Kashere Journal of Geography and Sustainable Environment (KJGSE),
Vol. 2, No. 2. ISSN: 0795-6266 (ONLINE), 0795-6258 (PRINT).
https://www.kasherejgse.com.ng

GEOLOGIC STRUCTURES AND GEOCHEMICAL WEATHERING INDICES: IMPLICATIONS ON GROUNDWATER POTENTIALS IN PART OF MINNA, NIGER STATE, NIGERIA

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ABTSRACT

The major structural features that favour ground water potential in basement rocks are fractures, folds and inter-connected and penetrative joints. Joints often impart a well-develop fracture-induced permeability to bedrocks, as a result, joints strongly influence, even control the natural circulation of fluids, groundwater and pollutants within aquifers. The structural elements that accompany the tectonic event play different role in ground water quantity and quality within the basement complex of Nigeria. The study area falls within the north-western basement complex of Nigeria and extension of Kushaka Formation that comprises of migmatite, schist and granitiod of varying textural and mineralogical composition. Field mapping unrevealed the lithology and structural elements of the area while XRF was used to determine trace and major elements concentration in the sampled rocks. This study therefore unravels the lithology, geological structures and geochemical weathering intensity, and its control on groundwater potentials in Minna area. Correlation of all observed, measured structural elements and obtained bole-holes log with water yield potential in the study area varies with lithology. The average Ruxton Ratio Weathering Index value suggested of rocks in the area revealed weak weathering and intermediate weathering respectively. It is therefore worthy to note that Maitumbi, part of Tunga, Tunga Gade, Chanchaga and the Nigeria Army Barrack areas that constitutes the central part of the study area favored high yield ground water potential throughout the years. Its therefore recommended that the areas with low yield ground water potential and intermediate weathering index should be properly investigated before sinking borehole and a minimum depth of one hundred and eighty meters will increase water yield.

Key Words: *Structural elements, Aquifer, Groundwater, Weathering, Lithology*

INTRODUCTION

Geological structures and their role in ground water flow control, aid in the understanding of fundamental geological ground water potential and its interaction within rocks of a region. Structures such as faults and joints act as conduit it may make rocks good aquifers. Also, faults act as drains, lowering water table and thus affecting the distribution of groundwater (Mulwa *et al.*, 2005). The major structural features that favored ground water potential in basement rocks are fractures, folds and inter-connected and penetrative joints. Joints often impart a well-develop fracture-induced permeability to bedrocks, as a result, joints strongly influence, control on the natural circulation (hydrogeology) of fluids, groundwater and pollutants within aquifers. Fracture networks with shorter penetrative lengths and higher density on crystalline rocks, lower permeability, and less porous media lengths compare to fracture networks with longer penetrative lengths and lower density. Yield of water wells drilled on crystalline rock aquifers is characterized by the occurrence and interconnectivity of open, saturated fractures which decrease with increased depth (Mulwa *et al.,* 2005).

The Nigeria basement complex is known for its structural complexity associated with major tectonic event of the Pan-African Orogeny (600 my). The structural elements that accompanied the tectonic event play different role in ground water quantity and quality within the basement complex of Nigeria.

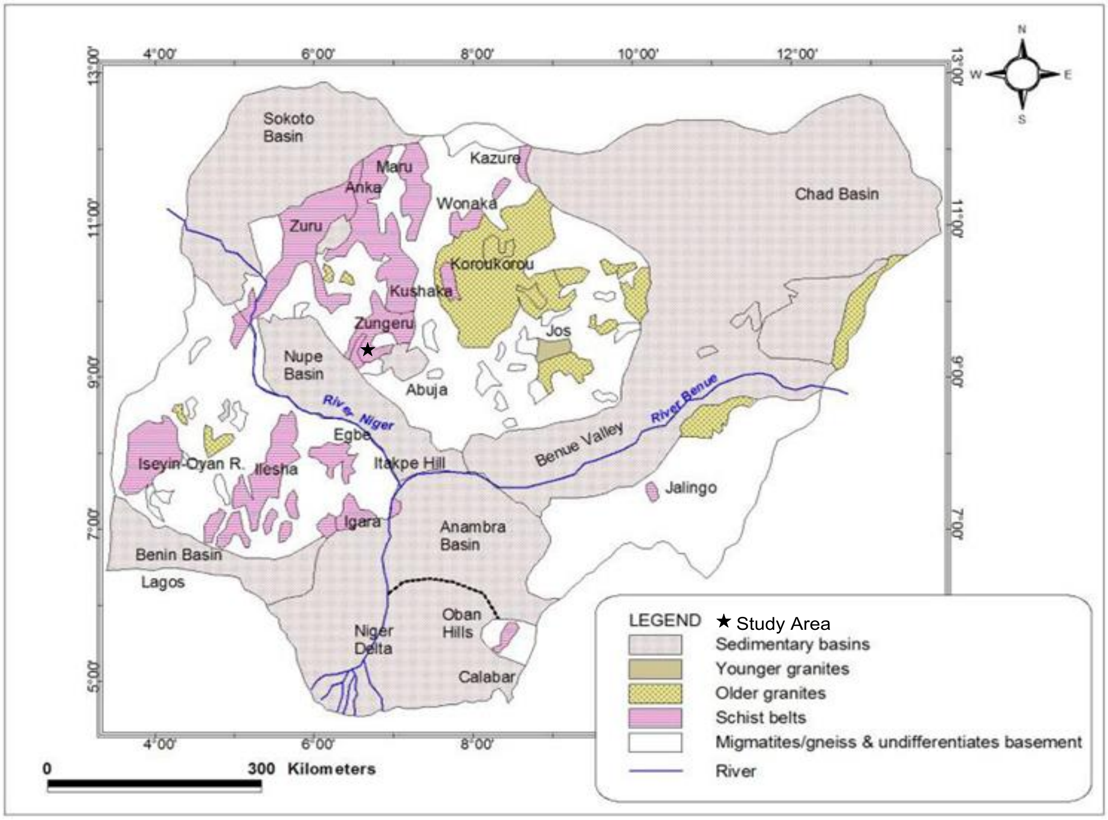
The study area falls within the north-western basement complex of Nigeria and extension of Kushaka Formation that comprises of migmatite, schist and granitiod of varying textural and mineralogical composition Ajibade (2008). The first attempt at systematic structural investigation in the area was carried out by Ajibade (2008), he identified four small sets scale structures of folds, foliation and lineation in the area. Alabi (2011), identify non-penetrating cross joints and faults which were mostly quartz healed or filled on granitic out crops in the north-eastern part of Minna. Akande *et al,* (2016) reported higher concentration of fractures, and hence possibility of weathered/fractured aquifer in the southern part of Minna and recommended borehole depth of 40 to 50 meters for optimum yields. Within the Birnin Gwari Formation in the northern part of Minna is fracture depth ranging from 25 meters to 130 meters, as reported by Idris-Nda *et al,* (2015).This study therefore unraveled the lithology, geological structures and geochemical weathering intensity, and its control on groundwater potential in Minna area.

MATERIALS AND METHODS

Geological setting of the study area

The surface geology of the Minna area is typical of the geology of the Kusheriki – Minna region basement, comprising of three groups of crystalline rocks of typical Nigeria basement complex (Figure 1). The basement rocks in the area includes; gneiss and migmatites with relicts of supercrustal rocks, north-south trending medium – low grade schist belt, Pan-african Granite which intrude both the gneiss and migmatites and the medium – low grade schist belt. Two genetic types of migmatite were observed in the northwestern block of the Nigeria basement complex, one is believed to form as a result of ultra-metamorphism and anatexix during Archean and Eburnean (< 1800 My) while the other as a result of magmatic injection in to the low grade schist during the Pan-Africa orogeny (600 my) (Ajibade 2008). Ajibade (2008) classified the two migmatite in to early and Pan-Africa (late) migmatite based on their structural complexity.

The Kushaka Schist Formation underlies extensive area in Minna and has been intruded by Older Granite which led to migmatization of the Kushaka Formationin in the area. Generally, the older granite occur as batholite and ridges within the Kushaka Formationin ranges from medium – coarse grain and in some locations porphyritic (Alabi *et al*, 2014). Grant (1978) and Ajibade (2008) mapped small scale folds of steep to vertical plunges, and locally developed axial plane cleavage and schitosity in the Kushaka sheet north east of Minna sheet, and reported the small scale structures. Major fault mapped in the area occur in Zungeru northeastern part of Minna. Four phases of folds were recognized within the schist belt and gneissic complex of Kushaka Formation and in the Kusheriki region which extended to Minna area, these folds are of small scale and considered to have similar orientation with Birnin Gwari Formation, Evidence of extensive shearing was observed in the Kushaka Belt were schist, amphibolites intruded by tonalites and granodiorites (Grant, 1978). The shearing was observed between Gunu and Prina and along River Gora near Minna (Grant, 1978).



(Figure 1): Location of the study area within the Geology map of Nigeria (Modified after Bassey, 2012)

Geological Mapping

Field mapping was carried out in the area using GPS to take coordinates and elevations, compass clinometers to bearing and measure structural elements in order to evaluate the lithology and associated structural elements. Two main qualitative and quantitative methods were employed, the qualitative method was based on field mapping, hand specimen observation and descriptions of rock samples based on mineralogical, textural observation and naming of rocks. The quantitative method was based on measurement of strikes and dips, joints/veins and foliations orientation for structural analysis, the structural elements measured helped in deducing attribute and tectonic forces that produce them. Joint length, aperture and spacing were quantified by observing and measuring the discontinuity trace lengths, and the aperture width on surface exposures, while joint

roughness was determined by visual observation as described by Palmström (2001). Average measured joint spacing was calculated using formula proposed by Sharma and Saxena (2001).
Geochemical analysis was done using X-ray fluorescence spectroscopy (XRF) to determine trace and major elements concentration in the samples, the XRF analyses were carried out at the National Agency for Science and Engineering Infrastructure (NASENI) center of excellence in Nanotechnology and Advanced material in Akure, Ondo State.

Fifty-two motorized and hand pump boreholes were visited during the study (wet and dry seasons) to ascertain the depth of borehole and onsite quantitative water yield, this was also combined with oral interaction with the host communities and households in the study area. Also, information of some boreholes was obtained from the reports (borehole log) submitted to the clients. The choice for each visit borehole was based on lithology variation encountered during field mapping in the study area. Borehole log data revealed depth range between 120 and 250 meters on the mica schist lithology and between 80 and 150 meters on the granitiods.

RESULTS AND DISCUSSION

The lithologic units mapped include granite (biotite and muscovite granites), mica schist, quartzite, and migmatite (Figure 2). The mica schist, quartzite, and migmatite which were intruded in place by un-deformed to partially deformed granitoid, which form prominent topographic batholith and ridge features at the northwestern and northeastern part of the Minna. Granitic plutons covers about 65% of the surface area while mica schist, quartzite and migmatite account for the remaining 35% of the rocks mapped in the area (Figure 2), the rock suites were concordantly and discordantly intruded by quartzo-feldsphatic veins, pegmatite and aplitic veins. The granitiod ranges from medium – coarse grained granite and tonalite, coarse porphyrite biotite granite (Plate I), while the mica schist is inter-layered with relicts of quartzite and amphibole schist in some places. Small outcrop of migmatite display lit-par-lit injection of light grey color mineral which occur as flat-lying outcrops in the northeast part of Minna along new Maikunkele – Maitunbi bypass (Plate II), this migmatite according to Ajibade 2008 is classified as Pan-Africa and late migmatite due to it simple structure of alternating schistose, granite or aplitic layers. At the eastern part of the study area is small outcrop of quartzite that locally grade into fine-grained quartz-mica schist forming small ridge.

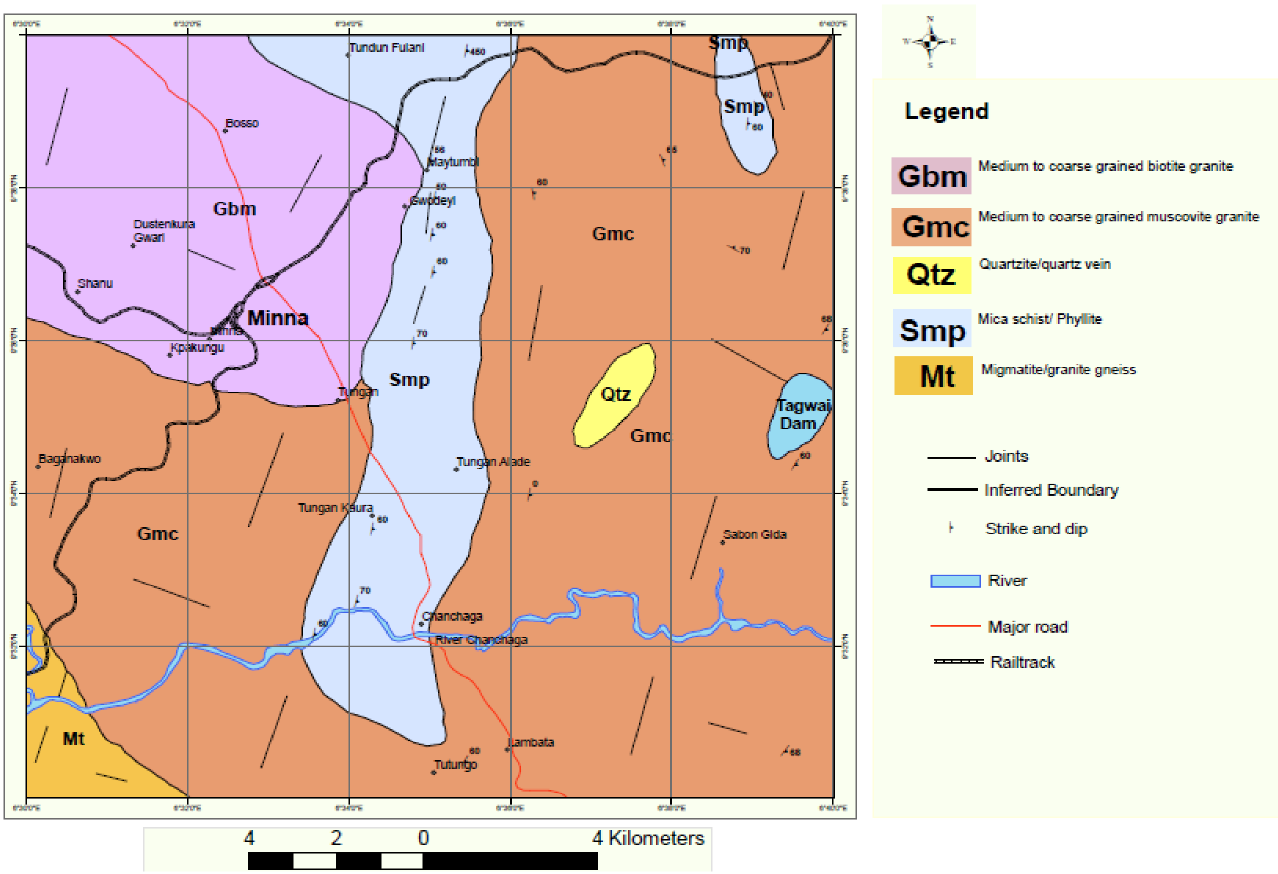


Figure 2: Geology map of Minna and its Environs

Plate I: Coarse porphyrite biotite granite outcrop (9° 39' 10″ N - 6° 37' 02″)

Plate II: Migmatite outcrop (9° 38' 10″ N - 6° 35' 09″)

Structural Geology

Varieties of structural element imprints where encountered, observed and measured where necessary and documented. The structures observed on granites are brittle structures imprint such as; joints, fractures and minor faults formed from tensional forces that accompanied crystallization of magma during Pan-Africa orogeny in the area while on mica schist and migmatite the structures include; foliations, lineation, joints and simple folds formed as a result of compressional tectonic forces resulting in ductile deformation of these rocks impacted by Pan-Africa orogeny.

Most of the joints in the field are simple joints and are either open (average aperture of 3centimeters) or healed joints (containing pegmatite, aplite and quartz veins) and are limited in length criss-crossing on granites in some locations (Plate III), while most of the joints observed on schist and migmatite were developed parallel to the foliation planes in SW-NE direction (Plate IV).

Plate III: Cross joint on Coarse grained biotite granite outcrop (9º 39' 10″ N - 6º 37' 02″)

Plate IV: Joint developed along foliation plane in schist (9º 37' 06″ N - 6º 39' 01″)

Joints observed in the field on mica schist (meta-sedimentary) are of two genetic types, namely;

hinge parallel joint and hinge perpendicular single joint, the hinge parallel joints runs in SW – NE direction parallel to the fold hinge and perpendicular to the fold limb while the hinge perpendicular single joint run in SE – NW direction perpendicular to the fold hinge and bisect foliation planes (Figure 3), these joints are tectonic product of shearing, compressional and tensional forces that accompanied emplacement of granites (Pan-African granite) and formation of mica schist (meta-sedimentary) and migmatite during the Pan- African orogeny.

Penetrative nature of the nature of hinge parallel joint act as conduit for ground water flow and favors water reservoir or aquifer within the mica schist in the study area, this conformed with the field observation, borehole log data (average depth of 160 meters) and good water yield throughout the year of visited boreholes in the study area.

Granites displayed regular and irregular joint systems in their occurrence which may be due to surface tensile forces during the cooling of magma that preceded Pan-African orogeny, these joint systems are non-penetrative joint and may retard ground water flow within the granites, except in some locations where there are intrusions of weathered pegmatites and well-connected joint system which favor water reservoir or aquifer for a short period in a year.

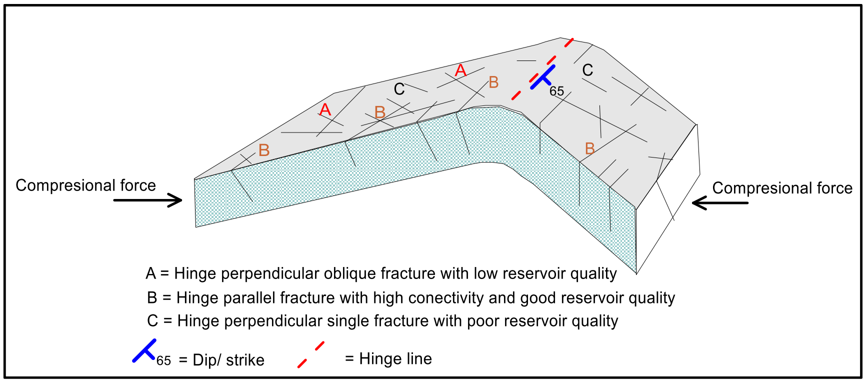


Figure 3: Schematic diagram of fracture system associated with schist in the study area

Generally, the plots of joint data on rose diagram show two principal joint sets of NE – SW and NW – SE directions on the granitiod (Figure 4a) while schist and migmatite trend NE – SW direction (Figure 4b). The schist and migmatite show average dip angle of 58°/165° while the dip direction is NE which concede with foliation direction (Figure 5a), Stereo net plot suggest steeply dipping of the mica schist in and may favor potential for water reservoir (Figure 5b).

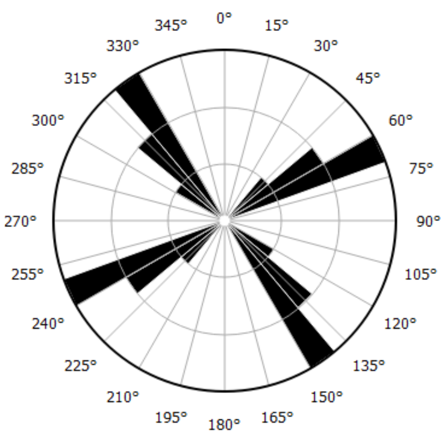


Fig. 4a: Joints trend on granite

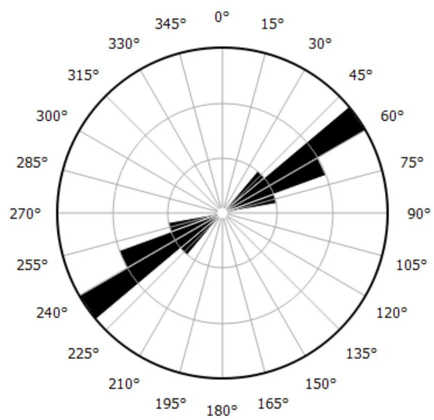
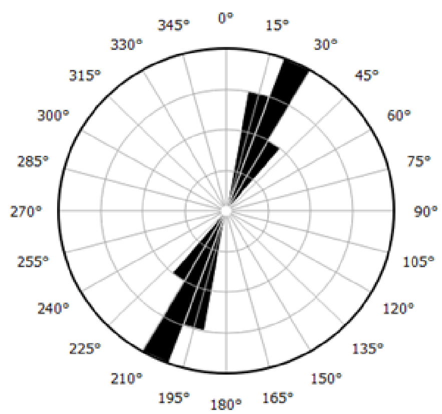


Fig. 4b: Joint trend on schist and migmatite



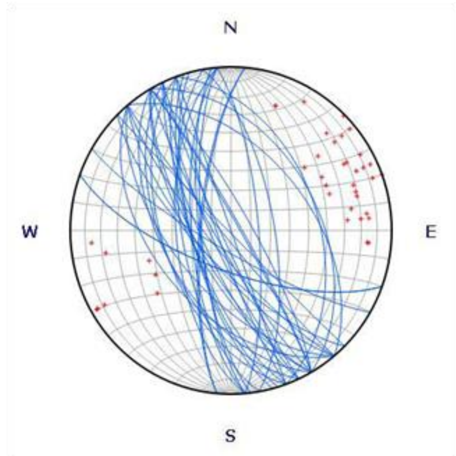


Fig. 5a: Foliation plane trend in schist and migmatite Fig. 5b: Dip angle of schist and migmatite

Average joint spacing on granites is 1.3 cm while that of mica schist is 3.3 cm suggest compressional tectonic stress impacted on the meta-sedimentary rock (schist) during the Pan-African orogeny, Average of 1.3 cm open joint spacing on granites suggest non-uniform tensile tress develop at the surface during the crystallization of magma and syn-genetic joint system, while closely joint spacing on mica schist suggest compressional tectonic stress impacted on the meta-sedimentary rock (schist) during the Pan-African orogeny representing post-genetic joint system.

According to Sharma and Saxena 2001, volumetric joint count of between 0.02 and 4.5 means low volumetric joint while > 4.5 means high volumetric joint. In study area average volumetric joint of granites is 2.3 while that of mica schist is 5.6 suggesting high frequency of joints in mica schist as a result of intensive Pan-African compressional forces and faulting.

Correlation of all observed, measured structural elements and obtained data log with bole-holes water yield potential characteristics in the study area varies with lithology in the area. The mica schist at the southern part of the study area favored high – medium water yield which suggest penetrative and well-connected joints that provide good aquifer, while the northern part favor low water yield particularly during the peak of dry season suggesting shallow penetrative, and poor connectivity of joints require to provide good aquifer system. The granites favor low to poor water yield and completely dry during the dry season, this may be attributed to high surface run-off, non-penetrative joint or weathering probably play a major role in the conversion of feldspars and hydrolysis of micas in pegmatite in granite into swelling clay that fill the joints and resulted to poor aquifer system.

Geochemical analysis

The major oxide composition of basement rocks is presented in Table 1a. The rocks generally have high SiO_2 contents.

Table 1: Percentage major oxide distribution in basement complex rocks

Oxide (wt %)	Medium grained Granite **(#15)** Minimum Maximum Average	Muscovite schist **(#5)**	Corse grained Granite **(#6)**	Biotite Schist **(#9)**	Migmatitic Gniess **(#3)**
SiO_2	73.2 74.01	58.65	52.93	59.89	73.07
Al_2O_3	73.89	15.12	11.09	14.13	13.56
Fe_2O_3	13.45 14.50 13	8.09	14.52	8.23	0.76
CaO	98	0.29	9.03	0.17	1.45
MgO	0.46 1.45	3.83	10.51	3.95	0.26
Na_2O	0.96	3.01	0.34	4.05	4.65
K_2O	0.66 0.75	1.89	0.14	2.10	3.56
MnO	0.17	0.16	0.14	0.22	0.07
TiO_2	0.01 0.09	1.32	0.68	1.01	0.08
P_2O_5	0.05	0.09	0.12	0.08	0.07
Cr_2O_3	3.00 2.79	0.03	0.06	0.05	0.07
LOI	2.99	6.09	6.38	6.99	0.67
	6.55 6.44				
	6.50				
	0.01 0.66				
	0.04				
	0.02 0.08				
	0.05				
	0.02 0.03				
	0.03				
	0.05 0.05				
	0.05				
	0.44 0.97				
	0.71				
SiO_2/Al_2O_3	5.28	3.87	4.77	4.24	5.39

Number of samples **(#)**

Ruxton (2006) proposed weathering index known as Ruxton Ratio that is best suited for determinations of weathering intensity of igneous and metamorphic rocks from humid regions using SiO_2/Al_2O_3 ratio, Ruxton Ratio value of <3.9 for intensively weathered rocks, 4 - 4.5 for moderately weathered rocks and >4.5 for least weathered rocks. In this study the average Ruxton Ratio value for medium grained granite (5.28), coarse grained granite (4.77) and migmatite gneiss (5.39) suggested weak weathering while muscovite schist (3.87) and biotite schist (4.24) suggested intermediate weathering (Figure 6), this result agreed with the field observations, measured structural elements and the obtained data log and bole-holes water yield potential characteristics in the study area.

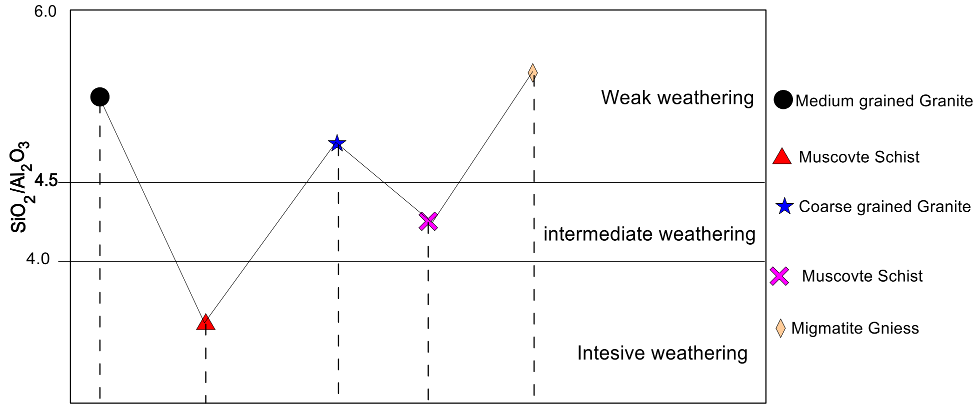


Figure 6: Plots of weathering intensity for basement rocks of the study area (Ruxton 1968)

CONCLUSION AND RECOMMENDATIONS

Hydrogeology potential variation in the study area is control by rock type distribution, structural elements that were impacted by the Pan-African orogeny, also the rocks elemental composition variation that influenced the weathering intensity play a major role in the aquifer system water potential of the studied area. It is therefore worthy to note that Maitumbi, part of Tunga, Tunga Gade, Chanchaga and the Nigeria Army Barrack areas that constituted the central part of the study area the favored high yield ground water potential throughout the years. Its therefore recommended that the areas with low yield ground water potential and intermediate weathering index should be properly investigated before sinking borehole and a minimum depth of one hundred and eighty meters will increase water yield.

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