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LITHOSTRATIGRAPHYAND HYDROGEOLOGY OF GWANDU FORMATION EXPOSED ON GULMA HILL NEAR ARGUNGU NORTHWESTERN NIGERIA

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ABSTRACT

Geological field mapping was carried out on the exposure of Gwandu Formation around Gulma Hill near Gulma village in the Sokoto sector of the Iullemmeden Basin to elucidate more on the interaction between rock types and their water source. Basic lithological characteristics including bed thicknesses, textural features, sedimentary structures, biogenic structures, and structural features were described. One lithostratigraphic section and a geological map were produced. Hydrogeochemical investigation was carried out in eight different locations in Gulma village near Argungu, northwestern Nigeria in order to determine the level of groundwater contamination. Eight groundwater samples were collected from the study area with their physico-chemical parameters such as electrical conductivity (EC), total dissolved solid (TDS), potential of hydrogen (pH), and temperature measured in situ. Both chemical and heavy metal analyses for the samples were conducted through the use of AAS machine. The results were used to plot the Schoeller and Piper diagrams which shows the dominant water type in the study area to be Ca-Mg-HCO_3 type. The concentration of the analyzed metals in the study area shows that, $Na^{2+}$and $NO_3^{-,}$ have values that are within WHO (2022) safe limit, while Ni^{2+} is within the NSDWQ (2015) safe limit, physical parameters like TDS, and EC values fall within the NSDWQ (2015) safe limit. pH of some water sample fell below the recommended NSDWQ (2015) safe limit whereas pH of water samples from some areas are within the NSDWQ (2015) safe limits. However, $Mg^{2+}$and Pb^{2+} have values above the NSDWQ (2015) recommended safe limits which suggest that the water could predispose consumers to health hazards..Standard procedures are highly recommended to remediate $Mg^{2+}$and Pb^{2+}in drinking water in the study areas.

KEYWORDS: Lithostratigraphic, water facies, Gulma Hill, northwestern Nigeria

INTRODUCTION

Because of unplanned development and the fast growth of the population, surface and groundwater quality has emerged as a significant concern for water resources. Water chemistry can have negative consequences if essential components are missing or, more frequently, if there is an overabundance of a dangerous molecule present. Particularly in rural areas that directly use these resources, highly toxic metals like nickel, cadmium, lead, arsenic, and mercury have been identified as hazardous surface and groundwater contaminants which provide serious health hazards. Safe drinking water is a basic need for good health, and it is also a basic right of humans (Yirdaw and Bamlaku, 2016).

Improved water supply is one of the essentials for a healthy lifestyle, constrained by uncontrolled anthropogenic activities (Chen, et al., 2016, Chitsazan, et al., 2019), flow of pollution from upland to lowland, too much use of fertilizers, pesticides in agriculture (Joarder, et. al., 2008).

Notable earlier researchers on the hydrogeology of the study area include: (Raeburn and Tattam, 1930, Anderson and Ogilbee, 1965, Oteze, 1976,Adelana and Olasehinde, 2003, Alagbe, 2006,Kwaya, et. al., 2020,Wali, et. al., 2020, Abdulganiyu, et. al., 2023, and Abdulganiyu, et. al., 2024). Oteze (1976) noted that the shallow and cavernous Kalambaina aquifer is easily contaminated by human and animal wastes. However, Wali et al.

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(2020) found that the physicochemical characteristics of the water quality and the mineral facies of the rock weathering of the Illo and Gwandu formations differ significantly.

This study set out to ascertain the geology and groundwater quality of Gulma Village in order to ascertain how the groundwater interacted with the geology using physicochemical characteristics and heavy metal contamination, as well as how it could be used for agricultural and residential purposes.

GEOLOGY OF THE STUDY AREA

Various authors, like (Jones, 1948); (Parker, 1965)]; (Faure, 1966)]; (Kogbe, 1979); (Abdulganiyu. 2021), (Ola-Buraimo, 2022); (Abdulganiyu et al, 2023) and others studied the Cretaceous and Paleogene sediments of the Sokoto Basin. These authors proposed several geological successions.

1. The Illo and Gundumi Formations are composed of grits and clays, which were deposited unconformably on the Pre-Cambrian Basement.
2. The Maastrichtian Rima Group rests unconformably on the Illo and Gundumi Formations. The group consists of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the fossiliferous Dukamaje Formation.
3. The Paleocene Sokoto Group consists of the Dange and Gamba Formations (mainly shale) and is separated by the calcareous Kalambaina Formation.
4. The Post-Paleocene Continental Terminal, which is the Gwandu Formation, occurs as tabular hills or low hummocks over the dip slope of the Paleocene Formation. The study area is predominantly of the Gwandu Formation

Detailed geological field mapping was carried out on the exposure of Gwandu Formation stretching across Gulma village in the Sokoto sector of the Iullemmeden Basin. It covers Sheet 27 Lema southeast (see inset on Fig. 1) situated between latitudes 12° 40' 00" and 12° 37' 00" N and longitudes 4° 20' 00" and 4° 23′ 00" E where outcrops were identified and studied. The area is accessible through the Makera-Sauwa-Gulma road and also through the Birnin Kebbi-Argungu - Gulma road with numerous footpaths, untarred roads, and cattle tracts. The biggest and most populous settlement in the study area is Gulma, surrounded by a large number of satellite villages like: Tunga Zazagawa, Tunga Lawa, and Sauwa. The bulk of people in the area are Fulani and Hausa. Agribusiness and livestock farming are the two-primary occupation in the study area. Crops grown in the area include; millets, Guinea corn, and maize are produced. Onions, garlic, tomatoes, peppers, groundnuts, and vegetables during the dry season in the villages' extensive fadama land.

Drainage and Relief Physiographic relief in the study area include distinctive flat-topped hills like the Tunga Zazagawa Hill (12 m) and Gulma Hill (35.33 m) which form watershed flowing southward into Rima River around Argungu town. The Rima River, which flows south to join the River Niger, dominates the drainage system of the "Sokoto Basin" (Adelana and Olaseinde, 2003). The Rima River is the Sokoto River's principal tributary and both rivers flow over expansive floodplains with countless channels that are bordered by gentle slopes that blend into the surrounding plain.

MATERIAL AND METHODS

Suitable field instruments such as the plastic bottles, for collecting rock and water samples, GPS, compass clinometer, TDS Meter, pH and Temperature meter, and Electrical conductivity (EC) meter were used in the field. Basic lithological characteristics including bed thicknesses, textural features, sedimentary structures, biogenic structures, and structural features were recorded. 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. CorelDraw software was used in producing lithologic logs from the well exposed outcrops and field photographs of outcrops were also taken. One lithostratigraphic section and a geological map sections were produced using CorelDraw software Fig. 4.

Different sources of water supply in the areas such as borehole (2) and hand-dug wells (6) serve as sources of collecting water samples for geochemical analysis. At each location two (2) samples were collected making a total of sixteen (16) samples collected from the study area and subjected to laboratory analyses with the average mean values determined. The APHA, (2018) criteria were followed for sampling, handling and analysis. Prior to the sampling, the containers were rinsed with water from which the samples were to be collected; in order to get representative samples, direct from the aquifer. Water was pumped out using a water drawer from the different groundwater sources for at least 10 –15 minutes. Two samples were collected from each of the sampling points, in one sample from which the cations were to be analyzed and few drops of 1.1 molar HNO_3 was added to reduce the precipitation of some metals by reducing the pH of the water to 2. Physical parameters of electrical conductivity (EC), total dissolved solids (TDS) pH, and temperature were measured in-situ at the sampling points using a handheld 3-in-1 conductivity and pH meters, respectively. Samples were stored at a very low temperature of 4^oC (ISO, 2006). The samples were taken to the multi-user laboratory of Umaru Musa Yara'adua University, Katsina, where they were processed and analyzed for major and minor cations, anions, and oxides using an atomic absorption spectrometer (AAS model AA 6300 SHIMADZU Japan). The Piper and Schoeller plots were employed through the hydrochem computer software for the samples to know the water types and the level of contamination and relative concentration of the anions and cations in the study area.

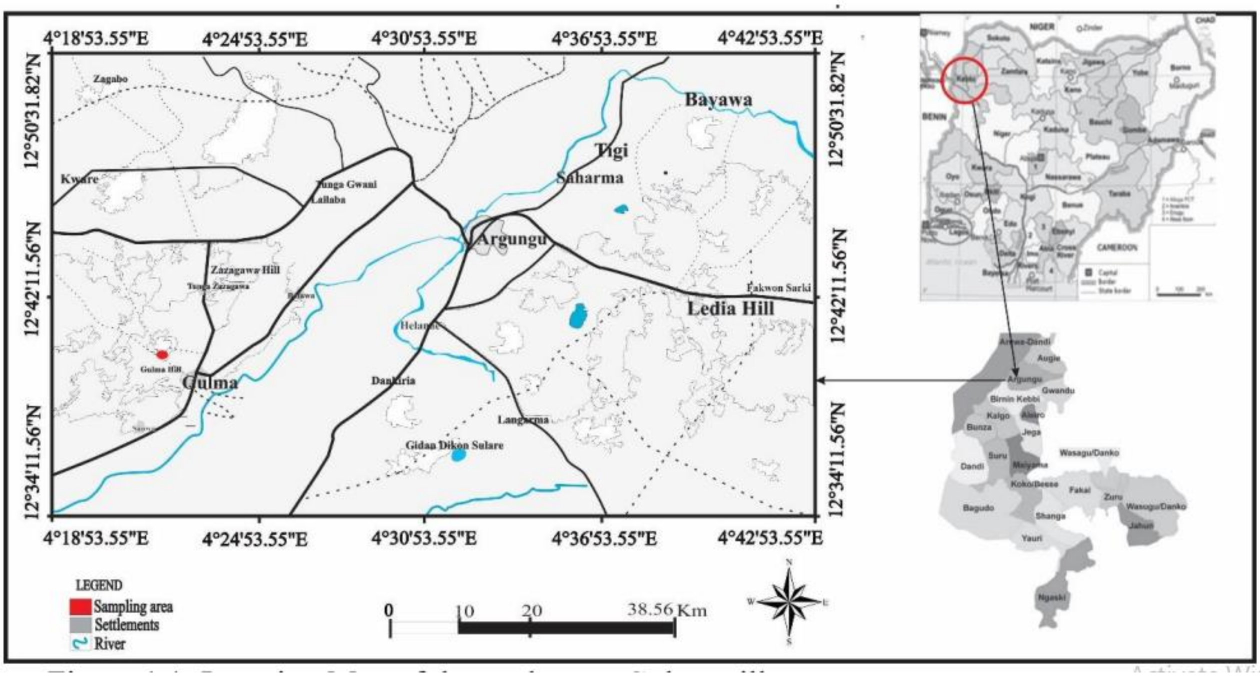

Figure 1: Location map of the study area

RESULTS AND DISCUSSION

The study area is located Sheet 27 Lema southwest, northwestern Nigeria and is composed of composed of sandstone, Kaolinitic clay and ironstone belonging to Gwandu Formation (Figure 2).

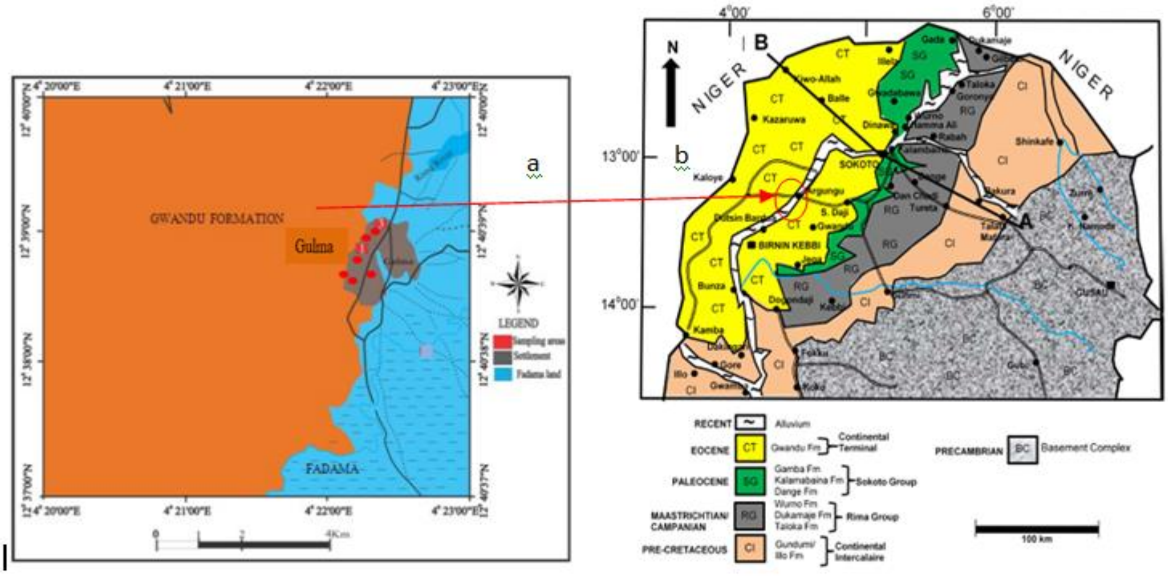

Figure 2: (a) Geological map of the study area. (b) Generalized geological map of the Nigerian sector of Iullemmeden Basin (Sokoto Basin) showing the study area in red.

Description of the Lithostratigraphic Section

Exposure of the Gwandu Formation on Gulma Hill near Gulma village was logged. It has a total thickness of 35.33 m with the lowermost portion composed of bioturbated siltyclay of 1.5 m thick. It is mottled and variegated in places displaying (yellow, white, milky, and pinkish in color). This is overlain by 2.2 m thick Kaolinitic clay with loadcasts of fine sandstone. It is fractured I places and slurry when wet but gritty when gnawed. It displays a variegated color ranging from white to yellow to pink due to differential iron concentration. This in turn is overlain by 0.76 m thick ferruginous silty clay which is variably bioturbated and laminated in places.

It is blocky with branching bioturbation. Above this is a 1.77 m Kaolinitic clay bed, which is well bioturbated and displaying lamination. It is variably bioturbated with fracture. This is overlain by fractured silty clay2.0 m with bioturbation and loadcasts. Overlying this bed is a finely laminated bioturbated and massively bedded sandstone with a thickness of 2.8 m. Overlain by fine, non-laminated sandstone of 2.0 mm thickness. Above this lies a 1.8 m thick ferruginized Kaolinitic clay on which lies a3.5 m Kaolinitic clay bed which is variegated due to differential ironoxide concentration. It is grey in color with branching bioturbation and fractured in places. This is overlain by pink-white, fine sandstone which is fractured, with a thickness of 2.0 m. It is overlain by brown fine sandstone, which is bioturbated in some parts and shows differential ironoxide concentration with a thickness of 4.0 m. This in turn is overlain by ferruginized clay which is slurry when wet. It is dark brown in color, showing high ironoxide concentration with a thickness of 8.0 m. This is overlain by 1.0 m thick Kaolinitic clay above which lies a 1.0 m lateritic ironstone.

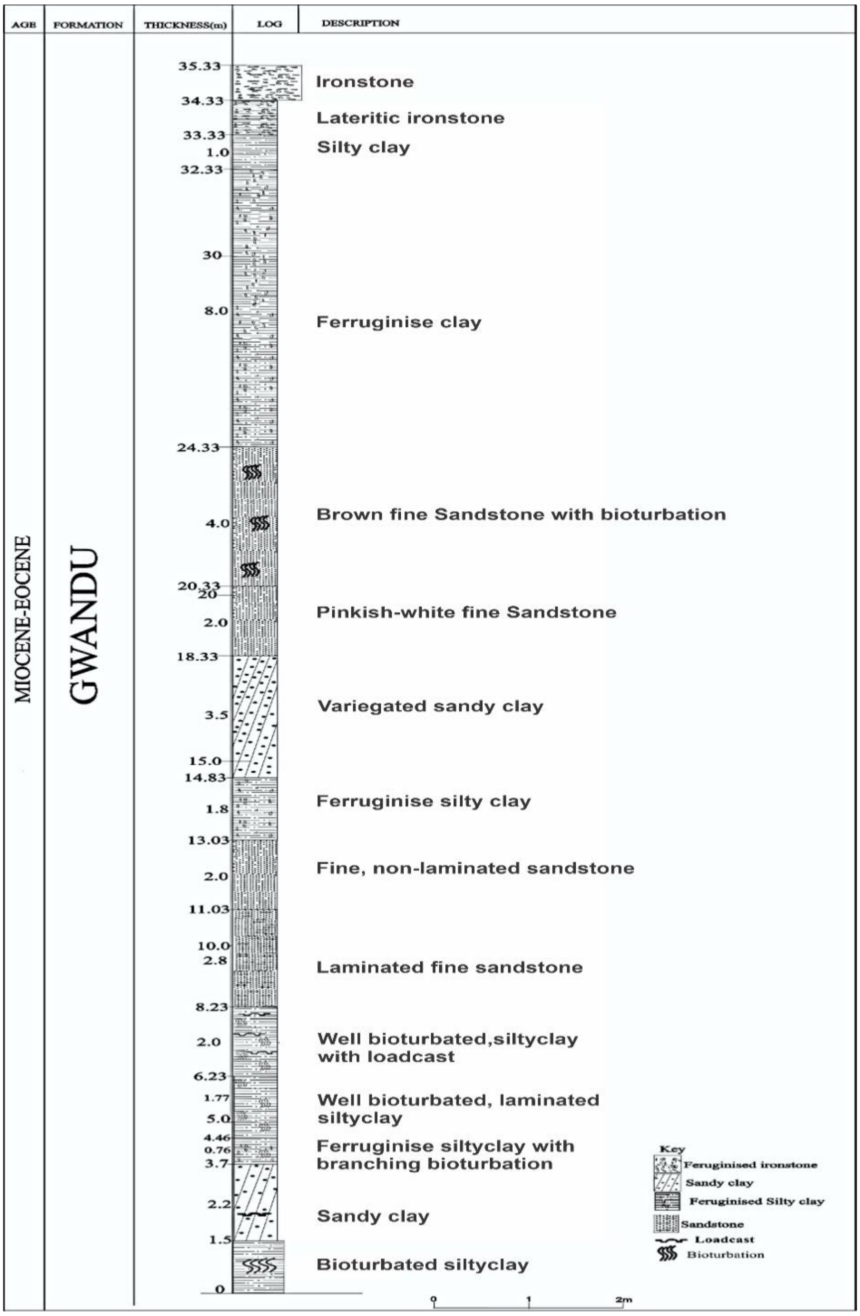

Figure 3: Exposed lithostratigraphic section of Gwandu Formation on Gulma Hill near Gulma village (12° 40′00" and 12° 37'00" N and 4° 20′00" and4° 23'00"E).

Sedimentary structures observed in the study area include: Loadcasts, parallel lamination and bioturbation. Structures that are produced at the time as the sedimentary rock in which they occurred as primary sedimentary structures. Sedimentary structures that are produced after deposition of sediments, subjected to compaction and tectonics are referred to as secondary sedimentary structures such secondary structures present include fractures and joints,.

Sedimentary structures observed in the study area include:

Bioturbation

These are burrowed structures formed as a result of burrowing activities and other forms of activity such as trails and tracks that may indicate feeding, movement, and the dwelling habits of the organism that lived in the environment. The bioturbation is branched, horizontal, and vertical. The vertical axis indicates movement in the organizing process, while the horizontal axis is for dwelling.

Plate 1: Bioturbation and Parallel lamination on fine sandstone near Gulma village (12° 40′ 00" and 4° 20′ 00" E).

Lamination

This is a small-scale sequence of fine layers that occurs in sedimentary rocks and is less than 1cm thick. Lamination consists of small differences in the type of sediment that occurs throughout the rock. They are caused by cyclic changes in the supply of sediment. These changes can occur in grain size, clay percentage, microfossil content, organic material content, or mineral content, and often result in a pronounced difference in color between the laminae. Lamination can occur as parallel structures (parallel lamination) Plate 1 or different sets that make an angle with each other (cross lamination).

Parallel lamination was as illustrated in Plate 1 above has an alternation of purple and milky-colored bands. The purple color is due to differential ironoxide concentration. It occurs at the waning stage of deposition, when the energy of the depositing medium reduces and fine materials are been deposited in lamina.

Loadcasts

Are bulges, lumps, and lobes that can form on the bedding planes that separate the layers of sedimentary rocks. The lumps hang down from the upper layer into the lower layer. These features form during soft-sediment deformation shortly after sediment burial, before the sediments is lithified.

Plate 2: Loadcast on kaolinitic clay near Gulma village (12° 39′ 1" N and 4° 21′ 7" E)

HYDROGEOCHEMISTRY OF GROUNDWATER OF THE STUDY AREA

Physical parameters, major and minor elements and oxides) are displayed in the Tables1, 2, and 3.

Table 1: Physical parameters of water samples obtained in the study area

	Mean ± SD		
Sample	**PH**	**TDS**	**EC**
Gulma 1	5.93 ± 0.212	172 ± 21.733	344 ± 57.167
Gulma 2	6.41 ± 0.030	137 ± 8.504	278 ± 32.221
Gulma 3	6.49 ± 0.000	73 ± 15.686	144 ± 18.426
Gulma 4	7.65 ± 0.438	155 ± 15.308	316 ± 46.584
Gulma 5	6.94 ± 0.170	79 ± 13.418	158 ± 50.931
Gulma 6	5.90 ± 0.223	31 ± 31.560	64 ± 48.663
Gulma 7	5.82 ± 0.253	96 ± 6.992	192 ± 0.2835
Gulma 8	6.80 ± 0.117	173 ± 22.111	346 ± 17.669
Max	7.65	173	344
Min	5.82	31	58
SEM±	0.628	52.334	109.955
(WHO,2022)	6.50-9.50	500mg/l	250µs/cm
(NSDWQ, 2015)	4.54	500mg/l	250µs/cm

Table 2: Chemical parameters (mg/l) of water samples obtained in the study area

			Mean ± SD						
Sample	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Na^{2+}**	**HCO_3^{-}**	**Cl^{-}**	**NH_4^{+}**	**NO_3^{-}**	**PO_4^{2-}**
Gulma 1	40 ± 1.512	48 ± 22.583	2 ± 0.472	3 ± 0.047	32 ± 2.457	4.3 ± 0.000	1.0 ± 0.019	8.6 ± 1.947	0.05 ± 0.008
Gulma 2	34 ± 0.756	64 ± 16.687	1 ± 0.850	1 ± 0.803	0 ± 14.552	0.0 1.625	0.6 ± 0.171	2.2 ± 0.472	0.06 ± 0.004
Gulma 3	30 ± 2.268	170 ± 23.679	2 ± 0.472	1 ± 0.803	60 ± 8.126	4.3 ± 0.000	0.8 ± 0.091	1.0 ± 0.926	0.08 ± 0.003
Gulma 4	48 ± 4.536	5 ± 38.911	4 ± 0.283	4 ± 0.331	68 ± 11.150	4.3 ± 0.000	1.8 ± 0.283	1.0 ± 0.926	0.08 ± 0.003
Gulma 5	36 ± 0.000	146 ± 14.533	2 ± 0.472	4 ± 0.331	48 ± 3.591	5.0 ± 0.265	1.2 ± 0.056	2.8 ± 0.246	0.08 ± 0.003
Gulma 6	40 ± 1.512	87 ± 7.843	8 ± 1.795	5 ± 0.709	40 ± 0.567	7.6 ± 1.247	1.0 ± 0.019	9.0 ± 2.098	0.07 ± 0.000
Gulma 7	30 ± 2.268	144 ± 13.701	6 ± 1.039	3 ± 0.047	30 ± 3.213	4.2 ± 0.038	1.0 ± 0.019	2.0 ± 0.548	0.08 ± 0.003
Gulma 8	30 ± 2.268	198 ± 34.111	1 ± 0.850	4 ± 0.331	30 ± 3.213	4.7 ± 0.151	1.0 ± 0.019	1.0 ± 0.926	0.07 ±0.000
Max	48	198	8	5	68	7.6	1.8	9	0.08
Min	30	5	1	1	0	4.2	0.6	1	0.05
SEM±	6.414	66.987	2.550	1.458	21.024	2.072	0.350	3.368	0.011
(WHO,2022)	75mg/l	150mg/l	120mg/l	200mg/l	125-350	250mg/l	-	10mg/l	6.5-8.5
(NSDWQ, 2015)	75mg/l	120mg/l	150mg/l	-	100mg/l	250mg/l	50mg/l	50mg/l	-

Table 3: Heavy metals contents in water samples obtained in Gulma

	Mean ± SD			
Sample	**Cd^{2+} (mg/l)**	**Pb^{2+} (mg/l)**	**Mn^{2+} (mg/l)**	**Ni^{2+} (mg/l)**
Gulma 1	0.026 ± 0.001	0.010 ± 0.028	0.431 ± 0.117	0.049 ± 0.007
Gulma 2	0.026 ± 0.001	0.010 ± 0.028	0.289 ± 0.064	0.029 ± 0.001
Gulma 3	0.025 ± 0.000	0.030 ± 0.021	0.026 ± 0.036	0.011 ± 0.008
Gulma 4	0.023 ± 0.001	0.050 ± 0.013	-0.005 ± 0.047	0.013 ± 0.007
Gulma 5	0.025 ± 0.000	0.460 ± 0.142	0.007 ± 0.043	0.054 ± 0.008
Gulma 6	0.024 ± 0.000	0.040 ± 0.017	0.168 ± 0.018	0.059 ± 0.010
Gulma 7	0.023 ± 0.001	0.040 ± 0.017	0.017 ± 0.039	0.045 ± 0.005
Gulma 8	0.023 ± 0.001	0.040 ± 0.017	0.028 ± 0.035	-0.006 ± 0.014
Max	0.026	0.46	0.431	0.059
Min	0.023	0.01	0.007	0
SEM±	0.001	0.152	0.162	0.024
(WHO,2022)	0.003	0.010	0.400	0.020
(NSDWQ, 2015)	0.014	0.223	0.356	0.091

The dominant water type in the study area as indicated in the Piper is Ca+Mg-HCO_3 Figure 4water while the Schoeller plot Figure 5 indicate the level of contamination and relative concentration of the anions and cations in the samples from study area depicting a shallow fresh groundwater that is slightly hard. The water may be is associated with the underlying limestone and carbonate hardness from recent precipitation occurring at shallow depths below the surface. Ca+Mg-HCO_3 is formed from the dissolution of carbonate minerals, most from the underlying Kalambaina (limestone) Formation in the study area.

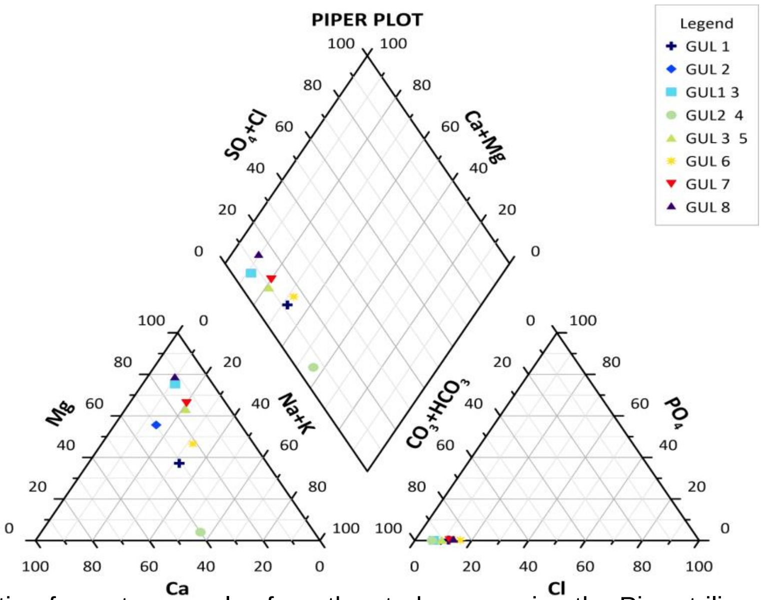

Figure 4: Type classification for water samples from the study area using the Piper trilinear diagram (Back and Hanshaw, 1965) A = Calcium type, B = sodium or potassium type, C = magnesium type, D = no dominant type, E = bicarbonate type, F = chloride type, G = sulphate type, H = no dominant type I = Ca+Mg type, J = HCO_3 +CO_3 type, K= Na+K type, L = Cl+SO_4 type M = Ca(Mg) HCO_3 type, N = Ca(Mg) Cl SO_4 type, O = Na(K) HCO_3 type, P = Na(K) Cl(SO_4) type.

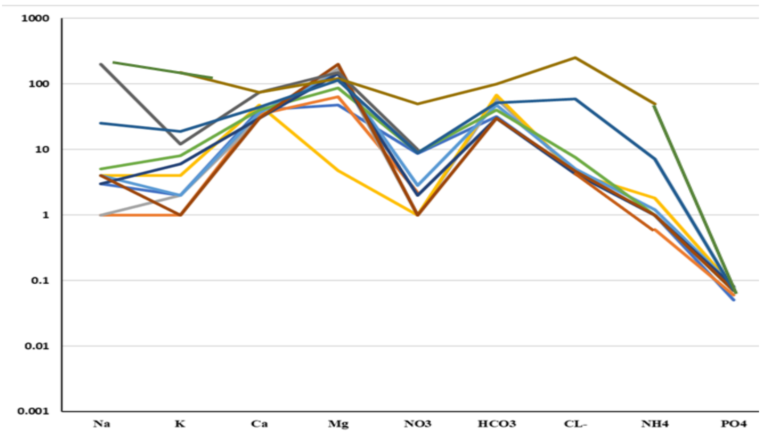

Figure 5: Schoeller Plot showing level of contamination in the analyzed water sample

DISCUSSION

Geological fieldwork revealed the sediment exposed around Gulma Hill near Gulma village are composed of clays and sandstone capped with ironstone typical of Gwandu Formation. The sediment display the characteristic loadcasts, cross lamination, parallel lamination and bioturbation (12° 40′ 00" and 4° 20′ 00" E, (12° 39′ 1" N and 4° 21′ 7" E)typical of sedimentary structures observed by earlier workers.

Results of the physical parameters measured in the study area are presented in Table 1. The measured temperature ranged between 33.3 and 34.2ºC while the pH values ranged between 5.82 to 7.65. This indicates an acidic to slightly alkaline water because the former samples were from a well located 4 m from a pit latrine Gulma 7, while the latter were away from pit latrines or where dry season farming with excessive use of fertilizers occurs.

The EC measured ranges between 58 and 344, while the TDS fluctuates between 31 and 173. The variation observed in these physical parameters is due to incessant anthropogenic behavior of the inhabitants of the study area, mainly agricultural activities and improper waste disposal. However, most of the physical parameters measured values fall within the acceptable limit of (WHO, 2022), as given in Table 1. All chemical parameters measured are within the recommended limits but Pb^{2+} is above the (WHO, 2022) recommended values for some water points (Gulma 3, 4 5, 6, 7 and 8). Exposure to lead is associated with wide range of effects. Young children, infants, fetuses are particularly vulnerable to lead because the physical and behavioral effects of lead occur at lower exposure level in children than in adults. A dose of lead that would have little effect on adults can have a significant effect on children. In children low level exposure of lead have been linked to damage of the central, peripheral nervous system, learning disabilities and shorter stature while exposure of adults to lead can cause cardiovascular effect, high blood pressure and decrease in kidney function, (WHO, 2022).

The results of the major elements and oxides measured for the samples Table 2, was used in plotting the Piper and Schoeller plots. The Piper diagram was used to classify the water type and facie in the study area. The dominant water facie is CaMg-HCO_3 figure 4, which can be attributed to the presence of Ca^{2+}, Mg^{2+}, and HCO_3^{2-}, which result from the breakdown and dissolution of limestone in Kalambaina Formation, underlying the Gwandu Formation in the study area Figure 2b. However, the results of heavy metals measured from samples in the study area as shown in Table 3. The level of contamination and relative concentration of the anions and cations in the study area indicate shallow fresh groundwater that is slightly hard. The water is associated with Kalambaina Formation underlying the area and carbonate hardness from recent precipitation occurring at shallow depths below the surface.

CONCLUSION

The field mapping and hydro-chemical study of the eight water samples from drinking water sources in Gulma village was conducted to determine the Interaction between the geology and the groundwater contamination. Results revealed groundwater with concentrations of pH reflecting acidic to slightly alkaline water, and lower concentrations of TDS and EC, which are below the (WHO, 2022) set limits. The results also show that the cations have values less than the maximum limit recommended by (WHO, 2022), while Mg^{2+} has higher values of 170mg/l and 198 mg/l from well 3 and 7 respectively which are above the WHO 2022 limit,. However lower values were recorded for trace elements like Mn^{2+} and Ni^{2+}. Also, the anions analyzed, NO_3^- ion have concentrations within the limits of (NSDWQ, 2015) recommended for drinking water. All heavy metal have values below the recommended values except Pb^{2+} at Gul 5 which is slightly higher in some samples creating the need for proper treatment of the affected water points periodically. The dominance of the $Ca^{2+}Mg^{2+}$-HCO_3 facie can be related to the interaction of geology of the study area with the groundwater and other geochemical processes that operate within the aquifers in the area.

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