mg/L. The concentration of NO3 in water can be a measure of how polluted the water is. Excessive nitrates can originate from various sources, including agricultural runoff, wastewater treatment plants, and failing septic systems. These sources contribute to the rapid transport of nitrates into rivers and streams, exacerbating water quality issues. Monitoring the concentration of nitrates in water is crucial as it serves as an indicator of potential pollution levels, helping to assess the health of aquatic ecosystems and ensuring safe drinking water standards are maintained.

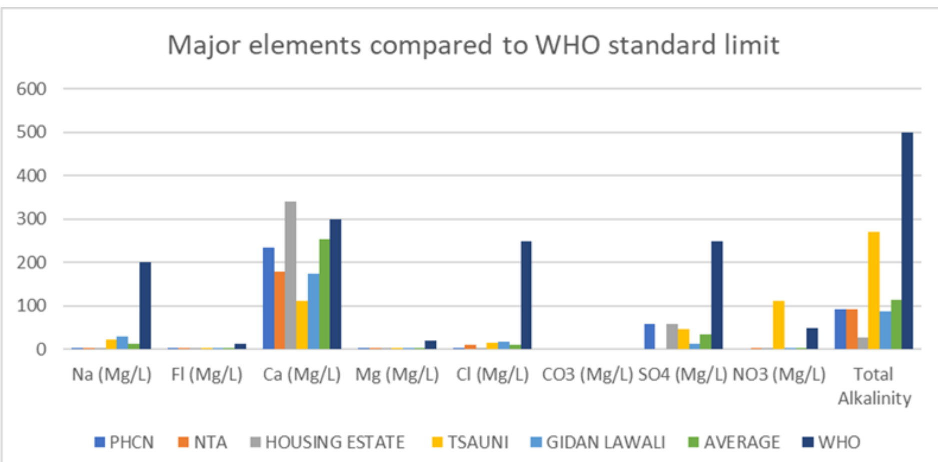


**Figure 6.** Major elements and Oxides compared to WHO and NSDWQ recommended limit

**Sulphate ion (SO42-).** High level of Sulphate in drinking water can cause gastrointestinal disorder in human and corrosion in pipes and may make water taste bitter. High Sulphate in water may be as a result of runoff from fertilizer, agricultural lands. The World Health Organization standard for Sulphate in drinking water is 250mg/L, the concentration of Sulphate in the water samples analyzed ranges from 0 mg/L to 59mg/L and an average of 35.4mg/L, this is below the permissible limit and is therefore safe for drinking. While sulfate is a common contaminant that can lead to health issues such as gastrointestinal disorders and corrosion of plumbing, current levels in the analyzed samples are within safe limits established by health authorities. Regular monitoring and management practices are essential to ensure that sulfate levels remain below harmful thresholdsmanagement practices are essential to ensure that sulfate levels remain below harmful thresholds.

*Minor Elements*

**Lead (Pb).** Lead is a highly poisonous metal affecting almost every organ in the body. Of all the organs, the nervous system is the mostly affected target in lead toxicity, both in children and adult. The toxicity in children is however of a greater impact than in adults. Lead (Pb) concentration ranges from 0.0005 mg/L to 0.0117 mg/L with an average of 0.00584 mg/L not exceeding the WHO permissible limit of 0.01 mg/L. while lead remains a significant health hazard due to its toxic effects on multiple organ systems—especially the nervous system—the current levels found in the analyzed water samples do not exceed safety guidelines established by health authorities. Regular monitoring and proactive measures are essential to prevent potential exposure risks.

**Nickel (Ni).** Nickel exposure is associated with skin allergies and dermatitis, particularly in individuals who are hypersensitive to nickel. Long-term exposure to high levels of nickel may also have respiratory effects and is considered a potential carcinogen. Ni is concentrated in all the samples ranging from 0.0012 mg/L to 0.0094 mg/L with an average of 0.00496 mg/L which is within the recommended limit by WHO 0.02 mg/L. while nickel exposure can lead to significant health issues such as skin allergies and respiratory problems, current environmental concentrations appear to be within safe limits according to WHO guidelines. However, ongoing vigilance is necessary due to the potential long-term health impacts associated with chronic exposure.

**Iron (Fe).** Iron is an essential nutrient for the body, but excessive intake, especially from non-dietary sources, can lead to iron overload. This can result in organ damage, particularly affecting the liver, heart, and pancreas. Iron toxicity can also cause gastrointestinal issues. The detected concentration of Iron in the study areas ranges from 0.00mg/L to 0.052mg/L with an average of 0.016mg/L not exceeding the WHO limit of 0.3 mg/L. While iron is essential for health, excessive intake can lead to severe complications due to iron overload. The current environmental concentrations of iron are within safe limits according to WHO guidelines; however, ongoing surveillance is necessary to mitigate any potential risks associated with elevated iron levels in the future.

**Cobalt (Co).** Cobalt is an essential trace element; excessive exposure can lead to health issues. Chronic exposure may result in respiratory problems, cardiomyopathy, and thyroid issues. Cobalt toxicity can also affect the nervous system. The concentration of Co in the study areas ranges from 0.0001mg/L to 0.0047mg/L with an average of 0.0021mg/L not exceeding the WHO limit of 0.07 mg/L. While cobalt is necessary for human health in trace amounts, excessive exposure poses significant health risks including respiratory issues, cardiomyopathy, thyroid dysfunction, and potential neurological effects. The current environmental concentrations of cobalt are within safe limits according to WHO guidelines; however, vigilance is necessary to prevent adverse health outcomes from chronic exposure.

**Chromium (Cr).** Chromium, including hexavalent chromium is an odorless and tasteless metallic element that occur naturally in rocks, animals, plants, and soils. It occurs naturally in most water supplies. The form most common in natural waters are trivalent chromium (chromium 3) and hexavalent chromium (chromium 6). The detected amount of Cr in all samples ranges from 0.0051mg/L to 0.0319mg/L with an average of 0.0157mg/L which is below the permissible limit given by WHO 0.05mg/L. While chromium is a naturally occurring element essential for human health in its trivalent form, excessive exposure to hexavalent chromium poses significant health risks. The current levels of chromium detected in the study areas are within the acceptable limits set by WHO guidelines, indicating no immediate health risk from drinking water sources. Continuous monitoring remains essential to ensure that chromium levels remain safe for public health.

**Cadmium (Cd).** Chronic exposure to cadmium is associated with adverse effects on the kidneys, bones, and respiratory system. It is known to be carcinogenic, particularly targeting the lungs. Cadmium can also interfere with the body's ability to repair DNA. WHO recommendations on the limit of Cadmium is 0.003mg/L. The concentration of Cadmium in the study areas ranges from 0.0001mg/L to 0.0031mg/L with an average of 0.0009mg/L which is within the permissible limit. While cadmium is a toxic heavy metal with significant health risks associated with chronic exposure, the current levels detected in the study areas are within acceptable limits set by WHO guidelines. Continuous monitoring is essential to prevent potential health risks, especially given cadmium's long-term effects on kidney function, bone health, respiratory system integrity, and its carcinogenic properties.

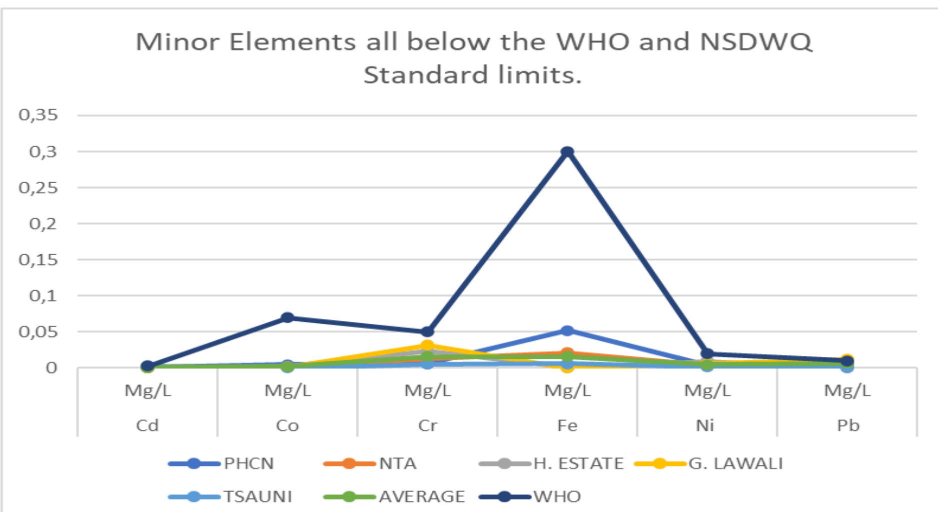


**Figure 7.** Minor elements compared to WHO and NSDWQ recommended limit

## Conclusion and Recommendations

The Five water samples collected from different locations around Lalan and environs, Gusau Zamfara State, were analyzed for a geochemical study to determine the quality of drinking water within the study area. The concentration of the analyzed metals in the study area shows that, $Na2+$, Ni, Cl, $NO3-$, $Mg2+-$, Fl-, $Pb2+$, SO4, $Ca2+$ are all within WHO (2022) safe limit. Physical parameters like TDS, pH and Temperature are within the NSDWQ (2020) safe limit. While Electrical Conductivity (EC) have values that are above the WHO (2022) recommended limits. Electrical Conductivity (EC) in water is a measure of the water's ability to pass an electric current, which is directly related to the concentration of dissolved ions in the water. Conductivity increases as the concentration of dissolved ions such as chlorides, alkalis, and salts increases in the water. Pure water has very low conductivity, while seawater has very high conductivity. Based on the findings of this study, the following recommendations are proposed:

i. Incorporating a variety of fruits, vegetables, and other edible plants into the diet can enhance the intake of essential nutrients that combat the effects of heavy metals. These foods provide not only vitamins but also phytochemicals that may offer protective benefits.

ii. Regular testing of soil and groundwater for heavy metal contamination is essential.

iii. In cases of significant toxicity, chelation therapy may be employed under medical supervision to bind heavy metals in the body and facilitate their excretion.

### Declarations

***Competing interests:*** All financial and non-financial competing interests must be declared in this section. If you do not have any competing interests, please write "The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article." in this section.

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## References

Agidi, B. M., Akakuru, O. C., Aigbadon, G. O., Schoeneich, K., Isreal, H., Ofoh, I., Njoku, J., & Esomonu, I. (2022). Water quality index, hydrogeochemical facies, and pollution index of groundwater around Middle Benue Trough, Nigeria. *International Journal of Energy & Water Resources*. https://doi.org/10.1007/s42108-022-00187-

Akakuru, O. C., Akudinobi, B. E., Nwankwoala, H. O., Akakuru, O. U., & Onyekuru, S. O. (2021). Compendious evaluation of groundwater in parts of Asaba, Nigeria, for agricultural sustainability. *Geosciences Journal*. https://doi.org/10.1007/s12303-021-0010-x

Alagbe, S. A. (2006). Preliminary evaluation of hydrochemistry of the Kalambaina Formation, Sokoto Basin, Nigeria. *Environmental Geology, 51*(1), 23–87.

Anderson, H. R., & Ogilbee, W. (1973). Aquifers in the Sokoto Basin, Northwestern Nigeria, with a description of the general hydrogeology of the region: Contributions to the hydrology of Africa and the Mediterranean region. *Geological Survey Water-Supply Paper*, *1757*-L, 1–88.

Chinwuko, A. I., Danbatta, U. A., Shaibu, I., Ovwasa, M. O., & Shuaibu, A. M. (2018). Geological mapping of basement rocks in Federal University Gusau and its environs, Zamfara State, Northwestern Nigeria. *IOSR Journal of Applied Geology and Geophysics, 6*(1), 32–42. https://doi.org/10.9790/0990-060102324

Chinwuko, A. I., Anakwuba, E. K., Okeke, H. C., Usman, A. O., Ovwasa, M. O., & Okoye, I. F. (2015). Geo-electric investigation for groundwater potential in Awka, Anambra State, Nigeria. *International Journal of Science for Global Sustainability, 1*(1), 85–95.

Du Preez, J. W., & Berber, W. (1965). The distribution of chemical quality of groundwater in Northern Nigeria. *Nigeria Geological Survey Bulletin.*

Eyankware, M. O., Obasi, P. N., Omo-Irabor, O. O., & Akakuru, O. C. (2020). Hydrochemical characterization of abandoned quarry and mine water for domestic and irrigation uses in Abakaliki, Southeast Nigeria. *Modeling Earth Systems and Environment*. https://doi.org/10.1007/s40808-020-00827-5

Eyankware, M. O., Nnabo, P. N., & Ogwah, C. (2020). Impact of past mining activity on water resources around active and abandoned mines in Ebonyi State, South-Eastern Nigeria: A mini review. *Hydro Science and Marine Engineering, 2*(2), 29–35.

Obaje, N. G. (2009). *Geology and mineral resources of Nigeria.* Springer.

Offodile, M. E. (2002). *Groundwater study and development in Nigeria* (2nd ed.). Mecon Geology and Engineering Services Ltd.

Ola-Buraimo, A. O., Ologe, O., & Benemaikwu, O. D. (2018). Field geology and microbiological investigation of borehole, public tap water, and hand-dug well in some parts of Birnin Kebbi, Nigeria. *Nigerian Journal of Science Research, 17*(3), 322–333.

Ola-Buraimo, A. O., & Ologe, O. (2020). Geochemical investigation of groundwater in some parts of Birnin Kebbi, Northwestern Nigeria. *Global Journal of Science Frontier Research: H Environment and Earth Science, 20*(6), 40–52.

Ologe, O., & Ola-Buraimo, A. O. (2022). Evaluation of aquifer characteristics within Birnin Kebbi metropolis, Northwestern Nigeria, using geoelectric survey. *Jordan Journal of Earth and Environmental Sciences, 13*(1), 60–63.

Shaibu, I., Ovwasa, M. O., & Abdullahi, M. (2022). Investigation of layer thickness and groundwater potentials in Federal University Gusau and its environs, Zamfara State, Nigeria. *International Journal of Science for Global Sustainability*.

Shuaibu, A. M., Garba, M. L., & Abubakar, I. Y. (2022). Hydrochemical characterization and evaluation of groundwater quality of Zamfara area, Northwest Nigeria. *Global Journal of Geological Sciences, 20*(1), 35–48. https://doi.org/10.4314/gjgs.v20i1.3

Shuaibu, A. M., Murana, K. A., & Ajibade, I. I. (2020). Qualitative evaluation of groundwater condition from part of Gusau Metropolis, Zamfara State, Northwestern Nigeria. *International Journal of Science for Global Sustainability*.

Wasiu, O. (2022). Hydrogeochemical characterization and quality assessment of groundwater based on water quality index in an urban area in SE Nigeria. https://doi.org/10.21203/rs.3.rs-2092987/v1

World Health Organization. (2012). *Guidelines for drinking water quality* (4th ed.). WHO Library Cataloguing in Publication.

World Health Organization. (2022). *Guidelines for drinking-water quality: First addendum to 3rd edition* (Vol. 1, p. 515).