VODOPRIVREDA Vol. 57 (2025) No. 337-338
https://doi.org/10.46793/Vodoprivreda57.5-6.187PK
UDK: 556.3:549
Originalni naučni rad

# HYDROGEOCHEMICAL STUDY AND GROUNDWATER MINERALISATION PROCESSES IN THE SAVANNE REGION IN NORTHERN TOGO

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## ABSTRACT

In response to challenges related to drinking water quality in the Savane region of northern Togo, a detailed hydrogeochemical study was conducted to address the growing demand for safe groundwater. The study focused on analysing the major cations and anions that define the hydrogeochemical signature of the water. An initial assessment of mineralisation processes indicated that water–rock interaction is the dominant mechanism influencing groundwater chemistry. Analysis of water hardness showed that most samples fall within the "slightly hard" category. These elements are derived from the dissolution of certain silicate minerals such as plagioclases (abite, anorthite, etc.), micas and certain clay minerals (illite, kaolinite, smectite, etc.). Using the Piper diagram, the different water types were identified and linked to the lithology of their respective aquifers. Among others, we can mention: Bicarbonate–calcium–magnesium facies in basement aquifers**,** Bicarbonate–sodium–potassium facies for claystone, silexite, and carbonate formations**,** Bicarbonate–chloride–potassium/sodium facies in sandstone units**,** Bicarbonate–calcium–sodium facies for alluvial deposits.

Spatial distribution maps of the major ions were also generated, highlighting zones of predominance for each ion. The spatial distribution maps revealed a predominance of magnesium and silica in groundwater from basement formations, whereas $Na^{+}$, $Ca^{2+}$, $Cl^{-}$, $HCO_3^{-}$ and $SO_4^{2-}$ ions are more dominant in groundwater originating from other geological units. Finally, an evaluation of water potability based on WQI for consumptions purpose assigns a good quality (WQI=24.49) to all waters in the area. For irrigation purpose, sodium percentage and alkalinity power showed that most groundwater samples are of excellent quality, with only a few exceptions.

**Key words:** Northen Togo, Savanne area, contact water-rocks, minerals dissolutions, hydrogeochemical facies

## INTRODUCTION

The exchanges and processes that enrich or deplete groundwater make it possible to evaluate its quality or degree of pollution and to determine its suitability for various uses. To achieve this, water quality is assessed by comparing its physical and chemical characteristics with standards established by the World Health Organization (WHO) as well as with national or regional regulations. Therefore, conducting hydrochemical analyses is essential for determining water quality before use, particularly when the water is intended for drinking. In this context, the present study provides a detailed hydrogeochemical assessment of groundwater in the Savanna region of northern Togo, aiming to raise awareness among users regarding groundwater quality across different parts of the region. The objective is to identify the major and minor elements present in groundwater, determine their origins

Podaci o prihvatanju članka
Primljen: 26.10.2025.
Ispravljen: 11.11.2025.
Prihvaćen: 27.11.2025.
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and evolution, and classify the types of water found. More specifically, the study involves a spatial analysis of chemical elements and selected physical parameters that help assess water quality, followed by an investigation of the various sources of mineralisation and a refinement of the different hydrogeochemical facies. The methodology integrates spatial analysis techniques, approaches for studying water mineralisation, and Piper diagram methods for hydrofacies characterization. The results generated through these methods will guide users in determining the most appropriate uses for the groundwater.

## LOCATION, HYDROGEOLOGY AND GEOLOGY DESCRIPTION

The Savanne region is in the extreme north of Togo and constitutes the country's fifth economic region. It is bordered to the north by Burkina Faso, to the east by the Republic of Benin, to the west by Ghana and to the south by the Kara region (Figure 1). It lies between latitude 0°43'30‘’-0°57'30‘’ N and longitude 10°0'00’’E-11°20’00’’. With a population of more than one million, it is an agricultural region that supplies more than 75% of cotton production and 20% of maize production. It is also the region that supplies most meat products to the Togolese population, due to its large goat, cattle and poultry herds.

The relief of the area is made up of sandstone plateaux in the Bonbouaka and Dapaong zones, the Oti plain and the Berrimian basement peneplain, with altitudes ranging from 200 m to over 500 m.

The maximum rainfall is recorded in August, which remains the wettest month, followed by July and September. From November to February there is an absence of rain, marking the dry season. Temperatures in the area vary between 25°C and 32°C over during the year, [1]. Maximum temperatures are recorded between March and April and are 31.7°C, while minimum temperatures are recorded between July and August and are 25.5°C, [2]. The region's relative humidity depends on the season. It is highest in the rainy season and lowest in the dry season.

The geology of the area is complex and is made up mainly of two major geological units: the Precambrian-aged Birrimian Basement and the Proterozoic-aged Volta sedimentary basin.

The Birrimian basement: this is the southern position of the Leo ridge belonging to the West African craton. It outcrops in the extreme north-west of the Savanne region and is Togo's oldest geological formation. It is composed mainly of acid granite facies, including alkaline granites, pink granites, granites with two mica, granodiorites, migmatites and metamorphic rocks such as gneisses and amphibolite’s.

The Volta Basin: sedimentary in nature, covering more than 80% of the region and subdivided into tillite mega-sequence [3]. It slopes monoclinal towards the south-east. The supratillitic supergroup which is subdivided into the Dapaong group at the base and the Bounbonka group composed of sandstone and siltstone. The Supratillitic supergroup or OTI supergroup: It begins with a triad of flints, tillites and carbonates. It is subdivided into the Barkouassi group, made up of flint and manganite formations in the east, and the Mango group, which is essentially clay and Gando sandstone in the east.

Hydrogeologicaly, the environment is made up of discontinuous basement aquifers due to the lithological nature of these formations. These types of aquifers are located in the altered horizons and in the fractures in the rock, and the volume of water is linked to the length and density of the fractures, as well as to the thickness of the layer of alterities. The most productive formations of groundwater are sandstones, followed by granitic and gneissic formations, [2]. On the other hand, the areas covered by the Mango mudstones are almost entirely unproductive, except where sandstones are intercalated in the zone. This area is subject to a shortage of drinking water due to the non-productivity of groundwater catchment boreholes. The more or less thick layers of alteration constitute a significant reservoir. Isotopic analysis by [4] shows recent recharge attributed to groundwater in the area except for a few samples.

The hydrogeology of the area is very varied due to the discontinuous state of its aquifers. As a result, the groundwater abstraction rates also vary according to the geological formations and intrinsic reservoir structures (fracturing and fissuring conditions, presence of discontinuity zones, thickness of alteration layers).

The region is experiencing increasing difficulties in terms of supplying high-quality water due to rising water pollution levels linked to human activities and natural processes. Most of the water used for drinking comes from wells and boreholes, [5]. This study aims to identify some of the chemical components of this water that define its quality and hydrogeochemical classification.

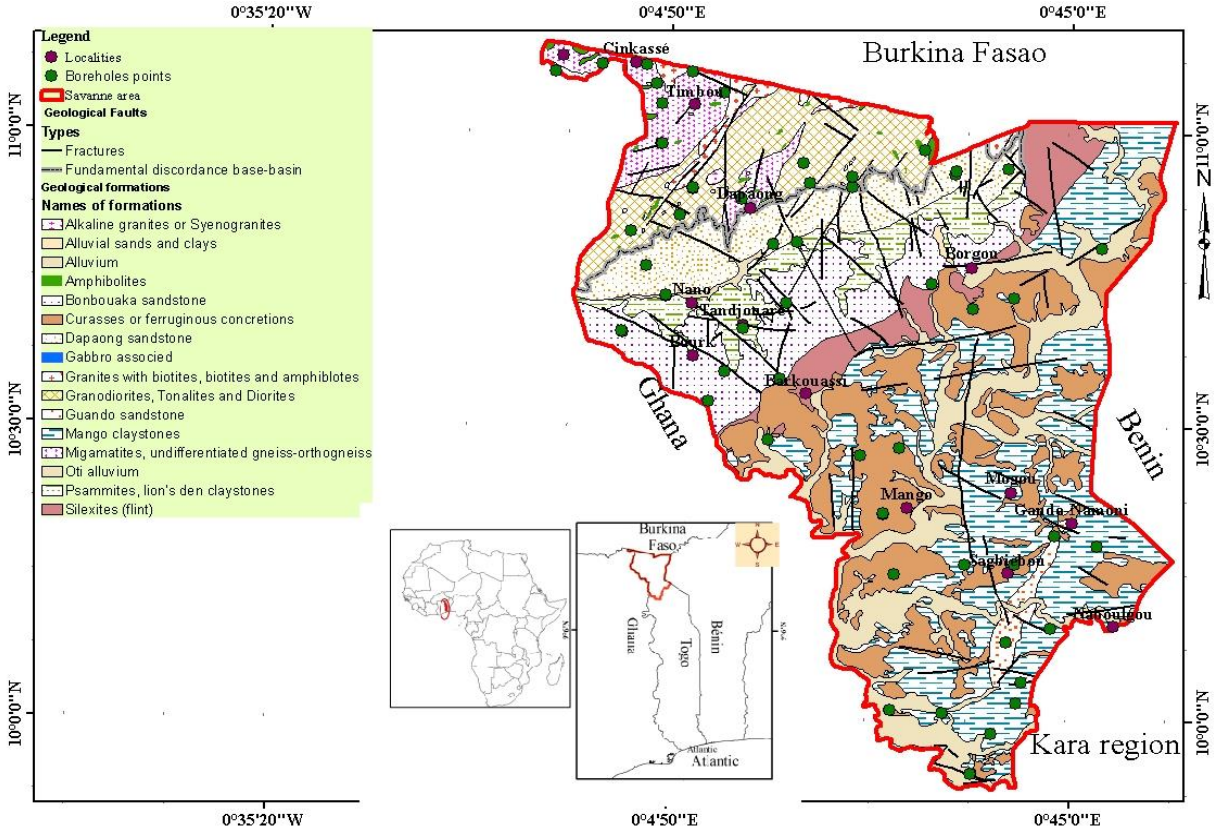


Figure 1: Location map of the study area showing local geology

## 2. MATERIALS AND METHODS

The analysis was conducted on 86 water samples, most of which were collected from newly drilled boreholes, with around a dozen taken from rehabilitated older boreholes. Physical parameters including temperature, pH, turbidity, taste, colour, and electrical conductivity were measured in situ. Sampling was carried out according to the local lithology to ensure that the chemical characteristics of the water could be linked to the nature of the underlying geological aquifer formations. Six main aquifer types were considered: crystalline basement formations, sandstone formations, claystone formations, siliceous and carbonate formations, lateritic cuirass formations, and alluvial zones. Laboratory analyses were performed by the Water Chemistry Laboratory of the University of Lomé, and for some samples, by the TdE laboratory in Kara. The study focused primarily on major cations and anions, including $K^+$, $Ca^{2+}$, $Na^+$, $Mg^{2+}$, $Cl^-$, $CO_3^{2-}$, $HCO_3^-$, $SO_4^{2-}$, and $NO_3^-$. The measurement was assessed by the value of the ionic balance (IB):

$$IB = \frac{\sum Zm_{cations} - \sum Z_{m_{anions}}}{\sum zm_{cations}^{+} \; \Sigma Z_{m_{anions}}}$$, [6].

$m_{cations}$ and $m_{anions}$ refer to the molar concentration of cations and anions, and

Z represents the charge of the ions. In this study, this value is significantly lower than 5%, which implies that the analysis data is reliable.

The methods used in this study include hydrogeochemical techniques such as the hydrogeochemical classification of water using Piper diagrams and the analysis of mineralisation processes using Gibbs diagrams. Spatialisation techniques were also applied through GIS tools to produce spatial distribution maps of the chemical elements. These maps provide decision-makers with valuable information on the characteristics of different areas in the region to support sustainable water use. The “Split, IDW” and “Kriging” interpolation tools in ArcGIS were used for spatial analysis. This approach considers the lithological nature of the aquifer units. Accordingly, the study distinguishes between aquifers in Birimian crystalline

basement formations, sandstone formations, flint and carbonate formations, claystone formations, cuirass formations, and alluvial deposits. Water quality was evaluated using the water quality index (WQI) for consumption purpose, the sodium percentage and the sodium adsorption ratio (SAR) for irrigation purpose, defined by the following expressions:

$$WQI = \sum_{i=1}^{n} SI_{i-n}$$

Where IS the Sub-Index of i[th] parameters: $SI_i = W_i \times Q_i$, $SI_i = Q_i \times W_i$

$W_i$ is the relative weight of the parameters: $Wi = \frac{wi}{\Sigma wi}$, wi represent the weight of each chemical parameter, and qi is the quality rating of each element in meq/L which is calculated as $Qi = \frac{C_i - S_0}{Si - So} * 100$

Ci= concentration of each parameter in meq/L, Si= WHO standards values, $S_0$ is the ideal value, [7]. WQI allow to classify 5 class of water quality, table 1.

Table 1: Water quality range and appreciation status, [7]

| WQI range | Category of water | Samples in category (%) |
|---|---|---|
| [0-25] | Excellent water | - |
| 26-50 | Good water | 5 (17.86%) |
| 51-75 | Poor water | 15(53.57%) |
| 76-100 | Very poor water | 5(1786%) |
| >100 | Unfit for drinking | 3(10.71%) |

For irrigation purpose, it is assessed by the percentage of sodium and the analysis of the alkalising power of the water.

$$\boldsymbol{SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}}}}, [8].$$

It indicates the level of sodium in the water sampled, as well as the percentage of clay that increases flocculation. Where $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ are the concentrations of each ion in meq/ L.

## 3. RESULTS AND DISCUSSION

The statistical distribution of the measurement and analysis results for these samples is presented in Table 2. It shows the maximum, minimum, median, mean, Std.Dev= standard division values for the various parameters considered in this study, compared with the World Health Organisation (WHO) standards.

The representation of water hardness on the scatter plot diagram shows that most waters are less hard, (Figure 2).and are in soft-fresh water areas, except for a few samples located in brackish waters.

Analysis of the mineralisation processes of those waters shows that the dominant process is the leaching of water-rock contact. The position of most samples on the Gibbs diagram (Figure 3) indicates a predominance of water-rock reactions.

Table 2: Statistical distributions results of the various elements analysed (in mg/L), and measured (SD=standard division)

| | Descriptive Statistics | | | | | |
|---|---|---|---|---|---|---|
| Variable | Mean | Sum | Minimum | Maximum | Variance | Std.Dev. |
| T°C | 30.7471 | 2675.00 | 28.0000 | 32.500 | 1.0 | 0.9883 |
| Ph | 7.2683 | 632.34 | 5.8400 | 8.930 | 0.3 | 0.5833 |
| c25°C | 559.3333 | 48662.00 | 120.0000 | 2210.000 | 115213.3 | 339.4308 |
| TDS | 423.3687 | 35986.34 | 8.0400 | 1993.000 | 95892.6 | 309.6652 |
| HCO3 | 291.6926 | 25377.26 | 73.2000 | 725.900 | 23045.0 | 151.8057 |
| TH | 12.5425 | 1091.20 | 0.8000 | 30.200 | 46.2 | 6.7964 |
| Ca | 26.0460 | 2266.00 | 1.6000 | 65.600 | 194.2 | 13.9357 |
| Mg | 16.8317 | 1464.36 | 1.0000 | 322.000 | 1170.1 | 34.2070 |
| Na | 74.9494 | 6520.60 | 3.2000 | 384.000 | 5929.8 | 77.0054 |
| K | 2.7690 | 240.90 | 0.6000 | 7.200 | 1.8 | 1.3351 |
| NO3 | 5.8389 | 507.99 | 0.0250 | 70.400 | 139.7 | 11.8215 |
| Cl | 27.0318 | 2351.77 | 0.5000 | 582.500 | 5951.7 | 77.1472 |
| NH4 | 0.1035 | 8.90 | 0.0500 | 1.300 | 0.0 | 0.1816 |
| SO4 | 11.9846 | 1042.66 | 1.0000 | 152.800 | 496.0 | 22.2709 |

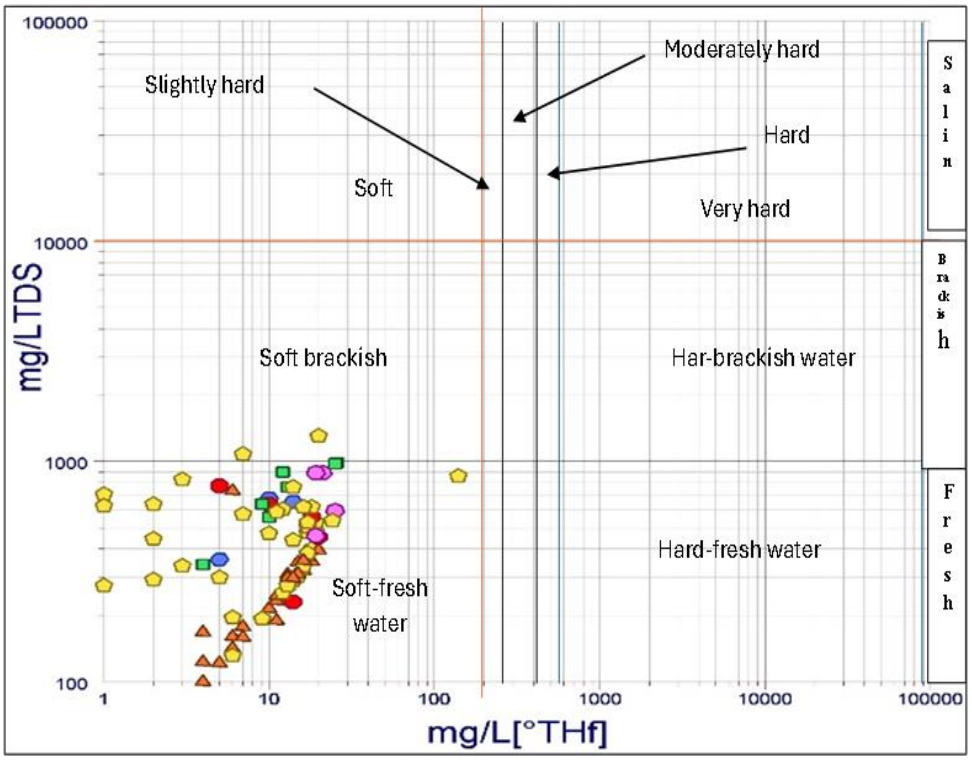


Figure 2: Scatter plots diagram showing the different hardness of samples

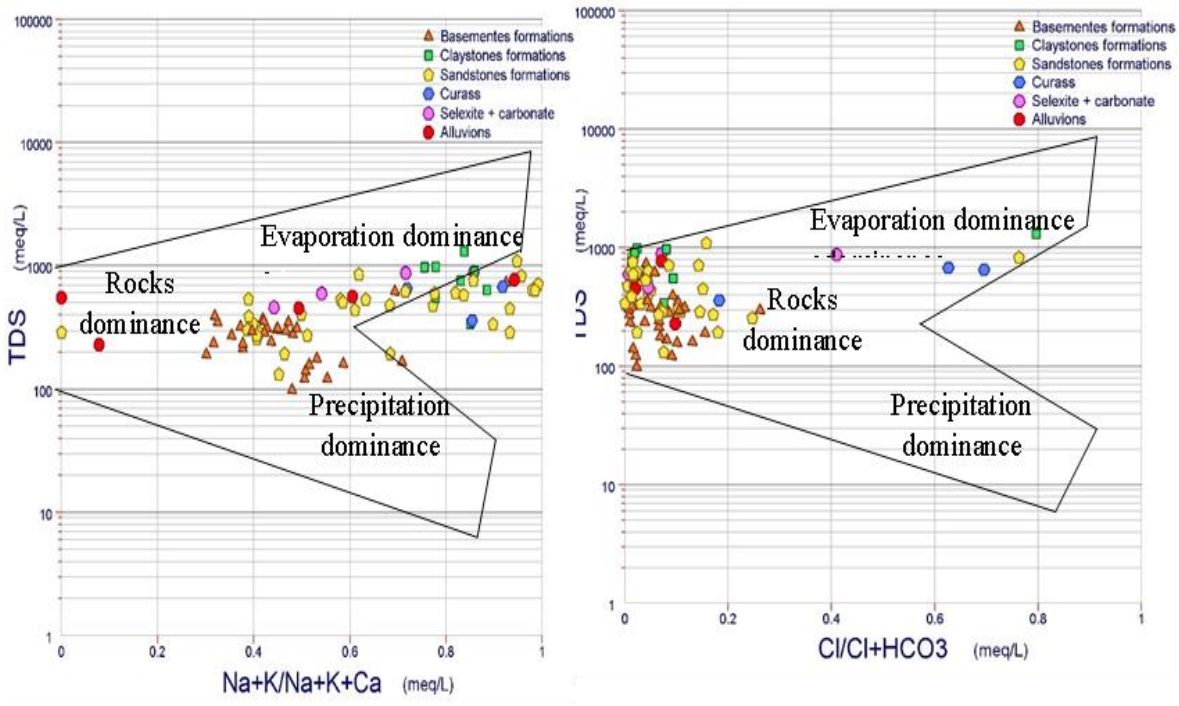


Figure 3: Gibbs diagram showing all the processes involved in the mineralisation of water in the Savanes region of Togo

This result is consistent with the findings of [9]. That study also attributed the main hydrogeochemical process responsible for mineralisation in the waters of the Volta Basin in northern Togo to water–rock interactions. Using binary diagrams based on the $HCO_3$/Na–Ca/Na and [Ca + Mg]– [$HCO_3$ + $SO_4$] ratios, the influence of the weathering of dominant minerals in local rocks was demonstrated.

Mineral alteration processes play a key role in this mineralisation. These include the weathering of albite and anorthite, among others, as illustrated by the following reactions:

**Albite:**

$2NaAlSi_3O_8 + 2CO_2 + 11H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4H_4SiO_4$

**Anorthite:**

$CaAlSi_2O_8 + 8H_2O \rightarrow Ca^{2+} + Al(OH)_4^- + 2H_4SiO_4$

**Diopside** in ultrabasic magmatic rocks:

$CaMgSi_2O_6 + 4H+ + 2H_2O \rightarrow Ca^{2+} + Mg^{2+} + 2H_4SiO_4$

These alteration processes are most pronounced in basement formations. However, in clay formations and certain sandstone units, minerals such as illite and kaolinite undergo weathering, releasing chemical species according to the following reactions:

**Illite:**

$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2 + 11H_2O \rightarrow 0.6K^+ + 0.25Mg^{2+} + 2.3Al(OH)_4^- + 3.5H_4SiO_4 + 1.2H^+$

The work of [5] on the Birrimian basement in northern Togo further highlighted the ion-exchange relationships among major ions in groundwater by examining their saturation indices. This study attributed the fundamental ion-exchange processes to the dissolution of local minerals, particularly plagioclase minerals such as albite and anorthite.

In silicate and carbonate formations, the dissolution of calcite and aragonite is evident, following the reaction:

$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$.

Magnesite: $MgCO3 \rightarrow Mg^{2+} + CO_3^{2-}$

In addition to these reactions, evaporation contributes to an increase in the concentration of certain ions in solution. Precipitation, on the other hand, introduces elements into groundwater that often originate from human activities.

However, analyses of mineralisation processes in the waters of southern Togo and the basement aquifers of the Kara Basin conducted respectively by [10] and [11] revealed that, although water–rock interaction remains the dominant process, groundwater is also enriched through anthropogenic inputs and, to a lesser extent, through evaporation.

In view of all these processes involved in mineralisation, the next step of the study focuses on the study of hydrogeochemical signature of the waters associated with each type of reservoir or geological formation. Thus, displaying water samples on the Piper diagram according to lithology has made it possible to identify some hydrogeochemical facies in the area. As facies, there are facies such as: The bicarbonate-calcium-magnesium facies characterised by a predominance of calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$) and bicarbonate ($HCO_3^-$) ions and characteristic of the waters of the Birrimian basement aquifers. Bicarbonate-sodium-potassium facies, this facies shows a predominance of sodium ($Na^+$), potassium ($K^+$) and bicarbonate ($HCO_3^-$) ions, characteristic of claystone formations and silexites-carbonate formations. The bicarbonate-chloride-potassium and sodium facies, a facies with a mixed composition of sodium, potassium, chloride ($Cl^-$) and bicarbonate, characteristic of sandstone formations. Sulphate-chloride-sodium facies with a predominance of chloride, sodium and sulphate ($SO_4^{2-}$) ions characterising waters originating from lateritic cuirasses. Bicarbonate-calcium-sodium facies, mainly composed of calcium, sodium and bicarbonate, are dominant in water samples from alluvial deposits. All these types of water are represented on the Piper diagram in Figure 4 below.

The HCO3-Na-K and HCO3-Ca-Mg facies, characteristic of basement waters, have been found in previous studies, [5], while the waters of the Volta basin are attributed to the sodium bicarbonate (Na-HCO3) facies and evolving facies such as Ca-Na-Mg-HCO3 and Ca-HCO3. All these results corroborate the studies conducted by [9] on the southern Togo basin and [10] on the Kara basin in northern Togo.

This analysis of the Piper diagram enabled the creation of spatialisation maps of the major elements identified in the water analysis.

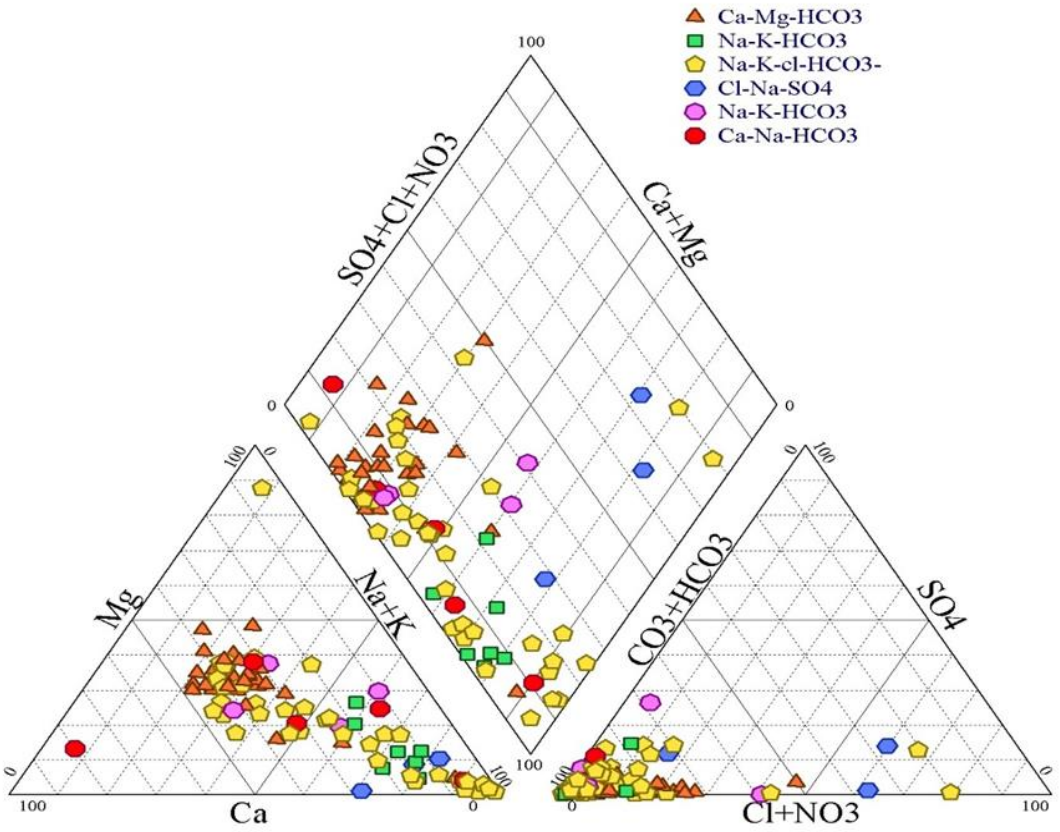


Figure 4:Piper diagram showing the different types of water according to lithology

Figure 5 shows the spatial distribution of major cations of the area. The Barremian basement formations in the extreme north-west have a low cation content, With a predominance of magnesium ions ($Mg^{2+}$) in the water from the area. The sandstone and claystones formations, on the other hand, appear to be homogeneous, with contents ranging from low to medium, except for some isolated points. For example, high $Ca^{2+}$, $Na^{+}$ to medium concentrations can be found in the sandstone formations and at the level of the triad, probably because of the dissolution of carbonates and triadic mudstones. High $K^{+}$ concentrations are found in towns such as Dapaong and Mango, suggesting an anthropic origin, probably due to agricultural and livestock activities in the area. This spatial distribution gives groundwater from sandstone and clay formations a medium to high content of major cations.

Figure 6 shows the distribution of major anions associated with the spatialisation of pH and water conductivity in the region. As in the case of the major cations, the anions (carbonates, bicarbonates and chlorides) have very low concentrations in the extreme north-west, which corresponds to the formations of the Birrimian basement. High concentrations are found in the sedimentary formations of the Volta basin (sandstone and claystone's). There is a high concentration of bicarbonates and chlorides in the triages and in the contact zone between the Gando sandstone and the Mango mudstone. As this is an alluvial rice-growing area, this high concentration would be accentuated by the effects of the use of pesticides and chemical fertilisers [5].

The spatial distribution of pH shows that the waters of the basement formations are acidic to neutral with very low conductivity, while the waters of the sandstone, claystone, cuirass, alluvial and flint formations have a pH ranging from neutral to slightly alkaline with medium to high conductivity. The most common water pH levels are between 6.5 and 8; other pH values are exceptions. The most dominant conductivity frequencies are between 400 and 800 µs/cm.

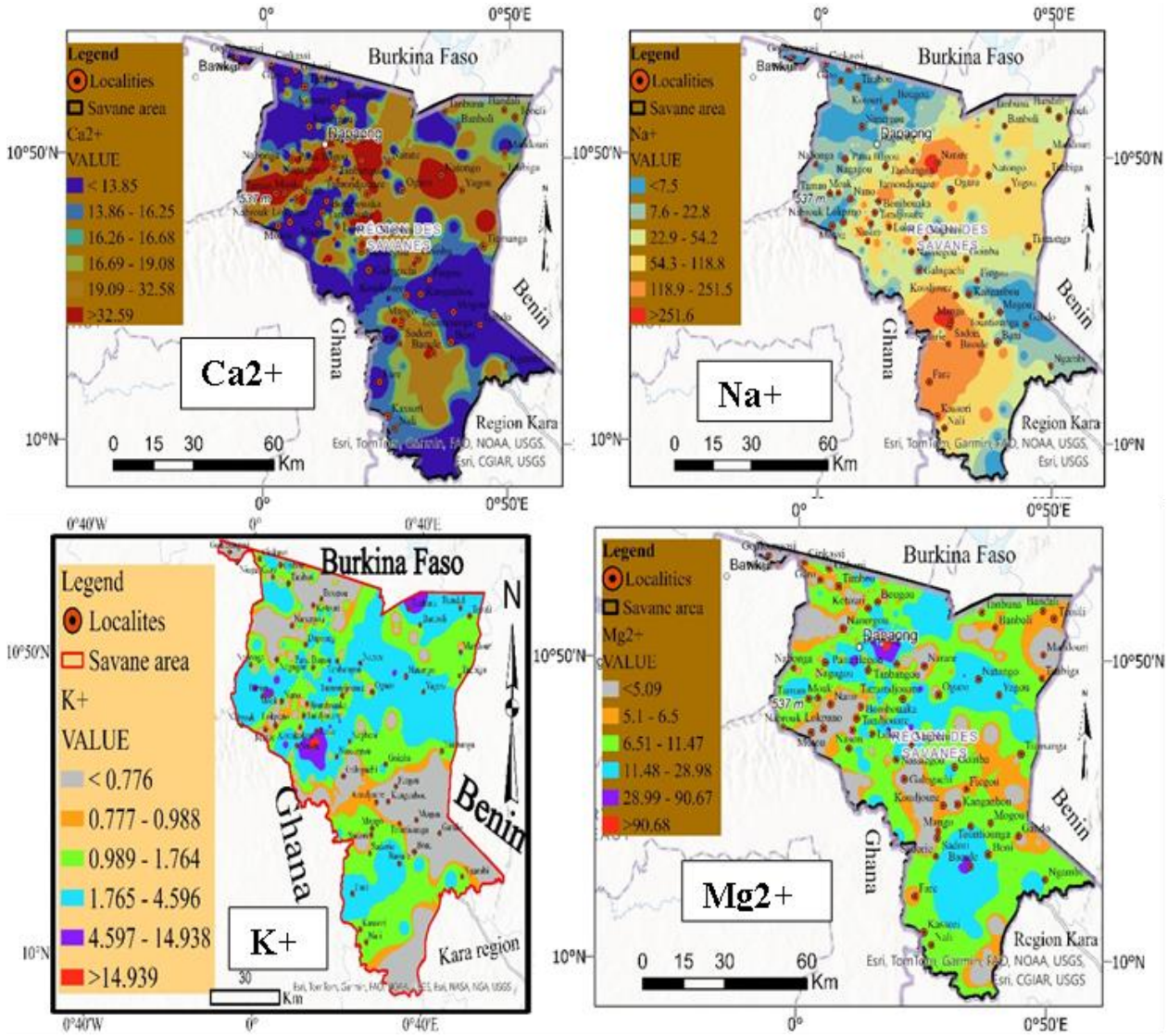


Figure 5: Map showing the spatial distribution of major cations ($Ca^{2+}$, $K^{+}$, $Mg^{2+}$, $Na^{+}$)

A final spatialisation map was produced for silicon compared to alkalinity found in water samples, as shown in Figure 7 below. Silicon, for its part, appears to be more abundant in groundwater from basement formations, where concentrations often exceed 50 mg/L. In the extreme south of the region, silicon concentrations are moderate, likely due to the onset of slight metamorphism and the precipitation of new quartz during the emplacement of sedimentary infill. The lowest silicon levels occur in claystone and alluvial zones. However, the water from basement formations shows very low alkalinity, while samples from other geological formations display moderate to high alkalinity levels. This contrast can be attributed to the much higher concentrations of major cations and anions in these formations compared with those in the crystalline basement rocks.

The final stage of the analysis focused on assessing the potability of the groundwater using first of all the water quality index Methode for drinking water and sodium percentage plus the alkalinity hazard. Water quality sub-indexs for some elements measured are showing in the table 2. Some of the parameters are not taken into account due to the lack of precise standard values. The different elements taken into account in this calculation are: pH, TDS, $Ca^{2+}$, $Mg^{2+}$, $Cl^{-}$, $SO_4^{2-}$, $NO_3^{-}$, $NH_4$, Fe, TH and Cond.

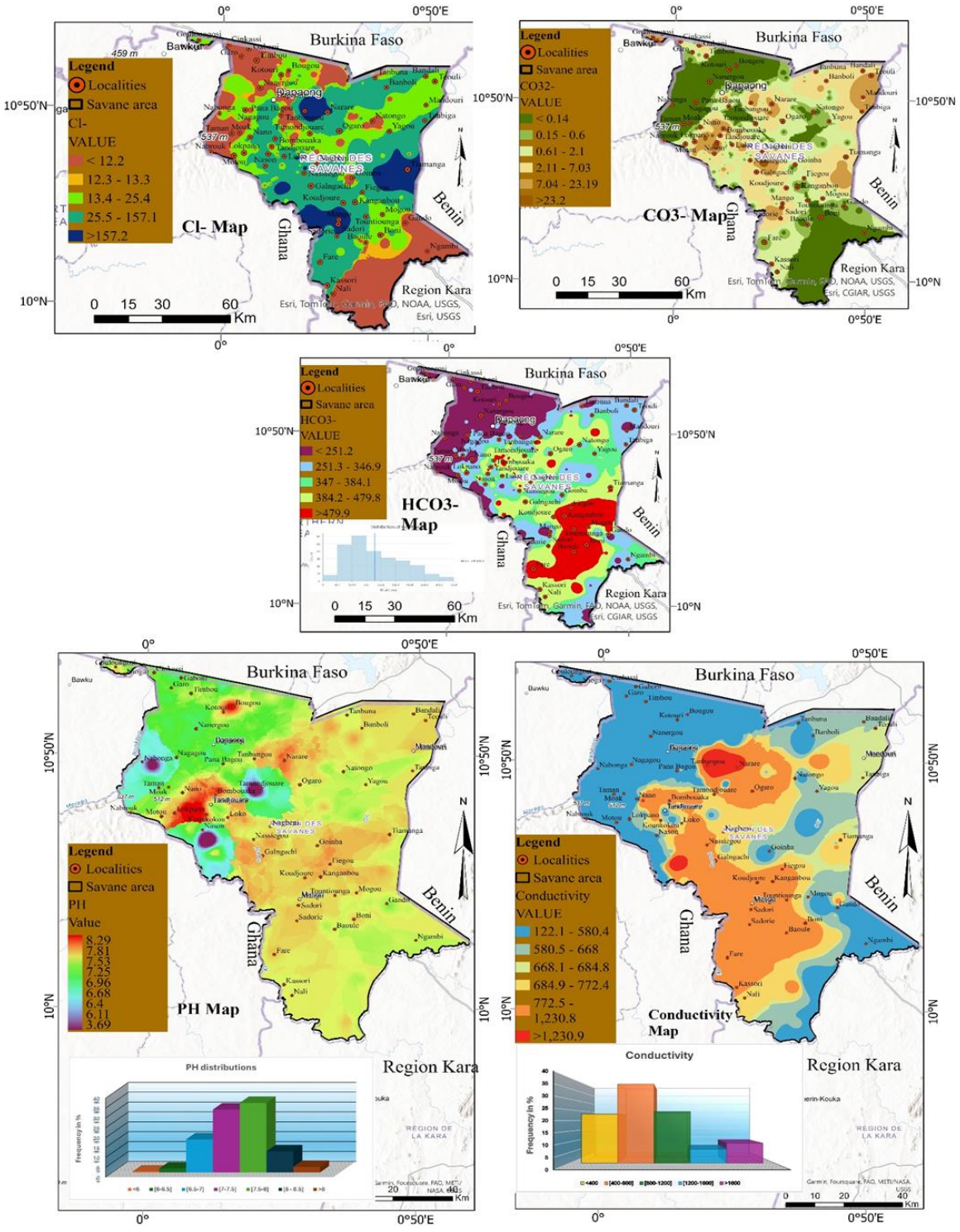


Figure 6: Map showing the spatial distribution of major anions ($Cl^-$, $SO_4^{2-}$, $HCO_3^-$) plus PH and Conductivity

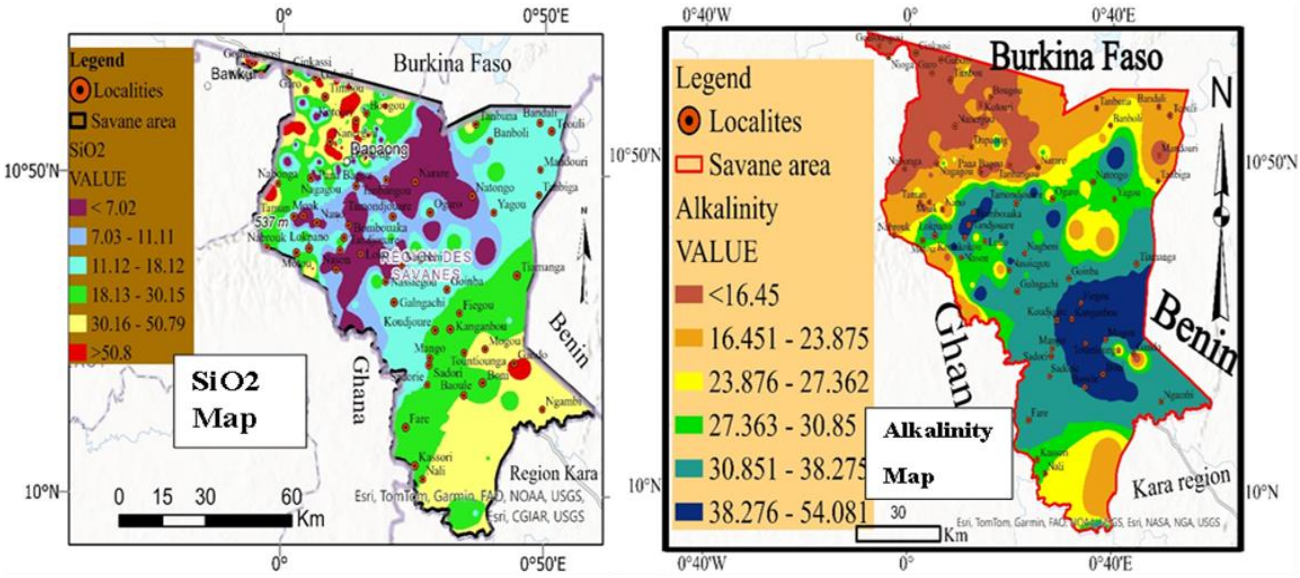


Figure 7: Silicium spatialisation map compare to alkalinity map

Table 3: Table showing the quality indices for each element contained in the water taken into account

| Parameters | Measured Value (Ci) | Standard Limit (Si) | Quality Rating (Qi) | Normalized weight (Wi*) | Sub-Index (SIi = Wi* Qi) |
|---|---|---|---|---|---|
| PH | 7.26 | 8.5 | 17.333 | 0.1142857 | 1.980 |
| Total Dissolved Solids (mg/L) | 423.36 | 1000 | 42.336 | 0.114285714 | 4.838 |
| Calcium (mg/L) | 26.04 | 75 | 34.72 | 0.057142857 | 1.984 |
| Magnesium (mg/L) | 16.831 | 50 | 33.662 | 0.057142857 | 1.923 |
| Chloride (mg/L) | 27.03 | 250 | 10.812 | 0.085714286 | 0.9267 |
| Sulphate (mg/L) | 11.9846 | 500 | 4.793 | 0.057142857 | 0.274 |
| Nitrate (mg/L as NO3-) | 5.83 | 50 | 11.66 | 0.142857143 | 1.665 |
| Amoniac NH4 (mg/L | 0.10348 | 0.5 | 20.69 | 0.114285714 | 2.365 |
| Fer (Fe mg/L) | 0.179 | 0.3 | 59.728 | 0.142857143 | 8.532 |

The water quality index value for the area is 24.49, which falls between [0 and 25], corresponding excellent to good quality water for consumption. However, some samples have high nitrate and iron content and are often not recommended for consumption.

Figures (a) and (b) in Figure 8 illustrate these assessments. The results show that most of the water samples are of excellent quality, with only a few exhibiting very high sodium percentages and correspondingly high alkalinity hazards.

Overall, more than 70% of the water samples are of excellent quality, 25% fall into the good to acceptable category, and about 5% are of poor quality mainly originating from sandstone formations. Most groundwater from crystalline basement aquifers is of excellent quality, whereas water from claystone and lateritic cuirass formations is generally of lower quality but still suitable for consumption and irrigation. These findings are consistent with those reported for the same region by [5] (Figure 8). Based on this analysis these figures, it is conclusive that most of the water is suitable for irrigations.

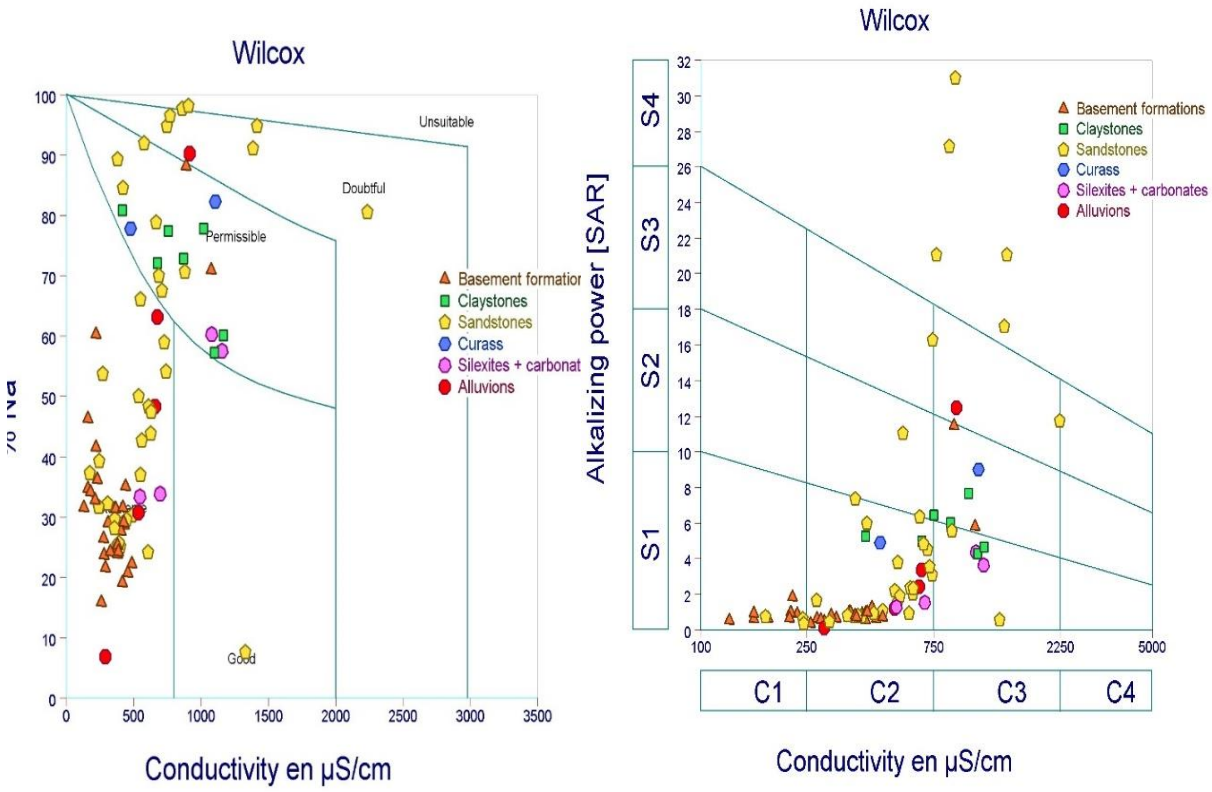


Figure 8: Wilcox diagrams indicating water quality by means of sodium percentage and alkalising power

## CONCLUSION

Based on the various results, the analysis indicates that the processes responsible for the mineralisation of the region's waters are mainly linked to water–rock interactions. These processes primarily involve the dissolution of sulphate minerals (plagioclase, clays, etc.) as a result of weathering and erosion. Additional contributors, such as human activities and evaporation, also play a role in the overall mineralisation.

These mineralisation mechanisms help characterise the different water types associated with each aquifer formation. Thus, magnesium–bicarbonate waters dominate within the crystalline bedrock formations, while sodium–bicarbonate and chloride waters are more typical of claystones, alluvial deposits, and similar units.

The spatial distribution of the major ions reveals low alkalinity in the crystalline basement aquifers, with magnesium ions predominating. Similarly, low concentrations of anions ($Cl^-$, $HCO_3^-$, $SO_4^{2-}$) were observed. As a result, the waters of the crystalline basement are generally acidic to neutral in pH, with conductivities ranging from 122 to 550 µS/cm, lower than those recorded in other formations.

In contrast, silicon is highly concentrated in the crystalline bedrock, sometimes exceeding 50 mg/L. It is moderately elevated in some sandstone formations but almost absent in others.

The calculated Water Quality Index (WQI) value for the area (24.49) indicates that the water is excellent for drinking purposes. Furthermore, the distribution of sodium percentage and the water's alkalinity suggest that it is also suitable for irrigation.

To ensure long-term sustainability, regular water quality monitoring should be implemented to track the chemical evolution of the resource and minimise contamination risks. Additionally, a vulnerability assessment should be conducted to identify potential pollution sources and support effective protection and sustainable management of the aquifers.

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# HIDROGEOHEMIJSKA ANALIZA I PROCESI MINERALIZACIJE PODZEMNIH VODA U REGIONU SAVANA NA SEVERU TOGA

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Rezime

Kao odgovor na izazove povezane sa kvalitetom pijaće vode u regiji Savane na severu Toga, sprovedena je detaljna hidrogeokemijska studija radi rešavanja rastuće potražnje za sigurnom podzemnom vodom. Studija je fokusirana na analizu glavnih kationa i aniona koji definišu hidrogeokemijski potpis vode. Prvobitna procena mineralizacijskih procesa ukazala je da je interakcija vode i stena dominantni mehanizam koji utiče na hemijski sastav podzemnih voda. Analiza tvrdoće vode pokazala je da većina uzoraka pripada kategoriji "blago tvrda". Ovi elementi potiču iz rastvaranja određenih silikatnih minerala kao što su plagioklazi (abcit, anortit, itd.), micas i određeni glineni minerali (illit, kaolinit, smektit, itd.). Korišćenjem Dijagrama Pipa identifikovane su različite hemijske vrste vode i njihova veza sa litologijom odgovarajućih akvifera. Između ostalog, mogu se izdvojiti: facije bikarbonat–kalcijum–magnezijum u bazaltnim akviferima, facije bikarbonat–natrijum–kalijum za glineno, siletno i karbonatno formacije, facije bikarbonat–hlorid–kalijum/natrijum u peskuljasto kamenim slojevima, te bikarbonat–kalcijum–natrijum za sve aluvijalne slojeve… Prostorne mape distribucije glavnih jona pokazale su zone dominacije svakog jona. Mape su otkrile da je dominacija magnezijuma i silike prisutna u podzemnim vodama iz bazaltnog sloja, dok su joni Na+, $Ca^{2+}$, $Cl^{-}$, $HCO_3^-$ i $SO_4^{2-}$ češći u podzemnim vodama iz drugih geoloških jedinica. Na kraju, procena kakvoće vode prema WQI za piće namene prikazuje dobar kvalitet (WQI=24,49) za sve uzorke na području. Za namenu za navodnjavanje, procena odstoja natrijuma i alkalne snage pokazala je da je većina uzoraka vode od vrhunskog kvaliteta, uz nekoliko izuzetaka.

Ključne reči: sever Toga, region Savana, kontakt voda-stena, rastvaranje minerala, hidrogeohemijske analize