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Geology and Hydrogeology of the Gu-Line Volcanic Spring, Jos Plateau Nigeria

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Abstract

Gu Volcanic line lies at the piedmont of the southeastern flank of the Jos Plateau and is inundated by volcanic springs with their out flows constituting 30-40% of the base flows of the upper River Shemankar which is the main water supply source of the River Shemankar Irrigation Scheme and the proposed Shemankar Valley Hydroelectric Power Project. This study is focused on the geology hydrogeology, hydrogeochemstry and origin of the volcanic springs and their suitability for domestic and agricultural usage. The study was into two phase of –(1)geological/hydrogeological mapping/ sampling and (2) laboratory analyses. Rock and spring waters were sampled for mineral and hydrogeochemical composition. The rocks elements and mineral composition was determined by petrographic analysis using cross polarized microscope and XRF methods The hydrochemical parameters of PH, EC, TDS and Temperature was determined using a combined Combo Hanna pH/ Temperature/ EC/ TDS meter in the field while the cations and anions concentrations was determined in the laboratory using AOAC method/techniques. The stable isotope composition of the springs was analyzed by Isotope Ratio Mass Spectrometer. The spring flow- discharge measurement carried out using velocity-area method.

The Gu Volcanic line is underlain by 3 major rock types and stratified in the order of : (1) Basement, (2) Sub-basalt, (3) Basalt. The 4 volcanic cones are generally stratified and composed of basalts, pyroclastic and ash. All the spring flows out from fractured basalts and or sub-basalts layers in seepage or gushing form. The springs minimum and maximum base flow range between 0.0004906 and 0.04787104m^3/s. Hydrogeochemical analysis shows that GVL springs physical parameter of (T), pH, EC, and TDS values ranges from 24-27.8^{o}c, 7.52-8.43, 219-311µS and 106-150ppm respectively. The cations of Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} concentration range from 19.67-20.25mg/l, 0.14-0.31/Mg/l, 12.5-22.5mg/l, 4-6.5mg/l respectively. The anions concentration of Cl, HCO_3 and NO_3 are 10.175—31.89mg/l, 9.24-16.31mg/l, 13.73-18755mg/l and 9.12-25.14mg/l respectively. The Piper Trilinear diagram shows that the major water facie for the volcanic springs is Mg-Na-HCo_3 type. However, the exception is that of Kwak spring with Mg-Na-(SO_4-Cl) type. From Gibbs plot, the spring water elements sources are from water- rock interaction from hydrolytic and weathering processes. Isotopic analysis of oxygen-18 and deuterium(2H) and their plots on the Global Meteoric Water Line shows that there of meteoric origin. Comparative hydrogeochemical characteristics of the spring with WHO and FAO standards shows that they all fall within the permissible levels for usage.

Key words: Geology, Gu Volcanic line, Hydrogeology, Hydro geochemistry, Water Quality.

1.0 INTRODUCTION

The volcanic cones of the southeastern flank of the Jos Plateau volcanic region area are aligned in a NNE-SSW direction as displayed in the Gu and Panyam volcanic lines. The Volcanic cones generally rise hundreds of feet (meters) above the general surrounding elevations (Macleod, etal 1971; Schoneich and Ugodulunwa, 1994; Lekmang, 2019; Longpia, 2021). These volcanic cones are associated with volcanic springs and they emanates either proximally or distally from the volcanic cones in fractured basalts, sub-basalts or volcanic ash (Longpia et al., 2021). The springs are major sources of the rivers that rises close to the volcanic cones or uplifted areas (Longpia, 2021, 2022).

Preliminary geophysical investigations around the Gu and Panyam Volcanic Lines revealed a 3 - 5 geo-electrical layering/lithological sequences comprising of lateritic topsoil, weathered basalt, fractured basalt, sub-basalt and basement (Dami, 2023; Longpia, 2021; Longpia etal, 2013, 2017). The Panyam Volcanic Line springs flows out in either seepage or gushing forms (Longpia,2021).

Volcanic springs are classified as either hot or cold springs depending on their outflow temperature. The Jos Plateau volcanic springs are characterized by low outflow temperatures ranging from $20\text{-}23^{0C.}$ (Longpia,2004, 2021 Evian,1981) Flow discharge characteristics of springs are used as one of the major forms of classification (waterdata.usgs.gov). The PVL springs have been classified as a 3rd degree springs (Longpia, 2021). Several groundwater studies have shown that hydrogeochemical composition of groundwater closely follows the geochemical pattern of the aquifer rock type which they flow through (Zhou et al., 2005; Tavis et al., 2006; Siebe, 2007; Offodile, 2014).

Hydrogeochemical composition of groundwater has been used to classify spring waters into different water types Generally, the major ions in groundwater include-Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO^{3-} and SO_4^{2} (Minisale et al, 1997; Lar and Gusikit, 2015, Offodile, 2014). The hydrogeochemical concentration patterns of the Panyam Volcanic Line springs closely relates to the aquifer rock geochemical concentration (Lar and Gusikit 2015). The hydrogeochemical composition of the PVL springs are dominated by Mg^{2+} and $HC0_3^{2-}$ ions respectively. Isotopic Composition of the groundwater in the Panyam Volcanic Line falls with the meteoric composition (Longpia, 2021).

The Gu Volcanic Line springs are very significant as they contributes 30-40% of the base-flow of upper River Shemmankar flow-discharge. It is the major source of the irrigation waters of the 1,000 hectares River Shemmanker Irrigation Project at Longkat. Pre-irrigation development studies of the Longkat Irrigation delved little on the contributory sources of the River Shemmanker, especially the volcanic springs, and hence the need to study this aspect with emphasis on the geology, hydrogeology, hydrogeochemistry, origin and usage suitability.

2.0 GEOLOGIC SETTING

Physiographically, the volcanoes of the Gu Volcanic Line is situated south of the Panyam Volcanic Line near the piedmont of the Jos Plateau (900masl) and the rolling plains of the River Shemankar basin (650m asl). From the Jiblik volcano at Abwor-Dyis, the basement

Plateaux area slopes gently and rapidly in some segments and descends into the depressions that are occupied by the eastern and western upper reaches of the River Shemankar (Fig.--). The Gu Volcanic Line is comprised of four volcanic cones aligned in NNW-SSE directions which their eruption appears to be controlled by NNW-SSE major fault line (Macleod, 1971, Schoeneich and Ugoduluawa, 1994). The Volcanoes erupted through the basement and it's eject materials, especially, the lava flows and filled the valley/river/streams and breaching it basaltic rocks. The volcanic cones are composed of a pile of eject materials of basalts, pyroclashics and ash (Macleod etal, 1971). The area is underlein by two major rock types- undifferentiated basement and Volcanic rocks. The General stratigraphic succession of the Gu Volcanic line within the upper River Shemmankar basin is: (1) Basement (2) Basalt And (3) Sub-basalt.

3.0 MATERIALS AND METHODS

1. Geological mapping

A geological mapping of the Gu Volcanic Line to identify and delineate the various rock types and structures using base maps of 1:50,000 map scale. This is used to produce final geological and hydrogeological maps. Several instruments and materials were used which include Global Positioning System for location of coordinates. Areas geological hydrologic/hydrogeological interest, Hand lenses for macro mineral composition identification etc.

2. Hydrogeological Mapping

Employed hydrological and hydrogeological mapping techniques to gather field data and details to include -

i. Lithostratographic setting of the springs/geohydrology of the springs

ii. Study morphology of volcanic springs and in relation to main drainage system.

iii. Carry out flow-discharge measurement of springs using velocity-area method (Rhagunath, 2006).

iv. Employ geo-electrical reactivity sounding methods for sub-surface geologic investigation at spring sites. The ABEM Terrameter 1000 series was used for the field data acquisition and the Win Resist software (Vander, Velpen, 2004) for the interpretation.

3. Hydrogeochemical studies

Spring water samples were collected in two seasons-(1) at close of the peak dry and wet season in April and October 2022 respectively for hydrogeochemical analysis. The samples were collected in 100ml plastic bottles in duplicates. 0.1ml of nitric acid was added to the sample bottles for cation analysis. The acidification of the sample is to prevent precipitation and biological growth.

In the field, physical parameters of pH, Temperature (T), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured using a digital Hanaa Combo Combined pH/TDS/EC/Temp meter.

4. Laboratory

i. Whole rock geochemical analysis

Representative rock samples from the various geological units were analyze for whole rock geochemical analysis for major and trace element compositions. The sample were analysed at Kofa Laboratory Services and Laboratory Unit of the Department. of Geology, University of Jos.

ii. Petrographic Analysis

Rock slides from representative rock samples from the various geological units were produced and analysed for mineral compositions using petrographic microscope under planed and cross polarisation.

iii. Hydrogeochemical Analysis

The sampled spring waters were analysed for major cations and anion compositions based on the AOAC methods and standards. For the cation the AOAC 920.199, 974.27, 973.54 and 973.53 were used for Ca, Mg, Na and K respectively. For the anions the AOAC 920.129, 973.54, 973.57 and 970.50 methods and standards were used for HCO^-, Cl^-, SO_4^{2-} and NO_3^- analysis respectively.

iv. Hydrogeochemical modeling

1. The Piper plot: The piper plot was done in accordance with the piper diagram template (https//hetarlabs.com/ih-en/what-is-a-piper-diagram-aod-how-to-create-one).
2. Th Gibbs diagram were used to distinguish sources of hydrogeochemical elements in accordance with Gibbs, 1970.

v. Isotopic Composition of Spring Water

The isotopic composition analysis of δ^2H and $\delta^{18}O$ were carried out using a Thermo-Funnigan Gas beach connected to a Thermo-Finnigan Delta plus XP Continuous Flow Isotope Ratio Mass Spectrometer at the Isotope Resesarch Centre, University of Ontario, Canada using

VSMOW as reference materials. The method and process monitoring on accuracy standard deviation of 0.5% and 15% for $\delta^{18}o$ and $\delta^{2}H$ respectively.

4.0 RESULTS

4.1 Geology

The Gu Volcanic Line is underlain mainly by the Basement Complex and volcanic rocks (Fig.1). The Gu Volcanic Line has 4 volcanic cones namely-Jiblik, Kagu, Tokbet and Katul volcanoes are aligned in a NNE-SSW direction. The volcanoes erupted through the basement. The volcanic cones are typically stratovolcanic cones. The volcanic piles are comprised of basalts, scoria, pyroclastics and volcanic ashes. The general lithostratigraphic setting as revealed from dissected sections of some segments of the River Shemankar at Gheii and drilled borehole lithologic logs revealed a sequence of - (1)Topsoil ,(2)weathered basalts, (3) fractured basalt and (4) basement . The geologic structures are comprised mainly of fractures, veins and dykes and they generally trends in NNE-SSW direction. From lineament (Fig2), the general structural trend of the GVL is in NNE-SSW.

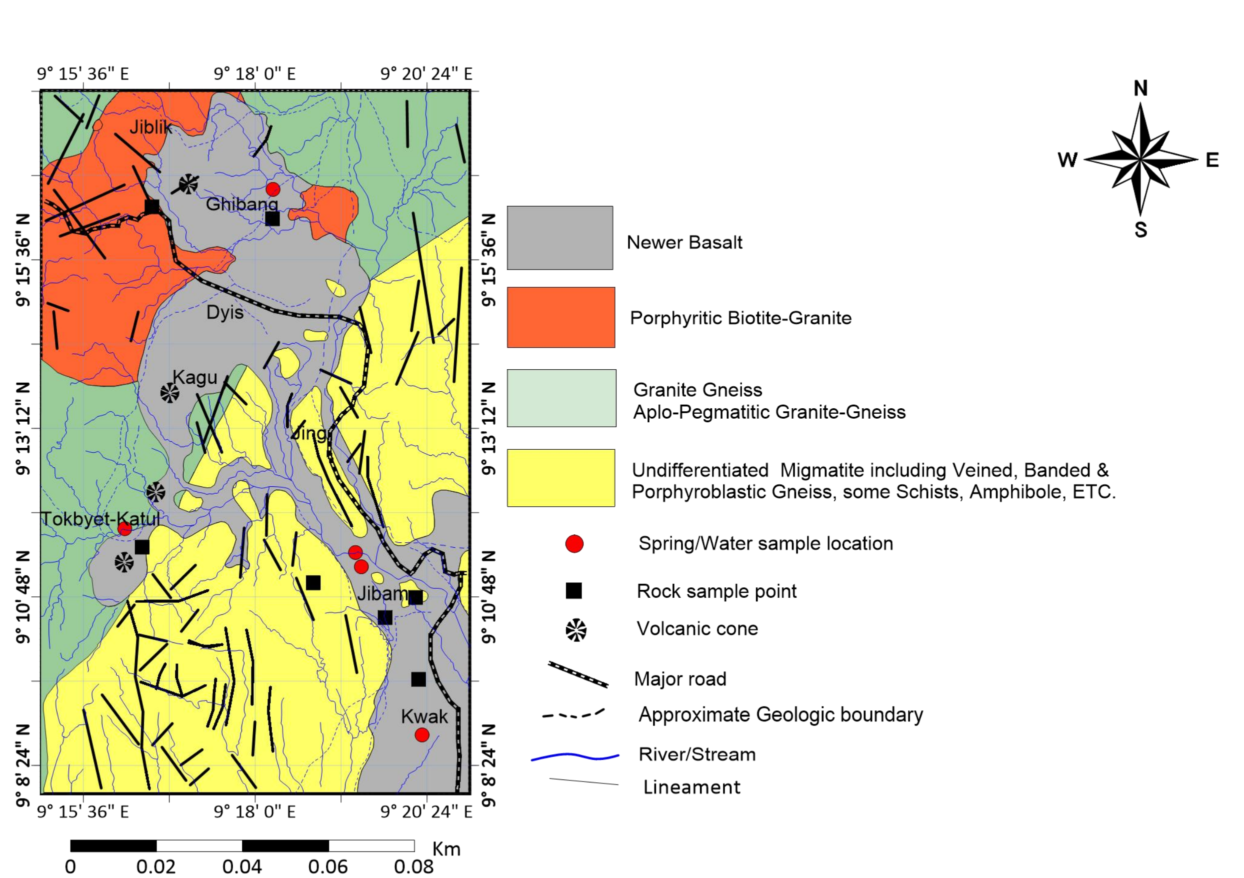

Fig 1: Geologic map of the Gu Volcanic Line (Modified after Macleod etal, 1971)

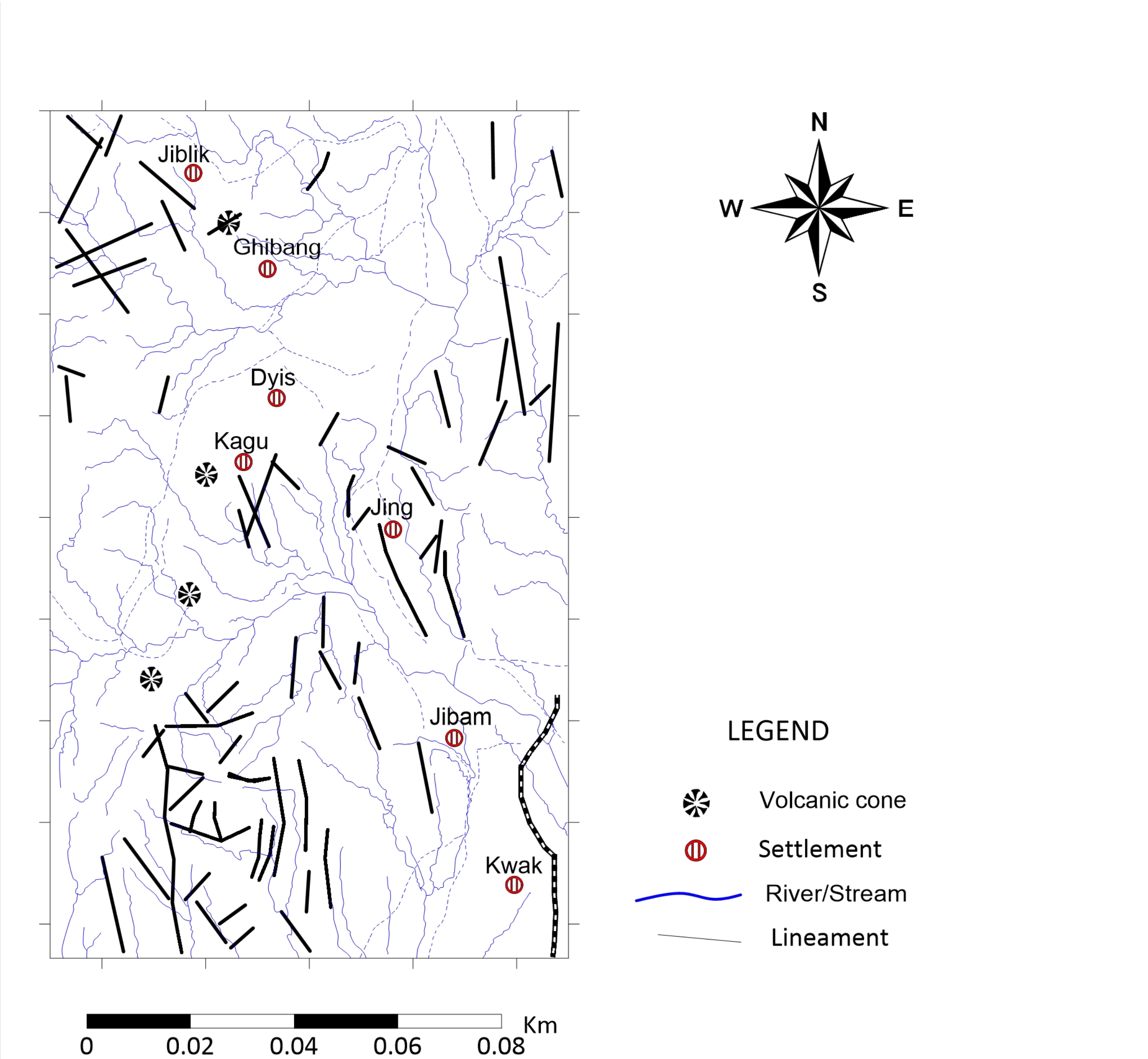

Fig 2: Lineament Map of the Gu Volcanic Line within the upper Catchment of the River Shemankar

4.2 Petrography

The petrographic analysis of biotite the granite and basalts are as shown in Table1 and 2. The modal compositions for the biotite granite comprising of quartz, biotite, feldspar, mica and accessary minerals are 35, 25%, 20%, 15% and 5% respectively. The modal composition for basalts comprising of mineral of olivine, plagioclaise, opague minerals and accessories are 20% 50%, 25% and 5% respectively.

4.3 Hydrology and Hydrogeology

The Gu Volcanic Line falls within the upper River Shemankar catchment(Fig1) and have several streams/rivers rising mainly from the volcanic cones and/or associated basement highlands. All the streams within the Gu volcanic line flows generally in the North-South direction. From the lineament map(Fig2) some of the tributries are structurally controlled The streams are generally sub- perenial to perennial in character along the flow lines. There are 4 major volcanic springs(Fig 1 &2) they emanates proximal or distally from the volcanic cones and are namely-Ghibang, Katul, Ghei and Kwak. The Ghibang and Ghei springs are typically gushing spring type while Katul and Kwak are more of seepage types. The spring flow-discharge measurements (Table3) and hydrograph (Fig4) shows that spring flow begin to increase gradually with the onset of the rainy season as a result of increased infiltration into shallow and deep water circuslation system and the resultant effect on the springs also. The Gu volcanic line springs contributes over 20-30% of the base flow of the upper River Shemankar catchment.

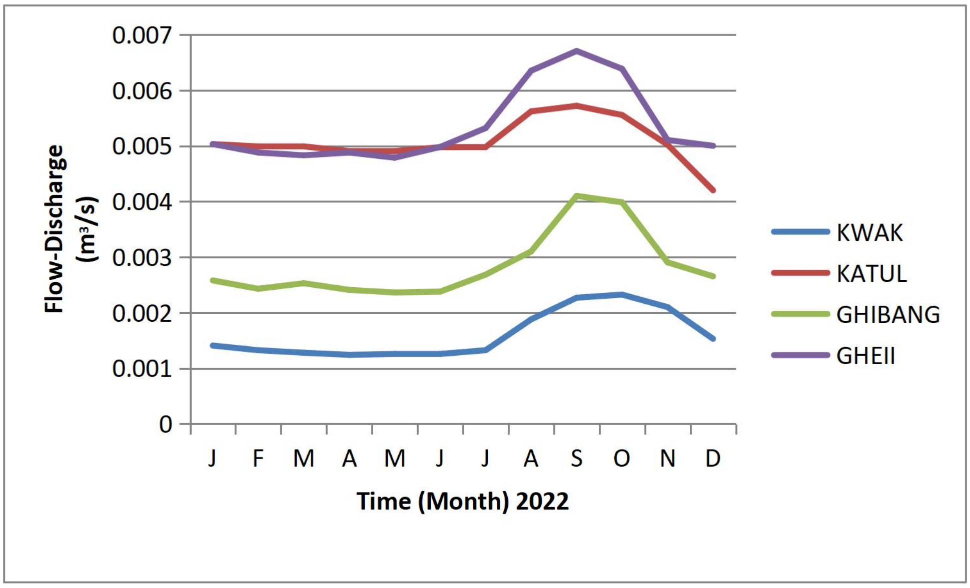

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Fig.4 Flow discharge measuring of Gu Volcanic Spring--2022 hychological ye

Plate 1: Ghei Volcanic Spring: Gushing spring

4.4 Geophysical Investigation and Drilling

The Geo-electrical parameters of the geo-electric resasulty sounding interpretation in form of geo-electric sections around Ghei and Kwak spring (Fig.5.) areas revealed a geoelectric/geologic sequences of Topsoil (0-2.6m), weathered basalts (2.6-15)m, fractured basalts (15.8-35m), Sub-basalt (25-40m) and basement (725m) which are characterized by average resistivity value ranges of 345-931ohm-m, 198-450ohm-m, 75-190ohm-m, 295-458 ohm-m respectively. A correlation of the geo-electric layer with a borehole lithologic lection near the Gheii and Kwak springs (Fig.6) showed a lithologic/geo-electric sequence of Topsoil, weathered basalts, fractured basalts, sub-basalts and basements.

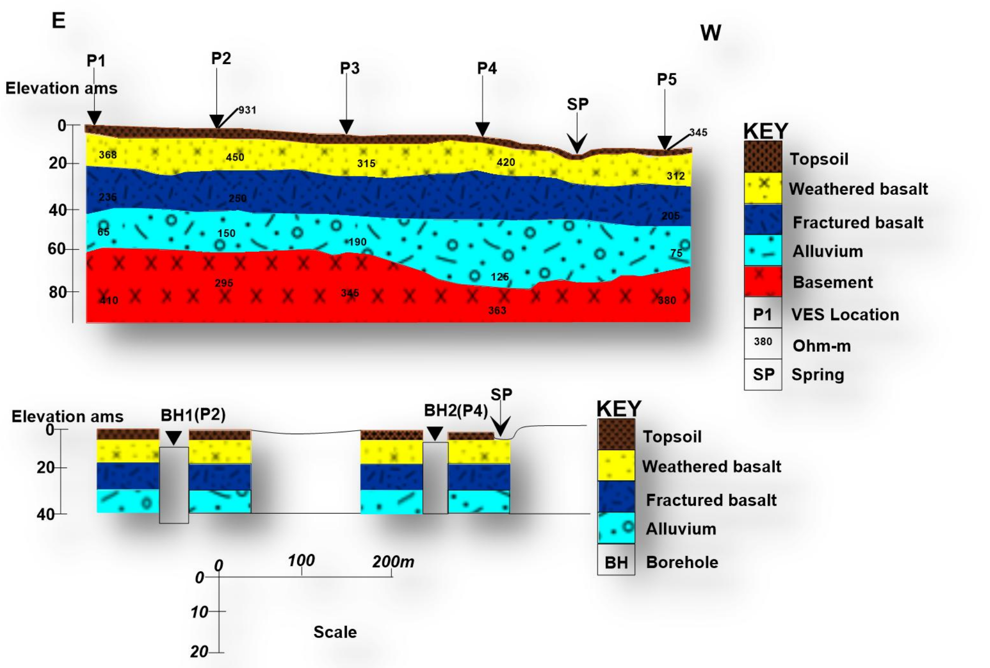
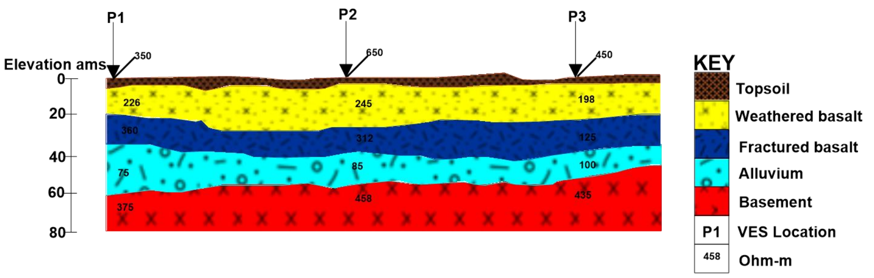
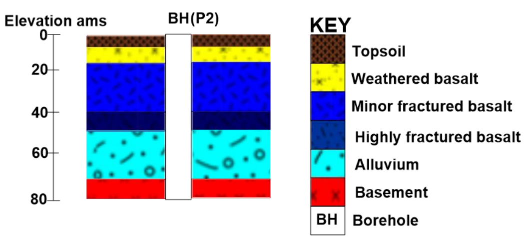


Fig.5 Geo-electric and borehole lithologic section along E-W direction around Kwak Spring



(a) Geo-electric section



(b) Borehole section

Fig.6 Geo-electric and borehole lithologic section along E-W direction at Ghei Spring

4.5 Laboratory Analysis

4.5.1 Whole Rock Geochemistry

Major oxide and trace element analysis of the three major rock types are as presented in Tables ----

Migmatite Gneiss

The major oxides distribution for the migmatite gneiss are: SiO_2 (48.984wt%), Al_2O_3 (17.3945 wt%), MgO (1.1801 wt%), CaO (1.8115 wt%), Fe_2O_3 (150009 wt%), K_2O (0.8596 wt%), Na_2O(3.518 wt%) TiO_2 (0.0095 wt%), MnO (0.0248 wt%) while P_2O_5 and Cr_2O_2 (<LOD)

The major oxide concentration or abundance pattern is as follows: Al_2O_3 MgO, $Fe_{2}o_{3}$, CaO, TiO_2

Basalts

The major oxides distribution for basalts are: SiO_2 (43.8348 wt%), Al_2O_3 (15.734 wt%), MnO (0.071 wt%), Fe_2O_3 (12.233wt%), CaO (5.1495 wt%), TiO_2 (0.7023 wt%), MgO (6.1741 wt%), K_2O (1.0311 wt%), , P_2O_5 (0.1714 wt%)and Cr_2O_2 (0.0188 wt%).

The abundance oxide concentration pattern or distribution for the basalts is as follows: S_{102} Al O_3 F_{e2O3} MgO Na_2O K_2O P_2O_5 MnO Cr_{205} S_1O_2 Al_2O_3

Granite

The major oxides distribution for basalts are: S_1O_2 (20.1503 wt%), Al_2O_3 (12.311 wt%), MgO (1.9209 wt%), CaO (3.7008 wt%), Fe_2O_3 (4.381 wt%), K_2O (1.8391 wt%), TiO_2 (0.498), MnO (0.0299 wt%) , P_2O_5 (0.0684 wt%)and Cr_2O_2 (0.0036 wt%). The abundance pattern of the oxide distribution is as follows: S_1O_2> Al_2O_3>Fe_2O_2> K_2O> CaO> P_2O5> MnO> C_2O_5

Table1: Major Oxide Distribution of Major Rock Types of Gu Volcanic Line.

Rock Type	Sample ID	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	K_2O %	Na_2O %	TiO_2 %	P_2O_5 %	MnO %	Cr_2O_3
Migmatite Gneiss	S1M1	48.984	17.3943	15.009	1.1801	1.03	1.5	3.5	0.0095	<LOD	0.0248	<87.5
Basalts	S2B1	43.8348	15.734	12.4	6.1741	5.1495	2.5	2.8	0.7023	0.1714	0.071	

0.0188

Biotitegranite S3G1 68.9 12.31 4.3 1.9209 3.7 1.8 3.25 0.498 0.0684 0.0299 0.0036

4.52 Trace element composition

The trace element composition of the rock types are presented in the Table.

Table 2-: The Distribution of Trace Elements in the Rocks of the Study Area

	Rock type		
Analyte	Basalt	Biotite-granite	Migmatite
S	< LOD	< LOD	< LOD
Cl	0.0373	0.0201	< LOD
Ti	0.7023	< LOD	0.0095
V	0.0218	< LOD	0.0103
Co	< LOD	< LOD	< LOD
Ni	0.0096	< LOD	< LOD
Cu	0.0043	0.0005	0.0015
Zn			0.0033
Ga	0.0013	0.001	0.0013
As	0.0004	< LOD	< LOD
Se	0.0006	0.0004	0.0005
Rb	0.0029	0.0056	0.0068
Sr	0.0451	0.0368	0.0369
Y	0.0019	< LOD	0.0008
Zr	0.0124	< LOD	0.0032
Nb	0.0035	0.0007	0.0013
Mo	< LOD	< LOD	< LOD
Rh	< LOD	< LOD	< LOD
Pd	0.0012		0.0011
Ag		< LOD	< LOD
Cd	< LOD	< LOD	< LOD
Sn	< LOD	0.0084	< LOD
Sb	< LOD	< LOD	< LOD
Ba	0.0768	0.1016	0.1488
La	< LOD	< LOD	< LOD
Ce	< LOD	< LOD	< LOD
Hf	0.0002	< LOD	0.0001
Ta	< LOD	< LOD	< LOD
W	< LOD	< LOD	< LOD
Pt		< LOD	< LOD

Hg	< LOD	< LOD	< LOD
Tl	< LOD	< LOD	< LOD
Pb	< LOD	< LOD	0.0021
Bi	< LOD	< LOD	< LOD
Th	0.0008	< LOD	< LOD
U	< LOD	< LOD	0.0016

4.6 Hydro geochemistry: Physicochemical Composition

The physicochemical composition of the Gu volcanic line springs are as shown in Table

Table 3: The Physio-chemical composition of the Gu Volcanic Line springs

Station ID	Spring Type	pH	T (^OC)	EC (µs)	TDS (ppm)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	SO_4 (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	NO^3 (mg/l)	δO^{18}	δ^2H
UPPER .R. SHEMMANKER	Flowing	7.95	27.8	234	117	14.4636	0.12	18.285	4.5	19.0858	13.4705	11.2845	7	27	4.9
KWAK	Seepage	8.43	27.4	311	150	20.2476	0.14	12.5	4.5	31.8901	16.307	18.755	25.14	27.5	4.9
KATUL	Seepage	8.15	24.7	219	106	19.6704	0.215	18.15	4.00	11.4112	11.343	13.7265	16.8	26	4.7
GHIBANG	Gushing	8.3	26.7	288	144	28.9258	0.31	22	6.5	10.1755	9.2485	19.52	9.55	27	4.75
GHIE	Gushing	7.52	27.5	236	118	20.2497	0.19	225	4.00	11.7681	11.3215	15.52	9.125	28	4.9

Kwak Spring

The field measured values for physical parameters of pH, Temperature, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are 8.43, 27.4°C, 3.11µS and 150ppm respectively. The average geochemical concentration of the cat-ions of Mg^{2+}, Ca^{2+}, Na^+ and K^+ are 20.476mg/l, 12.5mg/l, 0.14mg/l, 12.5mg/l and 4.5mg/l respectively. Meanwhile, the concentration for the anions of SO_4^{2-}, Cl^-, HCO_3^- and NO_3^- are 31.8901mg/l, 16.307mg/l, 18.755mg/l, and 25.14mg/l respectively. The major cations and anion abundant concentration patterns are $Mg^{2+} > Na^+ > K^+ > Ca^{2+}$ and $SO_4^{2-} > NO_3^- > HCO_3^- > Cl^-$ respectively.

katul Spring

The field measured values for physical parameters of pH, Temperature (T), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are 8.15, 24.7°c, 219µS, and 106ppm respectively. The average geochemical concentration values for the cations of Mg^{2+}, Ca^{2+}, Na^+ and K^+ are 19.6704mg/l, 0.125mg/l, 18.15mg/l and 4.00mg/l respectively. The anions concentration of SO_4^{2-}, Cl^-, HCO_3^- and NO_3^- are 11.4112mg/l, 11.343mg/l, 13.7265mg/l and 16.8mg/l respectively. The geochemical concentration abundance pattern of cations and anions are as follows $Mg^{2+} > Na^+ > K^+ > Ca^{2+}$ and $HCO_3^- > NO_3^- > SO_4^{2-} > Cl^-$ respectively.

Ghibang Spring

The hydrogen ion concentration value of pH, Temperature (T), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are 8.3, 26.7°C, 288µS and 144ppm respectively. The geochemical concentration values for the cations of Mg^{2+}, Ca^{2+}, Na^{+} and K^{+}are28.9258mg/l,0.31mg/l,22.00mg/l and 6.5mg/l respectively. For the anions concentration of SO_4^{2-}, Cl^{-}, HCO_3^{-} and NO_3^{-} the values are: 10.1755mg/l, 9.2485mg/l, 19.52mg/l and 9.55mg/l respectively.

Ghei Spring

The physical parameters of hydrogen ion (pH) Temperature (T), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are 7.52, 27.5°c, 236µs and 118ppm respectively. The cations concentration of Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} are 20.2497mg/l, 0.19mg/l, 22.5mg/l and 4.00mg/l respectively. The anions concentration of SO_4^{2-}, Cl^{-}, HCO_3^{-} and NO_3^{-} are 11.7681mg/l, 11.3215mg/l, 15.52mg/l and 9.125mg/l respectively. The cation and anion concentration abundance patterns of the cations and anions is in the order of $Mg^{2+} > Na^{+} > K^{+} > Ca^{2+}$ and $HCO_3^{-} > NO_3^{-} > SO_4^{2-} > Cl^{-}$ respectively.

Upper River Shemmankar

The physical parameters of hydrogen ion (pH), Temperature (T), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are 7.95, 27.8°C, 234µS and 117ppm respectively. The cations of Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} are 14.4636mg/l, 0.12mg/l, 18.285mg/l and 4.5mg/l respectively. The anions concentration of SO_4^{2-}, Cl^{-}, HCO_3^{-} and NO_3^{-} are 19.0858mg/l, 13.4705mg/l, 11.2845mg/l and 7.00mg/l respectively. The cations and anion concentration pattern abundance for the upper River Shemankar is as follows: $Na^{+} > Mg^{2+} > K^{+} > Ca^{2+}$ and $SO_4^{2-} > Cl^{-} > HCO_3^{-} > NO_3^{-}$ respectively.

4.6.1. Comparative Physico-chemical Characteristics of the Spring Waters

All pH values of the springs falls within 8.15 and 8.43 and are characteristically more of alkaline water with the exception of Gheii spring with pH value of 7.52 and falls in the neutral water pH value range of 7-< 7.9. The Gu spring outflow temperature range from 24-27.4°C. The electrical conductivity values range from 219-288µS with the exception of Kwak with slightly higher value of 311µS. The springs have minimum and maximum residual TDS value range 106-150ppm. Generally, pH, Temperature, EC and TDS of the Kwak springs are characteristics by higher values. The cation concentrations of Mg^{2+}, Ca^{2+}, Na^{2+} and K^{+} for all the springs range from 19.67 to 28.92mg/l, 0.14-0031mg/l, 12.5-22.5mg/l. and 4.0-4.5mg/l respectively. The anion of SO_4, Cl, HCO_3, and NO_3 have concentration values range of 10.17-31.89mg/l, 9.25-16.3mg/l, 15-15.5mg/l and 18.755mg/l respectively.The Kwak spring display highest concentration (Table3) of the anion than all the springs and the River Shemankar.

4.7 Isotope Hydrology

The δ^2H and $\delta^{18}O$ composition of hydrogen and oxygen isotope analysis for the springs are presented in Table 3. The δ^2H and $S^{18}O$ of the springs were plotted relative to the Standard Water Line (Fig7). All the compositional values plotted are clustered around the standard meteoric water line and is indicative of meteoric origin global values. 7

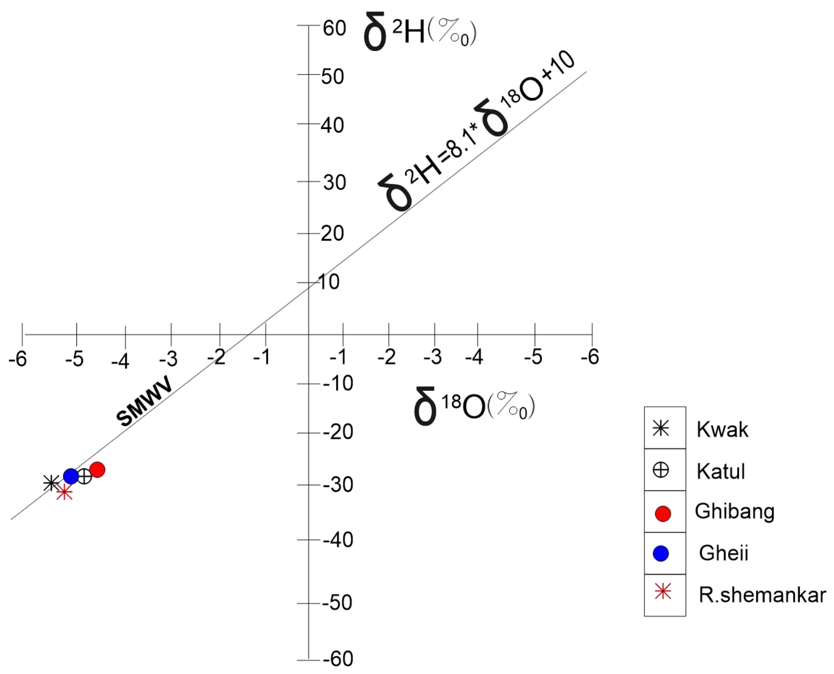


Fig 7. δ ^{2}H versus δ ^{18}o plot of Gu-Volcanic Line Spring correlation with Global Meteoric Water Line

4.8 Hydrogeochemical Facies Model: Groundwater classification

From the piper trilinear plot, the diagram shows higher ionic concentrations of Mg^{2+}within the 50%-75% range. Meanwhile, Na^+_K^+ have concentrations that range between 25%-45%. Calcium has the lowest percentage of the cation group. This means the cation distribution in the springs is patterned Mg^{2+}>Na^+>Ca^{2+}.

On the anion plot, the diagram shows predominant ionic composition of HCO_3^- within the range of 60%-80%. Chloride cl concentration ranged between 20%-50% while SO_4^- concentration ranged between 20%-40%. The predominant groundwater facies type in the Gu

Volcanic line springs is Mg-Na-HCO_3 type.

From Fig. 8 the Kwak, Katul, Ghibang, Ghei and upper River Shemankar types are: Mg-Na-SO_4-Cl, Mg-Na-HCO_3, Mg-Na-HCO_3, Mg-Na-HCO_3 and Ca-Mg-HCO_3 types respectively.

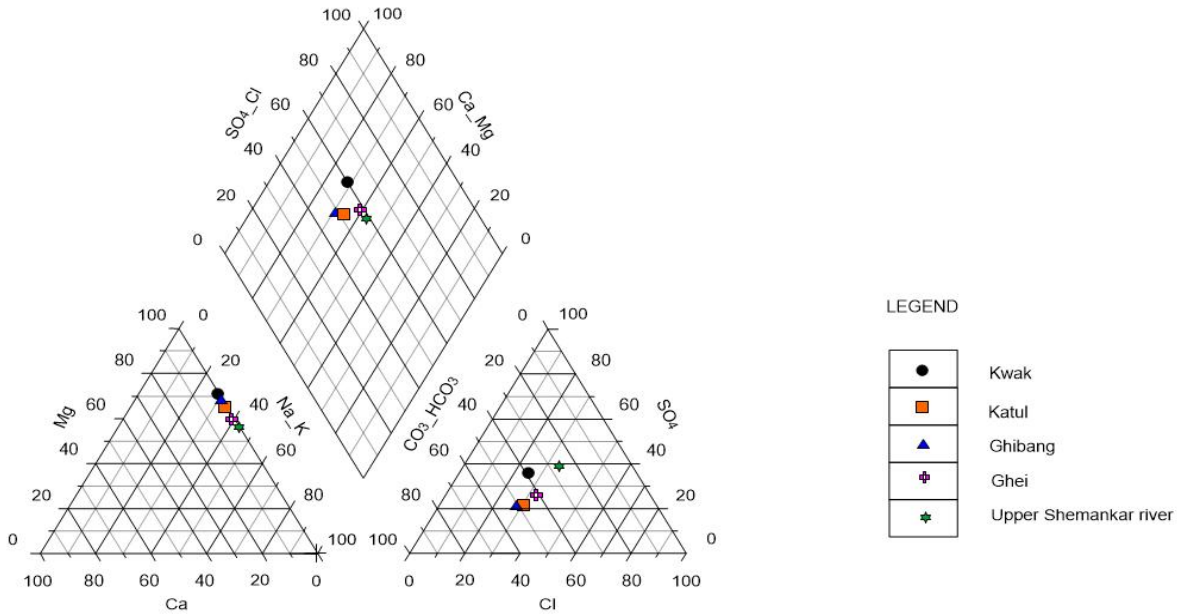


Fig 8: Piper Trilinear Diagram of the Gu Volcanic Line springs and upper River Shemankar

4.9 Water-Rock Interaction Processes

The Gibbs plot (Fig. 9) for the Gu volcanic line springs classifies the spring water into their respective hydro-geochemical sources. The diagram shows that all the spring waters fall within the water-rock dominance zone. This implies that water-rock interaction accounts for the characteristic hydrogeochemical constituents of the spring water and the River Shemankar.

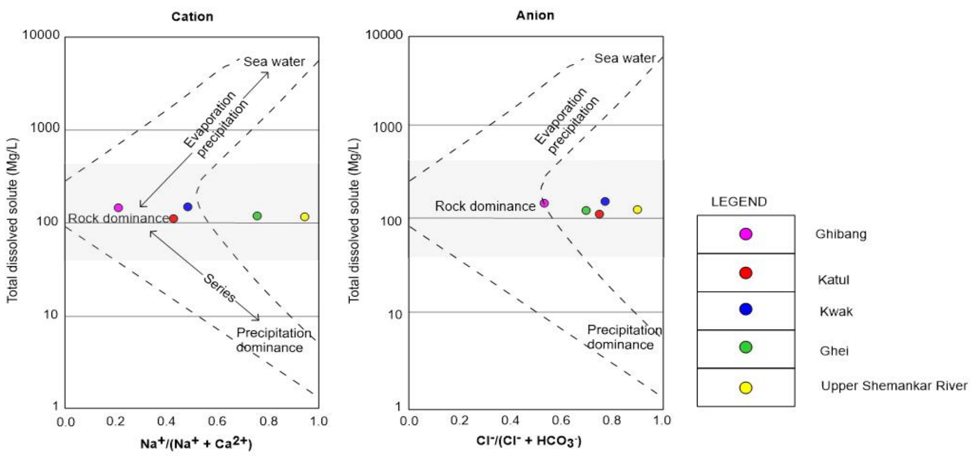


Figure 9: Gibbs Diagram for Gu Volcanic Line Springs

5.0 DISCUSSION

5.1 Geology

The Gu Volcanic Line is underlain by 2 main rock types: Basement Complex and volcanic rocks (Fig.). The Basement Complex rocks are made up of porphygrytic granite, granite gneiss, migmatile gneiss. The Gu Volcanic Line has a series of 4 volcanoes aligned in a NNE-SSW direction. The volcanoes erupted through the basement rocks and characterized by lava flows that filled and reshaped the pre-volcanic geomorphic features of the area. Modification of geomorphic landscape by volcanic lava flow is similar seen in the Panyam Volcanic line (Schoeneich and Ugodulunwa 1994, Evian 1981). The volcanic cones are pile or strata comprising of basalts, pyroclastics, ash etc. The volcanic cone ejecta materials of the Gu volcanoes are similar to the Panyam Volcanic Line volcanoes (Macleod etal, 1971; Schoneich and Ugoduluunwa, 1994; Lekmang, 2019; Lar and Gusikit 2015, Longpia, 2022). Geoelectric and borehole sections around some selected spring sites (Fig.5 and 6) revealed lithological sequence of topsoil, weathered basalt, fresh/fractured basalt, sub-basalt and basement. The geo-electric and borehole lithological sections of the Gu volcanic line are similar to those of the Panyam Volcanic Line (Evian 1981, 1982, Longpia et al., 2003, Longpia,2021, Longpia and Lar, 2021).

5.2 Hydrogeology of the Gu Volcanic Line Springs

The Gu volcanic line springs have two types of springs: seepage and gushing spring types. The Kwak and Katul springs flows out through fractured basalts in seepage form while the Ghei and Ghibang springs flows out through fractured basalts and/or sub-basalt in gushing form.

Typical seepage and gushing volcanic springs occur in the Biu volcanic region (Lar and Usman, 2012) and Panyam Volcanic Line (Longpia, 2021). The sub basalt occurrences in the Gu volcanic line is suggestive of existence pre-volcanic rivers/valleys sediments that have existed before the eruptions of the volcanoes (Evian, 1981, Schoeneich and Ugodulunwa, 1994, Longpia, 2021).

5.3 Hydrogeochemical characteristics of the Gu Volcanic Line springs

The physico chemical compositions (Table3 and Fig7.) of the Gu Volcanic Line springs display it's chemical characteristics. The average physico chemical composition of pH, Temperature T, EC, TDS, Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, HCO_3^{-} and NO_3^{-} of 8.1, 26.58^{0C}, 129mg/l, 22.19mg/l, 0.214mg/l, 18mg.l, 16.3mg/l, 8.31mg/l, 16.8mg/l and 15.38mg/l respectively shows that the Gu Volcanic Line springs are of neutral to slightly alkaline waters and characteristics low mineralization (Felter, 1990; LCBC, 2010-). Generally, low mineralized groundwaters are indicative of short travelled time from point of recharge to point of discharge (LCBC, 2010; Talabi, 2013). The hydrochemical characteristics (Table..) of all the springs falls within domestic and industrial usage standards (WHO, 2004,Table----Ref.). A comparative analysis of hydrogeochemical elements concentration of the springs and major oxide ($MgO > Na_2O > K_2O > CaO$) of basaltic aquifer rock abundance pallera shows they are closely related and is suggestive of hydrogeochemical derivation from the minerals constituting the rocks. Studies have shown that groundwater commonly have geochemical elements concentration patterns closely related to the aquifer rocks which they flow through (Tavits et al., 2006; Zhou et al., 2007; Ghadami et al., 2012; Offodile, 2014; Usman, 2012; Lar and Gusikit).

5.4 Water-Rock Interaction Process

The Gibbs diagram (Fig.9) for the Gu Volcanic springs falls on the rock-dominant segment, and therefore is suggestive of hydrogeochmical element sorces is frang aquifer rock.

The basalts of the Gu Volcanoes comprised mainly of olivine, plagioclase and opaque minerals (Table-1). Generally, in water-rock interaction processes either hydrolysis or oxidation processes may occur (Stephen, 2019,https://earthhowmineralcompositionofthe.com/chemicalweathering).

1. Hydrolytic process-

In this process, the minerals of plagioclase react with carbon dioxide with water as follows-

Plagioclase + carbonic acid →kaolinite + dissolved calcium + carbonic ions

Therefore, Hydrolysis of Calcium based feldspar is as follows:

i. $CaAl_2Si_2O_8 + H_2CO_3 + ½ O_2 \rightarrow AL_2Si_2O_5(OH)$ _ $Ca^{2+} + CO_3^{2-}$

ii. For Sodic alkaline feldspars ($2KAl_5Si_3O_8$ or $NaAlSi_3O_8$)

$2NaAlSi_3O_8 + H_2CO_3 + ½ O_2 \rightarrow Al_2Si_2O_5(OH) + Na^+ + CO_3$

2. Oxidation (chemical weathering for)

For magnesium silicate of pyroxene and olivine

Olivine $(Mg, Fe, Ca)_2\ SiO_4 + 4H_2CO_3 \rightarrow (M_g^{2+}, Fe^{2+}, Ca^{2+}) + 4HCO_3 + H_4SiO$

The hydrolytic and oxidation process in the water-rock interaction allows for the dissociation of the elemental constituents of cations. Therefore, in Migmatitic, gneiss or granite hydrolytic and oxidation process are suggestive of derivation from aquifer rocks and or the host basement rocks.

From the Piper diagram (Fig.8) two major water types of Mg-Na-HCO_3 and Mg-Na-(SO_4-Cl) were identified or distinguished. The water facie for the major drainage system (upper River Shemmankar) is mainly Ca-Mg-HCO_3 water which is slightly differ from the springs. From Table3 and Fig. 9 , the hydrogeochemical element concentrations of the springs are suggestive of derivation from water- rock interaction processes (Lar and Gusikit, 2015, Zhou, etal 2007, Offiodile 2014).

Groundwater Quality

Generally, water quality refers to the chemical, physical and biological characteristics of water based on the standard of usage (Tchobanogous et al., 1985, Omer,2019. The water quality of the Gu Volcanic Line springs were assessed based on –(1) drinking water quality (WHO, 2004) and (2) irrigation standards (Fao.org, LCBC, 2010, Tchobagonous, 2010) and all the hydrogeochemical elements concentrations falls within their permissible levels.

5.5 Drinking Water Quality Standard-

From Table 3, the hydrogeochemical concentration of the Gu volcanic springs falls within permissible levels for drinking water standard with the exception of the NO^3 concentration (WHO, 2004, Omer, 2019, LCBC, 2016). The NO_3 concentration for all the springs and R.iver Shemmankar range between 9.125 and 25mg/d. Katul and Kwak spring have NO_3 concentration of >10mg/d. Studies have shown that nitrate concentration of >10mg/l can cause health threat (Tchobanglous etal, 2003)

5.5.1 Irrigation Water Standard: SAR- There are 4 basic criteria for evaluating water for irrigation purposes and they include: – (1) water salinity (2) Electrical Conductivity (EC), (3) Sodium Hazard (Sodium Adsoption Ratios) (https://irrigation.tamuedu/files/2021/01/3-667). The value of SAR affects infiltration rate of water into the soil (Fao. org)

The formula for calculating SAR is given as

$$SAR=\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Where all concentrations are expressed as milli-equivalents of charge per litre. The calculated SAR value for the all the springs ranged from 0.21 to 0.37 (Table 4). These values falls within acceptable SAR range for irritation water standards (Fao.org).

Table 4: Calculated SAR for Gu Volcanic Line Springs and Upper River Shemankar

Spring	Calculated SAR
Kwak	0.21
Katul	0.31
Ghibang	0.31
Ghei	0.37
Upper River Shemankar	0.36

5.5.2 Salinity – This problem exists if salt accumulates in the cripraitzans that cause loss in yield (----). Electrical Conductivity and TDS values of irrigation waters have direct control on water salinity (Fao.org, Tchobagonous,2010). The springs EC and TDS value range between 219-311µS and 106-150mg/l respectively. Based on irrigation standards, EC and TDS values of EC < 70 and TDS < 450 and has no direct hazard for irrigation usage (https://www.fao--------------).

5.3 Specific Ion Toxicity: Na^+, Cl^-, NO_3^-, HCO_3^- Concentrations.

The SAR values for the springs range from 0.21to 0.31 (Table---). Generally SAR values < 3 has no effect on surface and sprinkler irrigation methods. However, for NO_3 and HNO_3, SAR values of > 5-30 and 15-85 have slight to moderate effects (Fao. org).

5.4 Water Use and Suitability

Meeting water quality standards essentially like biological, chemical and physical parameter characteristics are major factors in water use either for domestic (drinking), industrial or agricultural purposes (Tchobanoglous etal, 1985, Rao, 2017; Omer etal; 2019). A Comparative hydrogeochemical characteristics of the Gu volcanic spring with that of WHO drinking water standard (WHO, 2004) showed that all the cations and anions concentration are within permissible levels and hence, portable. For agricultural usage, especially irrigation, their chemical suitability are based critically on PH, TDS and EC values (LCBC, 2010, www.smartfertilizer.com, Rao, 2027, Omer, 2019). From physical parameter of the Gu volcanic spring the PH value range between 7.52 and 8.43 which is neutral to slightly alkaline waters. The TDS and EC values of 118-150ppm and 219-311µS respectively falls within fresh water group (LCBC,2010; Rao,2017).

6.0 Conclusion

This study was able to determine the general geological setting of the Gu Volcanic Line springs and characterized by a lithostratigraphic succession as follows:

1) Basalt
2) Sub-basalt alluvium
3) Basement etc.

(2) The springs are recharged through rainfall which infiltrates the ground through semi parmeable and permeable volcanic rocks and circulating in shallow and deep ground water which interns flows out through springs in fractured basalts or sub-basalts.

(3) Hydrogeochemical characteristics of the springs shows that the dominant water types is Mg-Na-Hco_3 water type. However, an exception is the Kwak spring which displays Mg-Na-So_4-Cl type. This exception may be due to pollution from agricultural activities close to the spring site. The spring waters are suitable for drinking and agricultural usage based on WHO and FAO standards.

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