Vol. 15(2), pp. 70-89, April-June, 2020
DOI: 10.5897/IJPS2020.4870
Article Number: 28678DF63872
ISSN 1992-1950

http://www.academicjournals.org/IJPS

ACADEMIC JOURNALS

International Journal of Physical Sciences

Full Length Research Paper

Determination and establishment of empirical relationship between magnetic susceptibility and mechanical properties of typical basement rocks in Southwestern Nigeria

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Received 17 February 2020; Accepted 11 May, 2020

Magnetic susceptibility and mechanical properties of rocks in a typical basement complex Southwestern Nigeria were correlated with the aim of establishing empirical equations relating the two parameters and evaluate the parameters as related to its competency in hosting civil structures. A total of thirty rock samples were taken across the geology of the area and subjected to mechanical properties determinations. Magnetic susceptibility measurements were carried out on in-situ fresh rock outcrops and it ranges from 2.1×10^{-4} to 9.5×10^{-4}. This signifies the amount of iron content in the rocks and its level of induration. The values of uniaxial compressive strength (UCS), Young's modulus (E), shear modulus (μ), bulk modulus (K) and Poisson's ratio (V̀) ranges from 49 - 107 MPa, 1003 - 3321 MPa, 416 - 1310 MPa, 707 - 2728 MPa and 0.232 - 0.316, respectively. The cross plots of the mechanical parameters with the magnetic susceptibility exhibit a direct linear relationship. The relationship shows a good correlation with coefficient of correlation (R) ranging from 0.60 to 0.85 for uniaxial compressive strength, bulk modulus and Poisson's ratio. The magnetic susceptibility relationship with shear and Young's Modulus are relatively weak with coeffecient of correlation (R) of 0.44 and 0.47, respectively. This implies that, magnetic susceptibility measurement may not be reliably applicable in determination of the stiffness of rocks and the rate of resistance of rocks to prevailing shearing loads. The validation results show that, reliable mechanical properties of rocks can be estimated from magnetic susceptibility measurements using the established empirical equations.

Key words: Magnetic, susceptibility, mechanical, properties, rocks.

INTRODUCTION

The mechanical strength of the subsurface bedrocks as foundation rock for any civil engineering structure requires having adequate knowledge of the mechanical properties of the rock before any structural design can be

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made. Rocks normally deform in response to an applied load, changes in temperature or water content and growth of secondary minerals such as Zeolite, Chromite and Calcite filling cracks and pores. This poses negative effect on the overall strength of rock (Morrow et al., 2001). The durability and stability of civil structures depend on the mechanical strength of the underlying rock/subsoil. Building collapse incidences are common in Southwestern Nigeria; despite the development of proactive, non-destructive, time saving, low cost and effective engineering idea of applying geophysical methods in delineating subsurface condition. 52% of the building collapse recorded in Nigeria is as a result of design error (Oke, 2011). This may be due to the mechanical strength of bedrocks hosting the foundation of the building. Foundation is one of the structural members of any building and any problem arising from it, will surely affect the whole building (Fadamiro, 2002). The mechanical strength of bedrocks is a function of its thickness.

This implies that bedrock can withstand more load based on its thickness even with moderately mechanical strength. Bedrock ridges and depressions are inimical to stability of foundations of civil engineering structures (Adelusi et al., 2013). The pore size can be a microstructural parameter that has strong influence on the uniaxial compressive strength of a rock that contains equal pores (Patrick et al., 2014). Structural design and quality management which depend on the condition of the underlying bedrock are the two major factors normally considered when examining causes of building collapse (Olusola, 2002). Rock mechanics properties can be characterized using correlated laboratory test and numerical interpretations of well logs (Hao et al., 2016). Good empirical relationship has been established between geophysical property; ultra-sound velocity (Vp)) and mechanical properties for evaluation of rock brittleness (B) (Chary et al., 2006). Also, good relationships were established between velocity and porosity as physical properties and rock strength which includes unconfined compressive strength and internal friction angles of sedimentary rocks (Chandong et al., 2006).

The conventional way of determining the mechanical properties of the parent rocks which weathered into subsoil is time consuming and very costly. These challenges call for the need to establish methods which are less time consuming and cost effective (Bayode et al., 2009). This has therefore necessitated this research work. This study aims at evaluating foundation competency conditions of typical Basement rocks by comparing their magnetic susceptibility and mechanical properties with a view of establishing empirical relationships relating them. This will help to determine the mechanical suitability of basement rocks as foundation bedrock for civil engineering developments by using geophysical approach.

Study area

Ado-Ekiti, Southwestern Nigeria covers a total area of 346.5 km^2. It is dominated by crystalline rocks (Figures 1 and 2), which consist mainly of migmatite-gneiss-quartzite complex, older granites, quartzite, charnockites, and fine to medium grained granites (Ayodele and Ajayi, 2016). In the area, there is a close association between the charnockites and granitic rocks due to their field relationship as documented in the Basement Complex Rocks of Nigeria (Rahaman, 1979). A plutonic complex containing both charnockitic and non-charnockitic granite rocks occurs within the amphibolite facie rocks of gneisses and migmatites in Ado Ekiti (Olarewaju, 1987).

METHODOLOGY

Magnetic susceptibility measurement

Magnetic susceptibility meter, which measures the amount of iron-bearing minerals in rock, was used as a geophysical tool for the study. It determines the “magnetisability” of rocks in their natural environments (Frantisek et al., 2009). It detects how convenient a rock can retain magnetic property after been exposed to an external magnetic field (Tarlingar and Hrouda, 1993). The relationship between the magnetic field strength, flux density and permeability of rocks is given by:

$$B = \mu H \text{ (Expressed in Tesla or flux per unit area)} \quad (1)$$

B is magnetic flux density, H is field strength
μ is absolute permeability of the medium.
In a vacuum, it is given by;

$$\mu = \mu_0 = 4\pi X 10^{-7} \text{ (Expressed in Henry per meter)} \quad (2)$$

Unit of flux density B is Tesla (T), commonly used unit is nano Tesla due to lesser size of anomalies (1nT = 10^{-9}T). Relative permeability, susceptibility and magnetization can also be related in a medium other than vacuum; the absolute permeability is given by;

$$\mu = \mu_r \mu_0 \text{ (Expressed in Henry per meter)} \quad (3)$$

From Equation 1, B = μH
Therefore,

$$B = \mu_r \mu_0 H \text{ (Expressed in Tesla or flux per unit area)} \quad (4)$$

Where, μ_0 is absolute permeability of vacuum

$$B = \mu_r \mu_0 H = \mu_0 H + \mu_0(\mu_r - 1)H \text{ (Expressed in Tesla)} \quad (5)$$

$$B = \mu_0 H + \mu_0 \kappa H, \text{ (Expressed in Tesla)} \quad (6)$$

where $\kappa = \mu_r - 1$;
Therefore,

$$\mu_r = 1 + \kappa \text{ (Expressed in Henry per meter)} \quad (7)$$

Where μ_r is the relative permeability of the medium and κ is the magnetic susceptibility (Telford et al., 1990).

Rock magnetic susceptibility was measured using the Mag-Rock Magnetic Susceptibility Meter. The positions of the sampling points

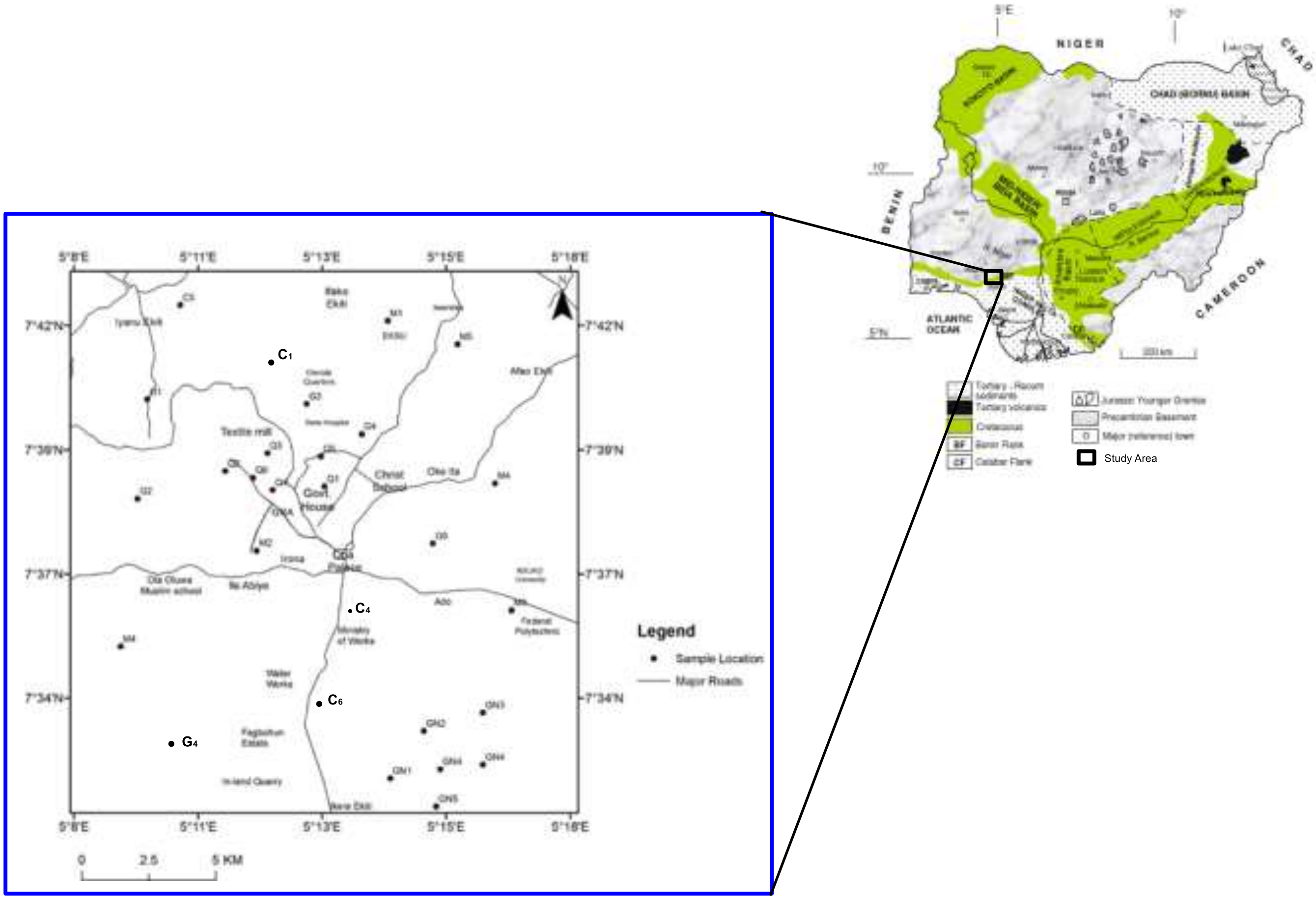

Figure 1. Map of Nigeria showing the study area.
Source: Modified after Ajayi et al. (2019).

surface were cleaned with methylated spirit before taking each measurement. A total of three hundred (300) measurements (ten readings per location) were taken at the thirty (30) sampling locations which were distributed across the study area.

Determination of mechanical properties of rocks

Sample collection and preparation

Fresh samples of rocks using ISMR standard were collected from outcrop within the study area (Figure 1). A total of thirty rock samples of cubic shape of 2 by 1.5 by 6 cm (Figure 2) were collected. The actual dimension of each of the prepared rock samples was determined and recorded. Each of the prepared samples was mounted on the Uniaxial Compression testing machine. The dial gauge and the load gauge of the machine were standardized to zero reading. The dial gauge measures the strain on the sample, while the load gauge measures the stress on the rock sample. The coarse adjustment load roller is then turned until the rock breaks. The plunger was made to touch the surface of the specimen, and the load and penetration measuring dial was set to zero. The plunger was made to penetrate the prepared rock sample at constant rate of 1 mm per min. The deformation readings were taken at every 25 deformation dial reading until the compacted rock specimen breaks or deforms. The normal stress was plotted against the axial strain. The peak of the resulted curve was taken as the Uniaxial Compressive Strength (MPa). The Young's Modulus was determined from the gradient of the stress-strain normal relationships before deformation took place (Table 1). From the uniaxial compression test curve, Mohr circle was generated from the normal stress and strain data. The shear modulus was determined from the shear stress-strain curve on the Mohr-circle.

Mavko et al. (2003) relate the young's modulus (E), shear modulus (μ) and the bulk modulus (k) as stated in Equation 8:

$$k = \frac{E\mu}{3(3\mu - E)} \quad \text{(Expressed in MPa)} \tag{8}$$

Poisson's Ratio (V) was obtained by applying Mavko et al. (2003)'s formula that relates it with the Young's Modulus (E) and the Shear Modulus (μ) as stated below.

$$V = \frac{E}{2\mu} - 1 \tag{9}$$

Correlation of geophysical and mechanical properties of the rocks

The regression plots of the magnetic susceptibility values as

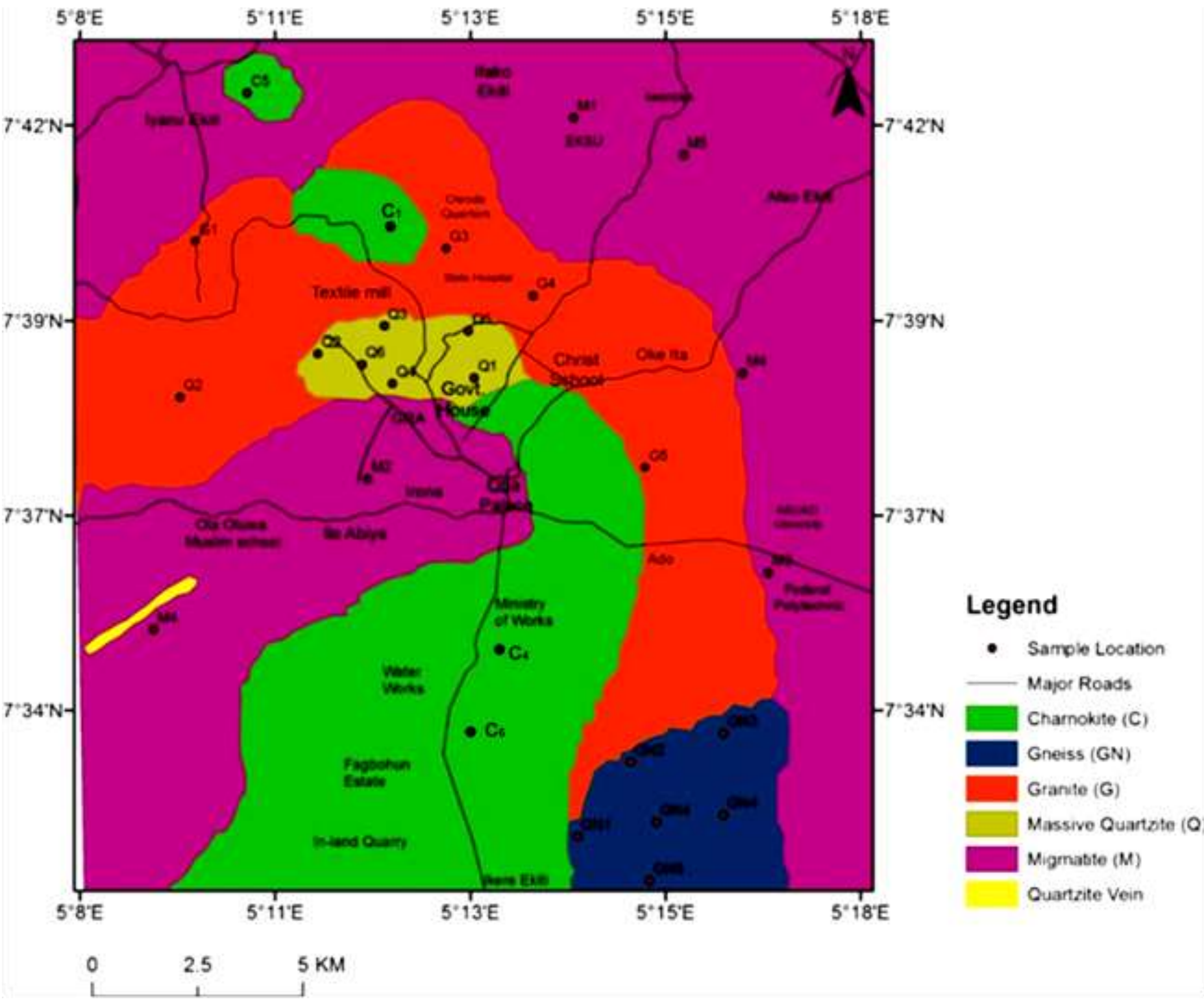

Figure 2. Geology Map of the Study Area Showing the Rock Types, Sampling Locations and the street roads. Source: Modified after Ajayi et al. (2019).

Table 1. Unconfined compressive test results of charnockite (sample S_1).

Deformation dial reading	Load dial reading (Unit)	Sample deformation (mm)	Unit strain E	% Strain	1 - ε	Corrected area (mm^2)	Total load on sample (Kg)	Sample stress (Mpa)
0	0	0	0	0.000	1.0000	3.780	0.00	0.00
25	21	0.25	463	0.463	0.9954	3.798	75.94	1.96
50	123	0.50	926	0.926	0.9907	3.815	444.77	11.43
75	252	0.75	1389	1.389	0.9861	3.811	911.23	23.31
100	323	1.00	1852	1.852	0.9851	3.851	1167.97	29.74
125	425	1.25	2315	2.315	0.9761	3.870	1536.8	38.95
150	530	1.50	2778	2.778	0.9722	3.888	1916.48	48.34
175	562	1.75	3241	3.241	0.9676	3.907	2032.19	51.01
200	706	2.00	3704	3.704	0.9630	3.925	2552.90	63.78
225	729	2.25	4167	4.167	0.9583	3.944	2636.06	65.54
250	640	2.50	4630	4.630	0.9560	3.963	2314.24	57.26

Table 2. Magnetic Susceptibility Values of the Study Area.

Sample	Rock type	Average magnetic susceptibility (10^{-9})	Average magnetic susceptibility (10^{-4})
C1	Charnockite	594200	5.942
C2	Charnockite	593300	5.933
C3	Charnockite	512600	5.126
C4	Charnockite	443000	4.430
C5	Charnockite	487100	4.871
C6	Charnockite	465000	4.650
M1	Migmatite	535800	5.358
M2	Migmatite	465200	4.652
M3	Migmatite	560200	5.602
M4	Migmatite	790700	7.907
M5	Migmatite	589600	5.896
M6	Migmatite	585300	5.853
G1	Granite	930500	9.305
G2	Granite	921700	9.217
G3	Granite	688400	6.884
G4	Granite	581600	5.816
G5	Granite	787900	7.879
G6	Granite	539200	5.392
GN1	Gneiss	338400	3.384
GN2	Gneiss	211300	2.113
GN3	Gneiss	186100	1.861
GN4	Gneiss	248100	2.481
GN5	Gneiss	412000	4.120
GN6	Gneiss	402800	4.028
Q1	Quartzite	0	0
Q2	Quartzite	0	0
Q3	Quartzite	0	0
Q4	Quartzite	0	0
Q5	Quartzite	0	0
Q6	Quartzite	0	0

geophysical parameters against each of the determined mechanical parameters can be represented by an empirical equation of the form;

$$Y = MX + C \qquad (10)$$

'Y' represents the mechanical parameters, 'X' represent the geophysical parameters, 'M' represent the gradient of the trend line, and 'C' is the intercept on the mechanical parameter (vertical) axis. From the plot, the relationship between the mechanical parameter and the geophysical parameters is best described by linear relationships, where the mechanical parameter is taken as the dependent variable.

RESULTS AND DISCUSSION

Magnetic susceptibility

The magnetic susceptibility values are presented in Table 2 and the magnetic susceptibility map is as shown in Figure 3. Table 3 indicated the classification and implications of the magnetic susceptibility judging from possible amount of the iron content within each of the rock sample. The value ranges from 0- 9.5. Relatively low values ($0 - 4 \times 10^{-4}$) were observed at the north-central and south-eastern parts of the study area dominated by quartzite and gneisses. The north-western, northern and north-eastern parts dominated by migmatitic rocks are characterized by relatively high susceptibility values ($6 \times 10^{-4} – 9.5 \times 10^{-4}$).

Mechanical properties

Uniaxial compressive strength (UCS)

The results of the mechanical properties in the study area

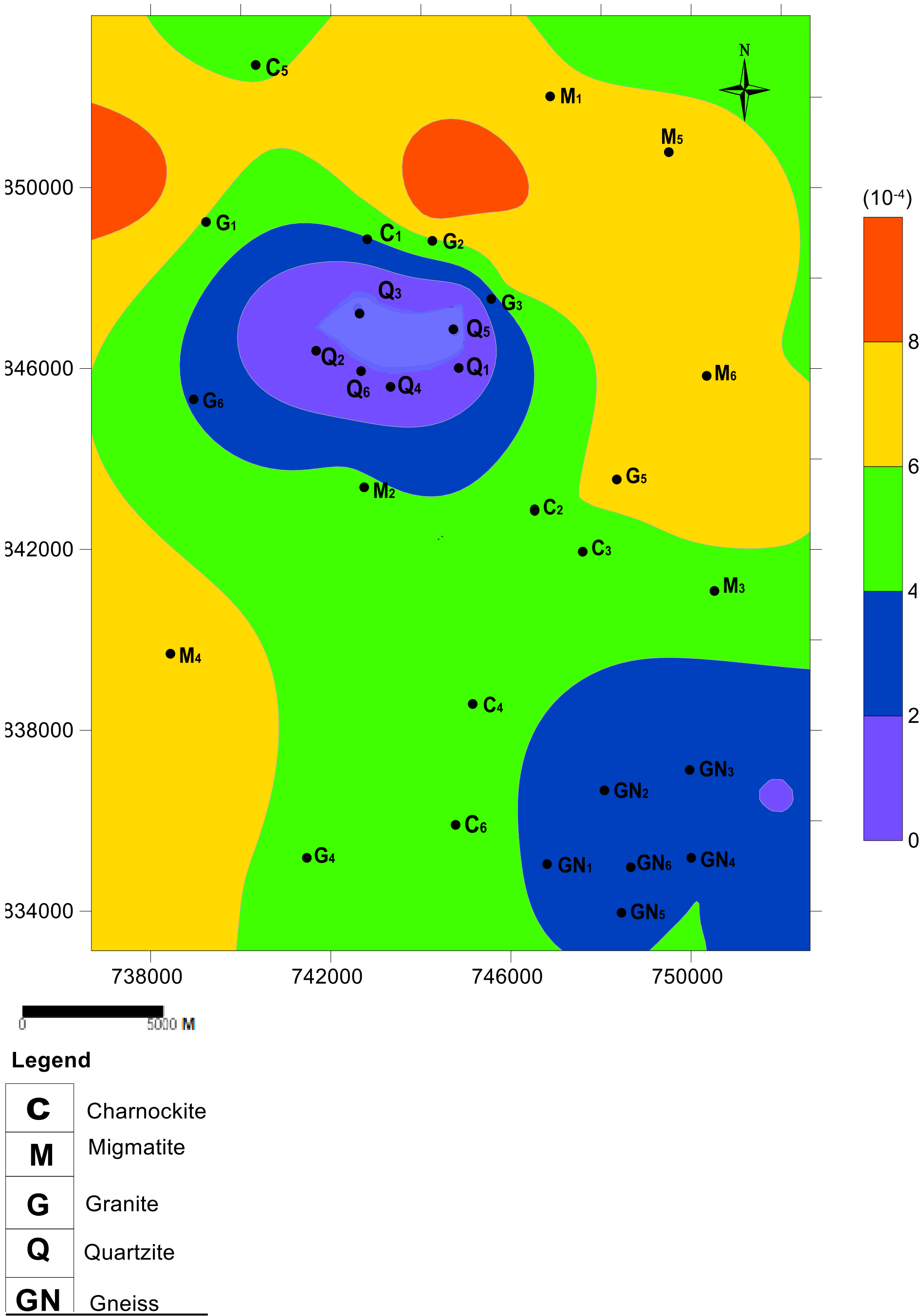

Figure 3. Magnetic susceptibility map of the study area.

are presented in Table 4. Figure 4a indicates UCS values of 40 to 70 MPa within North-central/South-eastern parts of the study area. These zones are dominated by charnockitic rocks. The north-eastern and the north-western parts of the study area show relatively high values (85 - 115 MPa).

The areas were underlain by granitic and migmatite rocks (Figure 2). The study reveals that migmatite and Granite are better foundation materials than other rock unit within the study area (Table 5). This suggests that rocks with high magnetic affinity will possess higher resistance to uniaxial compressive strenght.

Young's modulus

Young modulus is an indication of the stiffness of the rock when subjected to prevailing load. Figure 4b shows the

Table 3. Classification and implication of magnetic susceptibility values in the study area.

Description	Magnetic susceptibility (10^{-4})	Implication on surface structure
Very high	> 8.00	Very high iron content
High	6.00- 7.99	High iron content
Medium high	4.00-5.99	Medium iron content
Low	2.00 -3.99	Low iron content
Very Low	< 2.00	Very low iron content

Table 4. Result of mechanical properties of rocks within the study area.

S/N	Sample	Rock Type	Uniaxial compressive strength (MPa)	Young modulus (MPa)	Poisson's ratio	Bulk modulus (MPa)	Shear modulus (MPa)
1	C1	Charnockite	65.5	1709.72	0.251	1144.39	683.341
2	C2	Charnockite	74.2	2411.66	0.262	1688.84	955.491
3	C3	Charnockite	65.6	1881.57	0.252	1264.50	751.426
4	C4	Charnockite	63.4	1668.47	0.248	1103.49	668.458
5	C5	Charnockite	63.5	1677.11	0.262	1174.45	664.465
6	C6	Charnockite	77.7	2528.29	0.273	1856.31	993.044
7	M1	Migmatite	76	2172	0.271	1580.79	854.445
8	M2	Migmatite	72.3	3321.83	0.267	2376.13	1310.904
9	M3	Migmatite	81.5	2370.4	0.288	1863.52	920.186
10	M4	Migmatite	91.3	2677.6	0.297	2198.36	1032.228
11	M5	Migmatite	71.2	1791.5	0.247	1180.17	718.324
12	M6	Migmatite	87.1	2677.6	0.288	2105.03	1039.441
13	G1	Granite	107.3	2766.08	0.307	2388.67	1058.179
14	G2	Granite	107.8	2364.78	0.316	2142.01	898.473
15	G3	Granite	92.1	2070.89	0.292	1659.37	801.428
16	G4	Granite	93.8	3105.3	0.294	2512.38	1199.884
17	G5	Granite	104.8	2705.6	0.314	2424.37	1029.528
18	G6	Granite	90.2	3359.05	0.294	2717.68	1297.933
19	GN1	Gneiss	69	1044.68	0.254	707.778	416.539
20	GN2	Gneiss	49.3	1311.49	0.242	847.216	527.975
21	GN3	Gneiss	55.8	1757.78	0.245	1148.88	705.936
22	GN4	Gneiss	57.8	2181.23	0.251	1459.99	871.795
23	GN5	Gneiss	57	1063.03	0.252	714.402	424.533
24	GN6	Gneiss	63.2	1426.46	0.259	986.487	566.505
25	Q1	Quartzite	48.8	2076.1	0.235	1305.72	840.526
26	Q2	Quartzite	59.8	1767.34	0.232	1099.09	717.265
27	Q3	Quartzite	59.4	1766.75	0.233	1102.84	716.444
28	Q4	Quartzite	58.3	2044.28	0.234	1280.88	828.314
29	Q5	Quartzite	40.2	1539.25	0.228	943.168	626.730
30	Q6	Quartzite	47.9	2091.88	0.235	1315.65	846.915

Young's modulus ranges from 1000-3400 MPa within the study area. Relatively low values (1000-21300 MPa) were observed around the south-eastern and north western parts dominated by gneiss and charnockite rocks. Relatively high values (2900 - 3400 MPa) are indicated within the western and southwestern parts mostly composed of migmatite rocks, while the medium values (1090 - 2450 MPa) are observed within granite dominated areas. The study reveals that migmatite has the highest stiff strength capacity which made it more

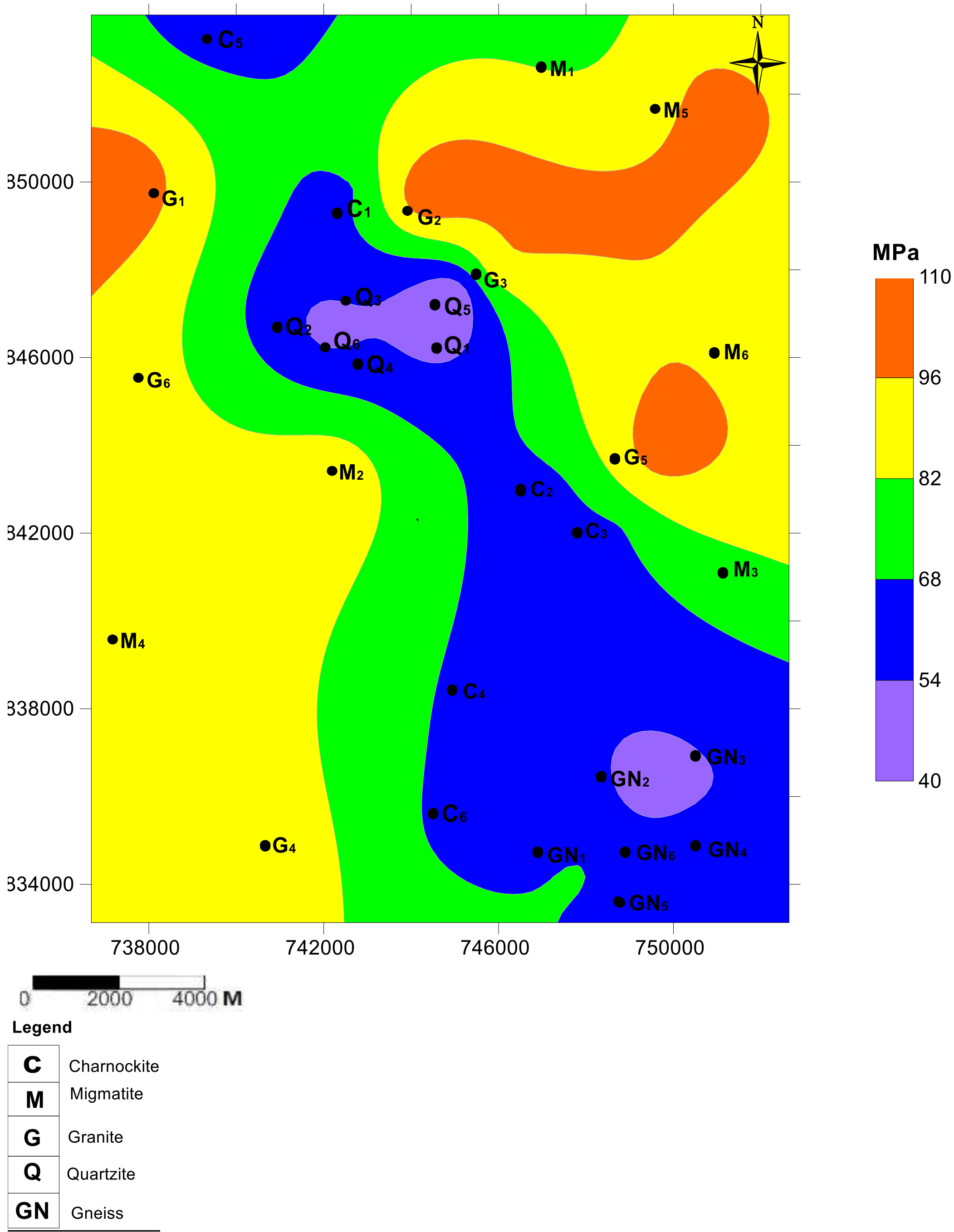

Figure 4a. Uniaxial compressive strength map of the study area.

Table 5. Classifications and implications of uniaxial compressive strength of rock samples within the study area.

Description	UCS strength (MPa)	Implication on the foundation
Very high	> 100	Sound
High	85- 99	Good for any structure
Moderately high	70- 84	Good for any structure except large dam
Low	45- 69	Variable
Very low	< 44	Unreliable

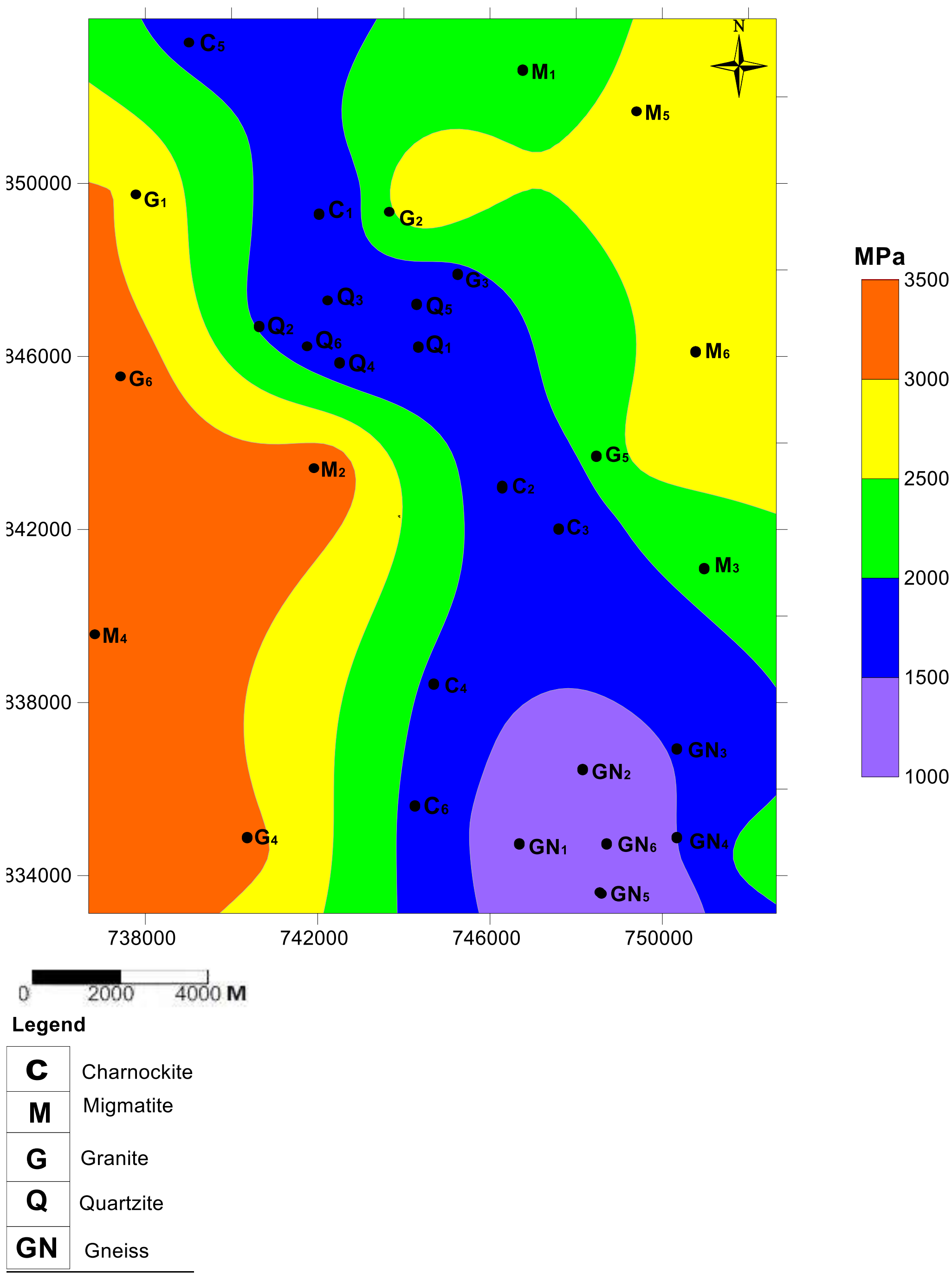

Figure 4b. Young modulus map of the study area.

reliable when subjected to angular or bending loads (Table 6).

Shear modulus

The shear modulus distribution within the study area is as shown in Figure 4c. It ranges from 400 to 1350 MPa (Table 4). The map indicates relatively low values (400 to 860 MPa) within the north-west/south-east areas. These areas include quartzite and charnockite rock. The western and south-western parts, composed of migmatites and granites are characterised with relatively high shear modulus values (1200 -1400 MPa). The measurements show that the area dominated by Charnockite has comparatively low strength than areas

Table 6. Classification and implication of young's modulus within the studied area.

Description	Young's modulus (MPa)	Implication on surface structure
Very high	> 3240	Very stiff
High	2680- 3239	Stiff
Medium high	2120- 2679	Medium stiffness
Low	1560- 2119	Low stiffness
Very low	< 1559	High yielding

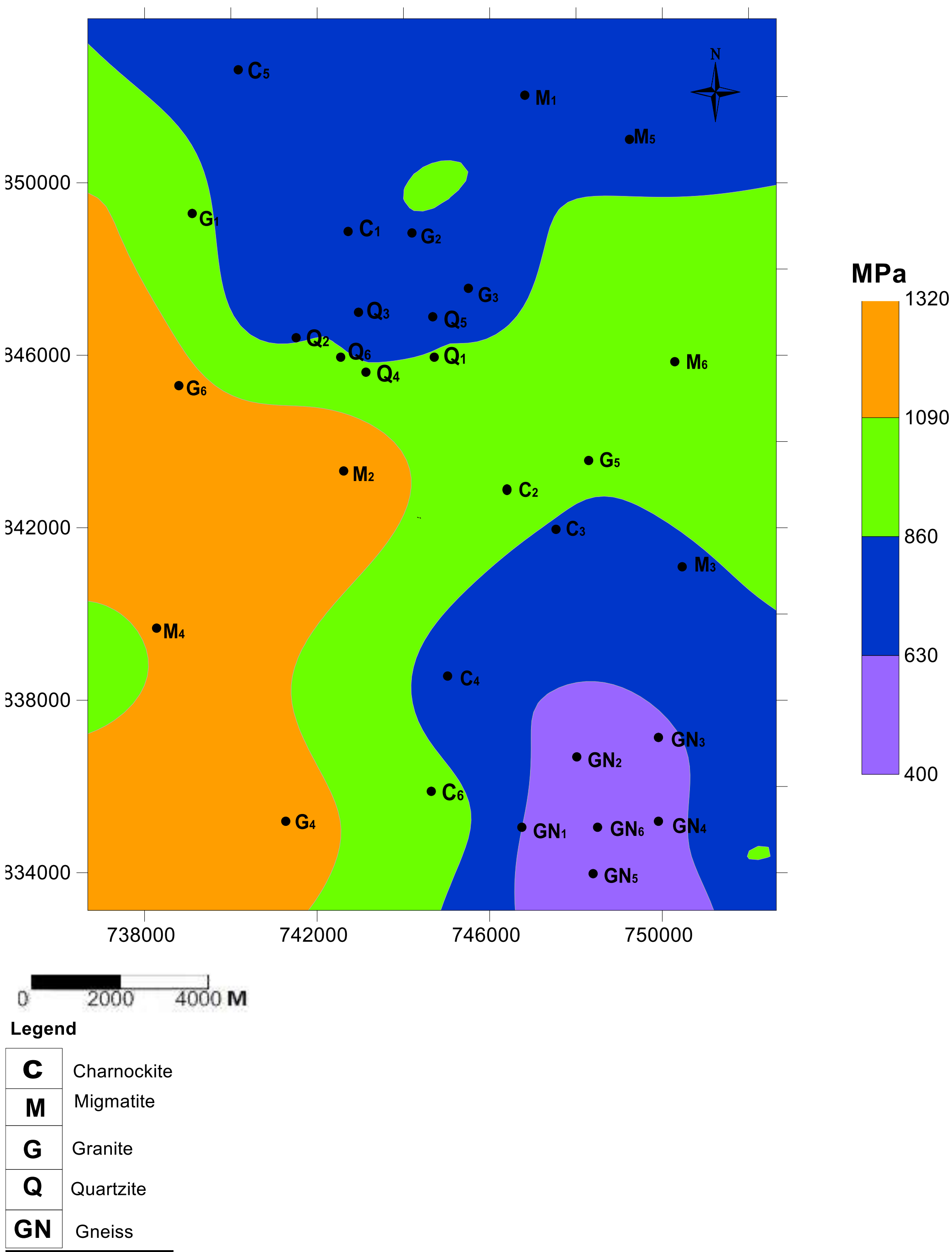

Figure 4c. Shear modulus map of the study area.

Table 7. Classification and implication of shear modulus within the studied area.

Description	Shear modulus (MPa)	Implication on surface engineering structure (To shearing forces)
Very high	> 1320	Highly resistive
High	1090 - 1319	Resistive
Medium high	860 - 1089	Medium resistance
Low	630 - 859	Yielding
Very low	< 629	Very yielding

underlain by migmatite and granite rock. Thus, migmatite and granite have proved to be more resistive to shearing stress than other rock types characterising the study area (Table 7).

Bulk modulus

It describes how resistive a material can be to compressive forces. The bulk modulus (k) map of the study area is as shown in Figure 4d. The value ranges from 700 to 2900 MPa. It reveals relatively low values (770-1200 MPa) of bulk modulus within the north-eastern, north-west and south-eastern parts of the study area. These areas are dominated by quartzite and gneissic rocks. The relatively high values (2500 – 2900 MPa) as indctaed in Table 8 were observed within the south-western and the eastern parts of the study area, which are geologically dominated mostly by migmatite and granitic rocks. This implies that migmatite and granitic rocks are more sound to resist susceptibility to failure when subjected to all side pressure compared to other rock types within the study area.

Poisson's ratio

Poisson's ratio describes the ratio of the longitudinal displacement to the axial displacement under compressive stresses. The values range from 0.225 to 0.32 (Figure 4e). Relatively low values as classified in Table 9 (0.225-0.25) were obtained in the areas underlain by quartzite, charnockite and gneiss. This implies that quartzite, charnockite and gneiss are weaker compared to other rock types within the area. Relatively higher (Table 9) values (0.3 - 0.33) characterize the area underlain by magmatic and granitic.

Evaluation of the geophysical and mechanical results

Relationship between the magnetic susceptibility (MS) and uniaxial compressive strength (UCS)

The values of iron minerals in a rock contribute to the elastic strength of the rock. The regression plot of magnetic susceptibility (Ms) against the uniaxial compressive strength (UCS) of the rock samples are presented in Figure 5a. The trend line equation for the cross plot gives coefficient of correlation (R) of 0.85, indicating a high correlation (Equation 11). This implies that magnetic susceptibility determination is reliably applicable in evaluating the stiffness of rocks for engineering purpose.

$$UCS = 7Ms + 38.91 \quad (11)$$

Where UCS is Uniaxial Compressive Strength, Ms is Magnetic Susceptibility (10^{-4})

Relationship between the magnetic susceptibility (ms) and Young Modulus (E)

The regression plot of magnetic susceptibility (Ms) against the Young modulus (E) of the rock samples is presented in Figure 5b. The trend line equation for the cross plot produces coefficient of correlation (R) of 0.47. This shows a relatively fair correlation (Equation 12). This implies that, magnetic susceptibility is not reliably applicable to determination of the stiffness of rocks for engineering purpose.

$$E = 150MS + 1357.4 \quad (12)$$

Where E = Young Modulus, Ms = Magnetic Susceptibility (10^{-4})

Relationship between the magnetic susceptibility(MS) and Shear Modulus (μ)

The regression plot of magnetic susceptibility (Ms) against the shear modulus (μ) of the rock samples is presented in Figure 5c. The trend line gives coefficient of correlation (R) of 0.44. Hence the equation shows a relatively weak correlation (Equation 13). This implies that magnetic susceptibility of rocks may not be reliably used to estimate the rate of resistance of rocks to prevailing shearing loads.

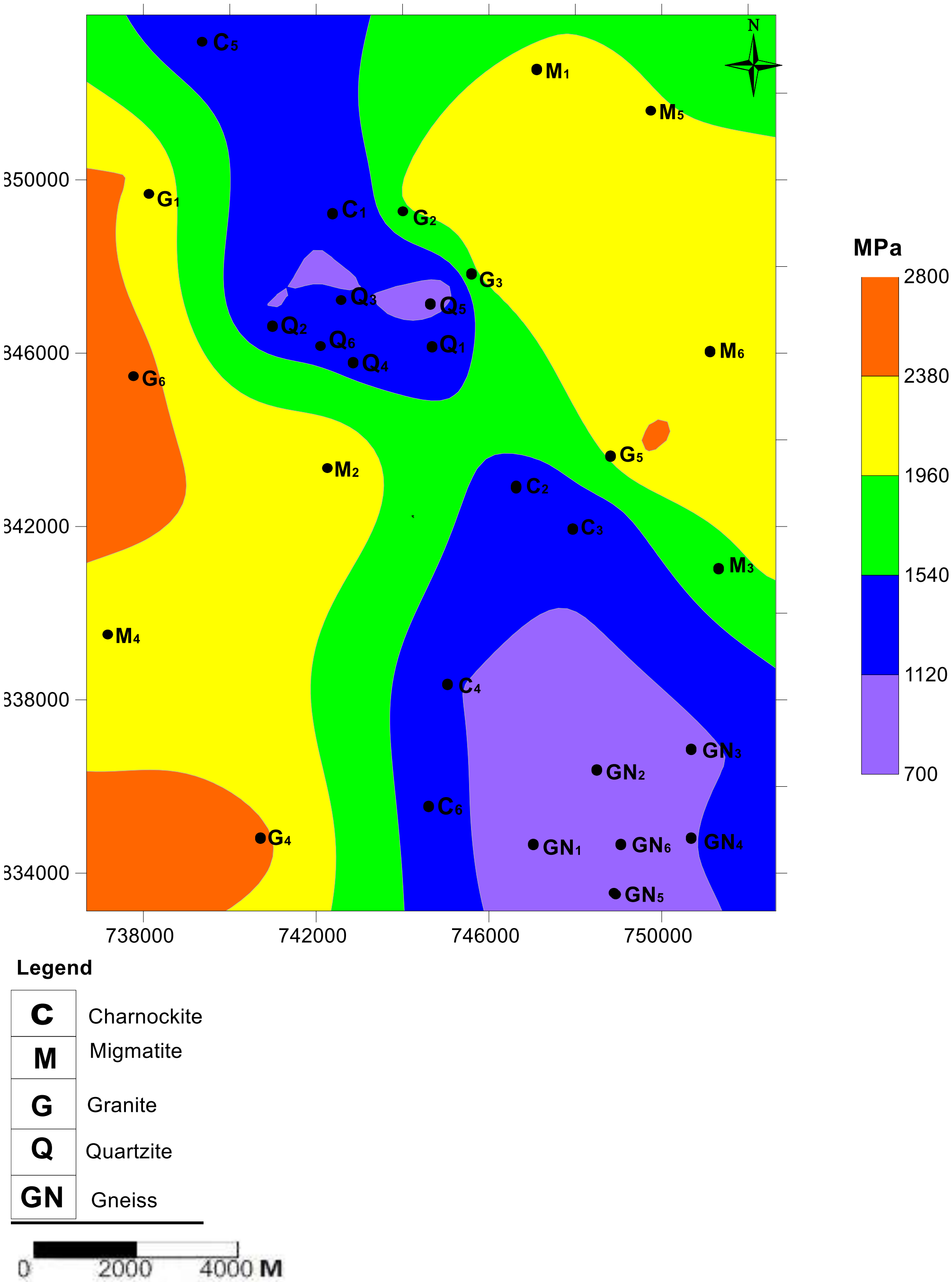

Figure 4d. Bulk modulus map of the study area.

Table 8. Classification and implication of bulk modulus within the studied area.

Description	Bulk modulus (MPa)	Implication on surface structure
Very high	> 2380	Sound
High	1960 -2379	Fairly Good
Medium high	1540 -1959	Good for any structure
Low	1120- 1539	Variable
Very low	< 1120	Unreliable

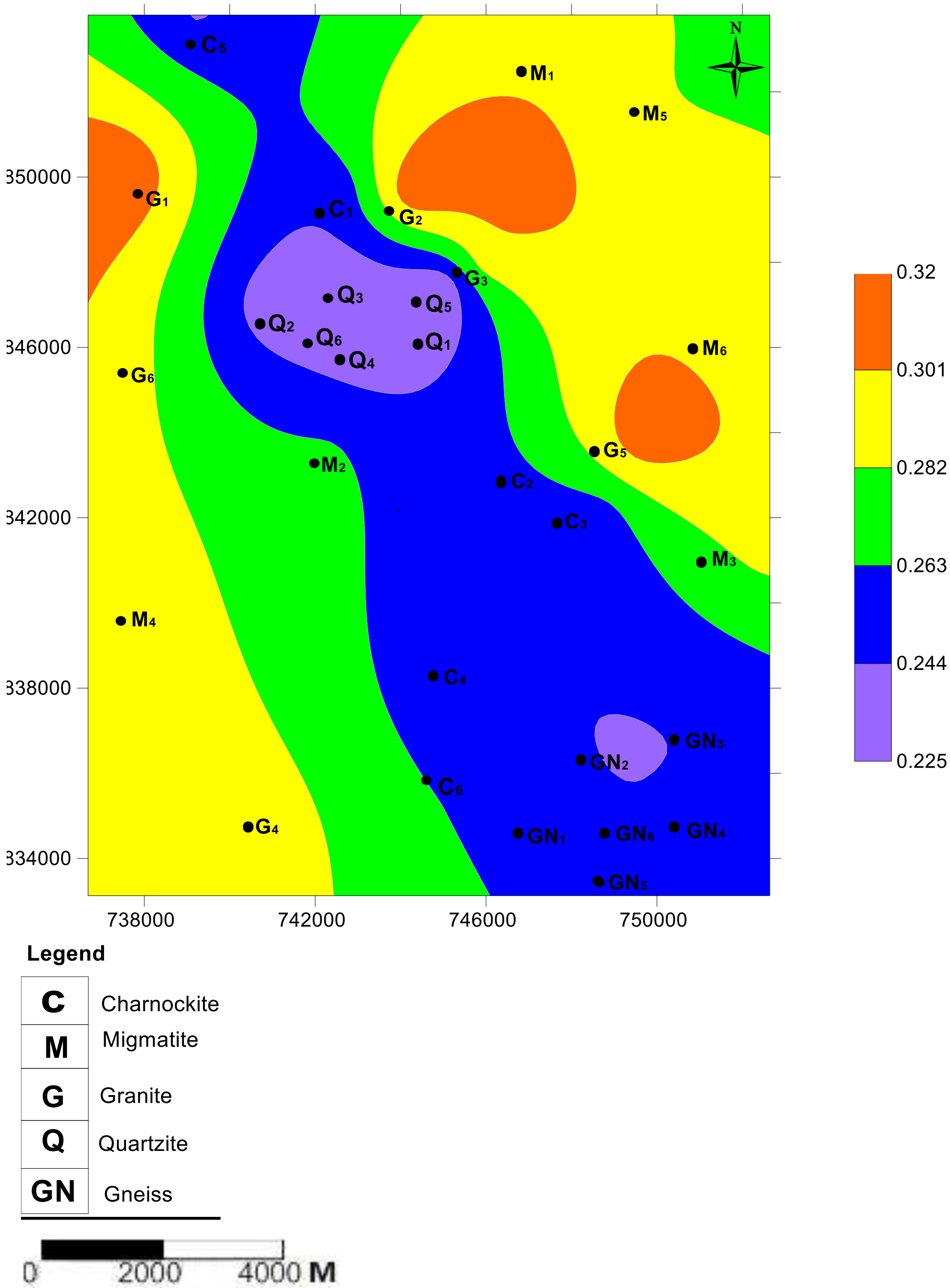

Figure 4e. Poisson's ratio map of the study area.

Table 9. Classification and implication of Poisson's ratio within the studied area.

Class	Description	Poisson's ratio	Implication on surface structure
A	Very high	> 0.301	Very strong
B	High	0.282 - 0.30	Strong
C	Medium high	0.263 - 0.281	Medium strong
D	Low	0.244 - 0.262	Weak
E	Very low	< 0.244	Very weak

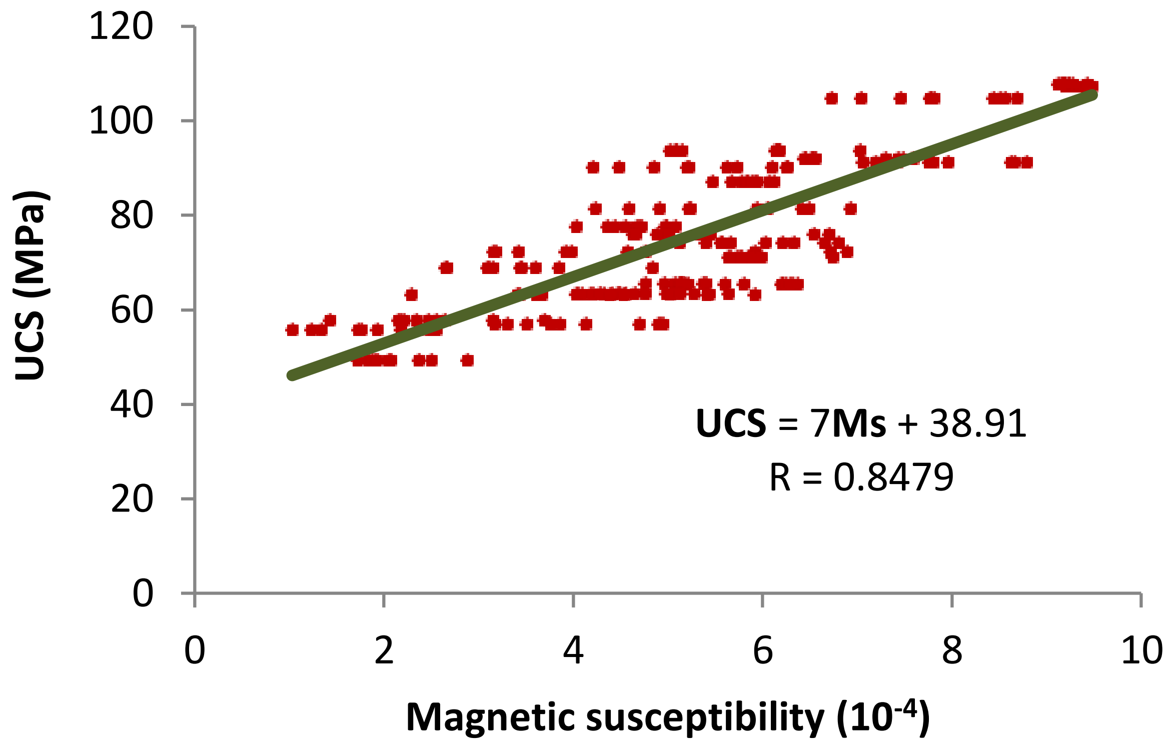

Figure 5a. Crossplot of the magnetic susceptibility (MS) and uniaxial compressive strength (UCS).

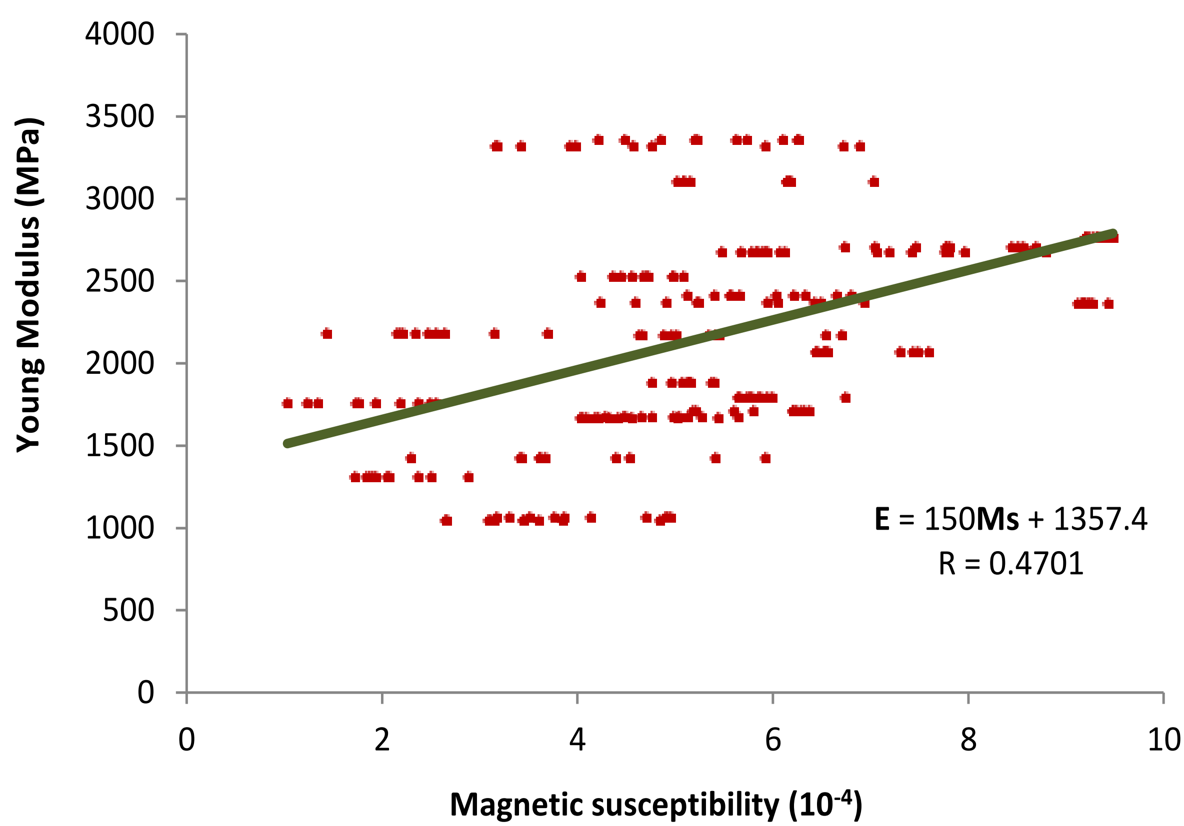

Figure 5b. Crossplot of the magnetic susceptibility (MS) and Young's modulus (E).

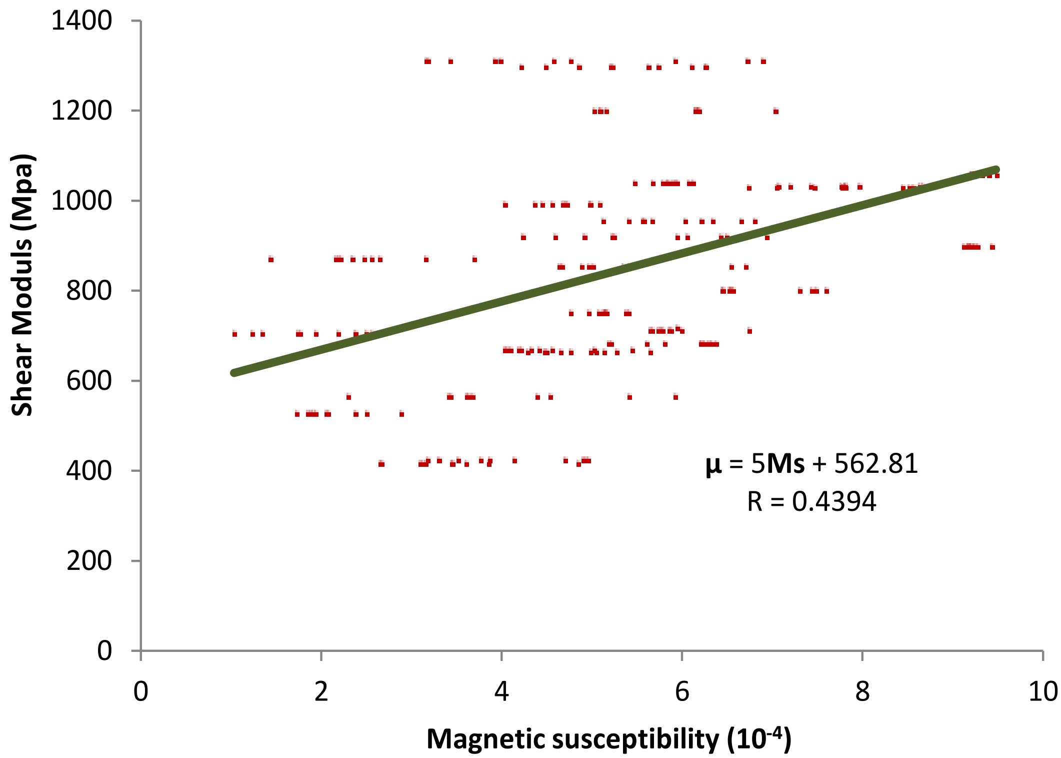

Figure 5c. Crossplot of the magnetic susceptibility(MS) and shear modulus (µ).

$$\mu = 5Ms + 562.81 \quad (13)$$

Where µ is shear modulus, Ms is magnetic susceptibility (10^{-4})

Relationship between the magnetic susceptibility(MS) and bulk modulus (K)

The regression plot of magnetic susceptibility (Ms) and the bulk modulus (K) of the rock samples are presented in Figure 5d. The trend line equation for the cross plot gives coefficient of correlation (R) of 0.60 showing a relatively good correlation (Equation 14); by implication, magnetic susceptibility can be helpful to some extent in judging the reliability of rocks to serve engineering construction purposes.

$$K = 180Ms + 666.93 \quad (14)$$

Where K is Bulk Modulus, Ms is Magnetic Susceptibility (10^{-4})

Relationship between the magnetic susceptibility (MS) and Poisson's ratio(V́)

Figure 5e shows the regression plot of magnetic susceptibility (Ms) and the Poisson's ratio (V́) of the rock samples. The trend line equation for the cross plot gives a coefficient of correlation (R) of 0.80 indicating a good correlation (Equation 15); this shows that the strength of rocks can be determined by the value of their magnetic susceptibilities.

$$\acute{V} = (8 \times 10^{-3})M + 0.2238 \quad (15)$$

Where V́ is Poisson's ratio, Ms is magnetic susceptibility (10^{-4})

Validation of the empirical relations

Samples were taken from ten different locations for the validation of the empirical relations. The results of the predicted mechanical parameters from the magnetic susceptibility with observed mechanical parameters are shown in Table 10.

The cross plots of the observed and predicted results give coefficients of correlation (R) ranging from 0.55 to 0.95 (Figure 6a to e). This means a good correlation exists between the observed and predicted mechanical parameters derived from the magnetic susceptibility. Hence, the established empirical equations for the determination of the mechanical parameters (UCS, Young's Modulus, Shear Modulus, Bulk Modulus and Poisson's ratio) from the magnetic susceptibility measurement are valid.

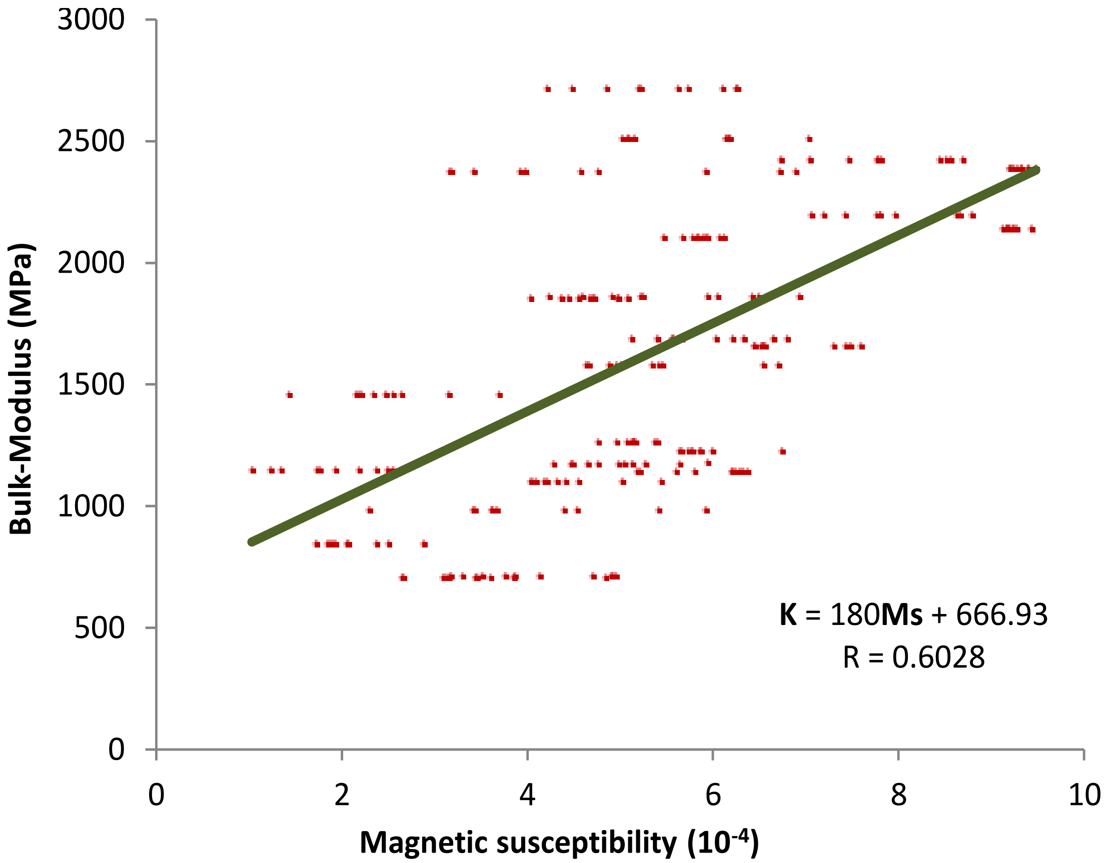

Figure 5d. Crossplot of the magnetic susceptibility(MS) and bulk modulus (K).

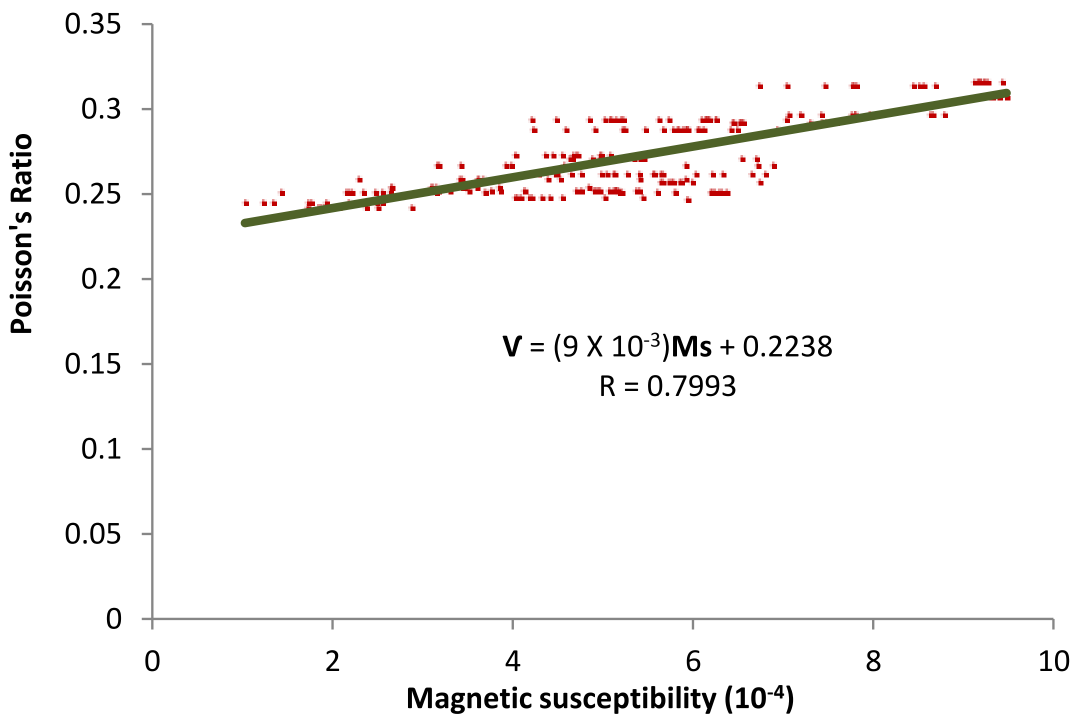

Figure 5e. Crossplot of the magnetic susceptibility(MS) and Poisson's ratio (V).

Table 10. Predicted and observed result of mechanical properties from the validation data.

Predicted mechanical results from magnetic susceptibility							Observed mechanical results				
Sample	**Magnetic susceptibility**	**Uniaxial compressive strength**	**Shear modulus**	**Young's modulus**	**Poison's ratio**	**Bulk modulus**	**Uniaxial compressive strength**	**Shear Modulus**	**Young's Modulus**	**Poison's ratio**	**Bulk modulus**
C1'	357600	63.942	741.61	1893.8	0.252408	1310.61	63.5	697.40	1758.1	0.26047	1223.30
C2'	453400	70.648	789.51	2037.5	0.260072	1483.05	70.1	949.90	2440.4	0.28456	1887.92
M1'	536200	76.444	830.91	2161.7	0.266696	1632.09	77.7	802.51	2069.14	0.28916	1635.63
M2'	626300	82.751	875.96	2296.85	0.273904	1794.27	84.6	1049.09	2665.54	0.27041	1935.00
G1'	652400	84.578	889.01	2336	0.275992	1841.25	92.6	929.59	2380.41	0.28035	1806.21
G2'	744300	91.011	934.96	2473.85	0.283344	2006.67	92.3	1241.88	3184.26	0.28203	2434.78
GN1'	344700	63.039	735.16	1874.45	0.251376	1287.39	71.7	1124.04	2832.38	0.25991	1966.19
GN2'	360900	64.173	743.26	1898.75	0.252672	1316.55	64.4	831.51	2112.76	0.27043	1533.85
Q1'	0	38.91	562.81	1357.4	0.2238	666.93	64.4	841.70	2112.76	0.25505	1437.55
Q2'	0	38.91	562.81	1357.4	0.2238	666.93	64.4	840.10	2112.76	0.25745	1451.77

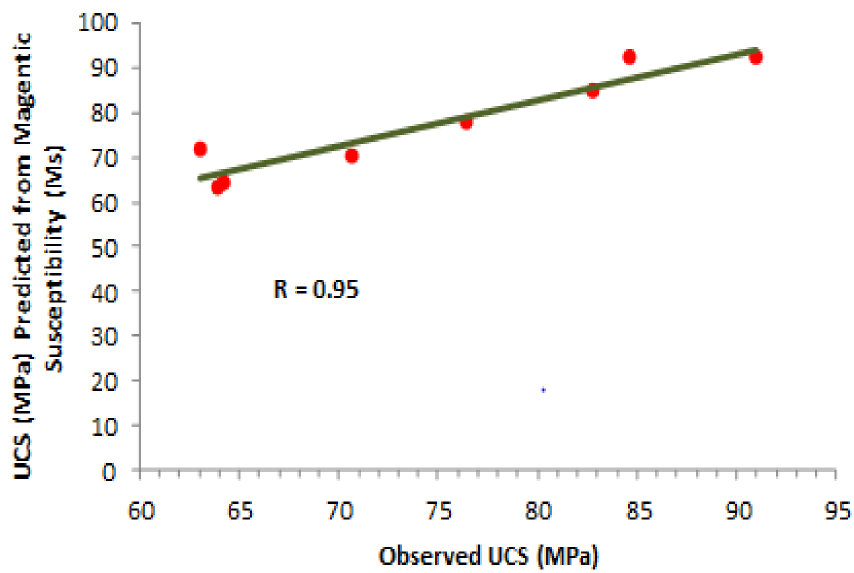

Figure 6a. Crossplot of the observed and predicted results of uniaxial compressive strength from results of magnetic susceptibility.

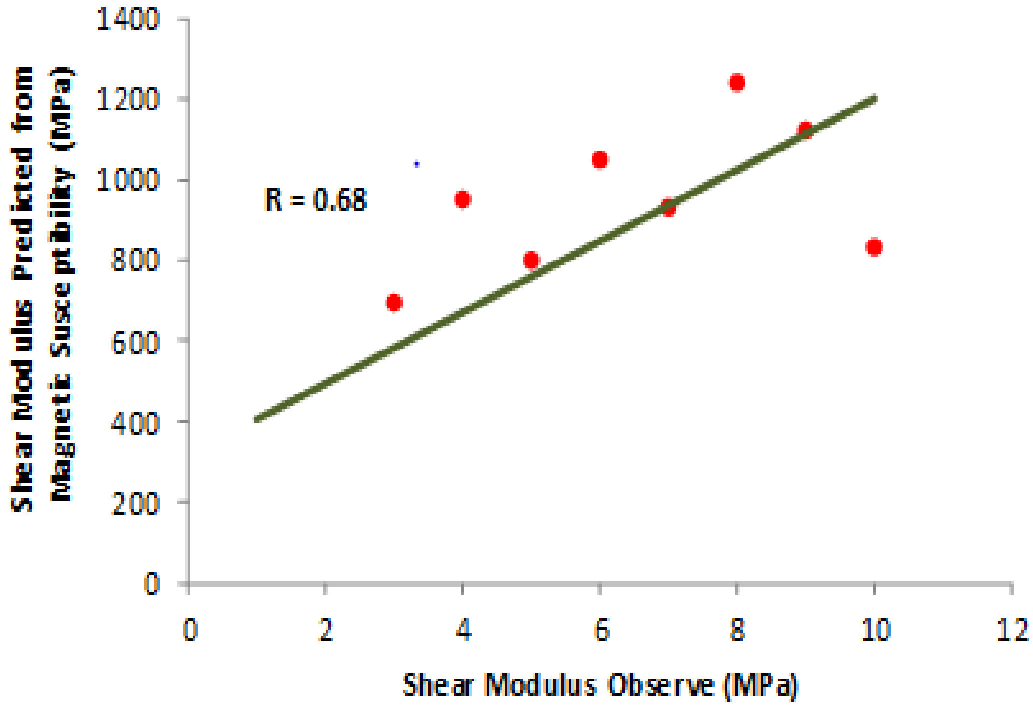

Figure 6b. Crossplot of the Observed and Predicted Results of Shear Modulus from result of magnetic susceptibility.

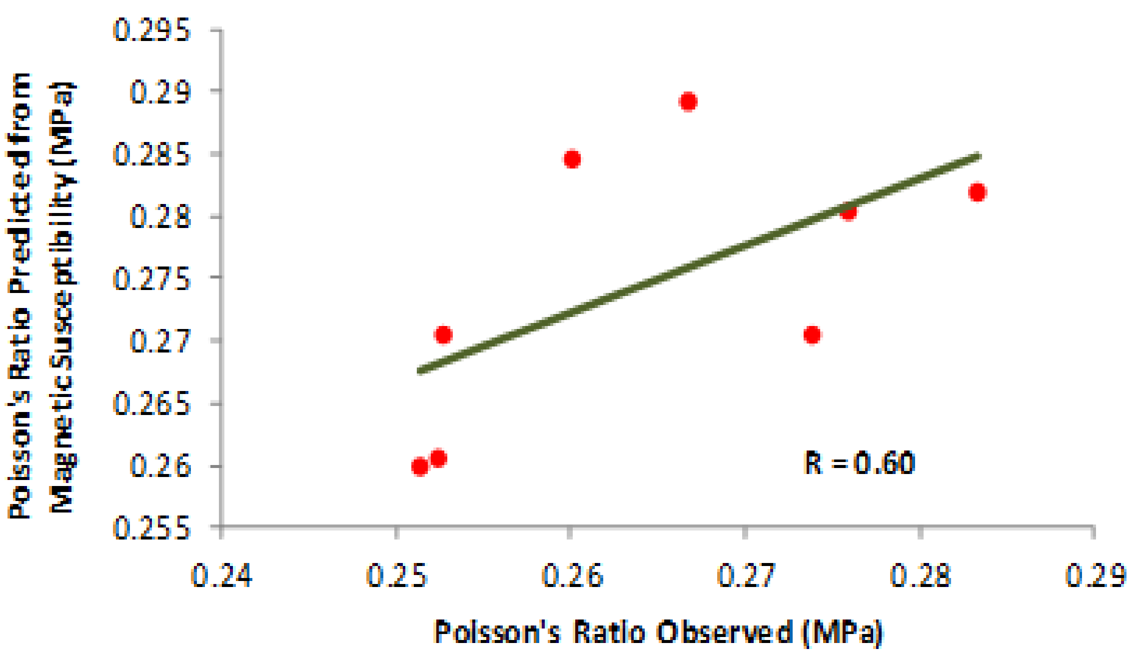

Figure 6c. Crossplot of the observed and predicted results of poisson's ratio from result of magnetic susceptibility.

Conclusions

The crossplots of the mechanical properties with the magnetic susceptibility show relatively fair/good correlation with coefficient of correlation (R) ranging from 44 to 85%. It implies that mechanical properties of

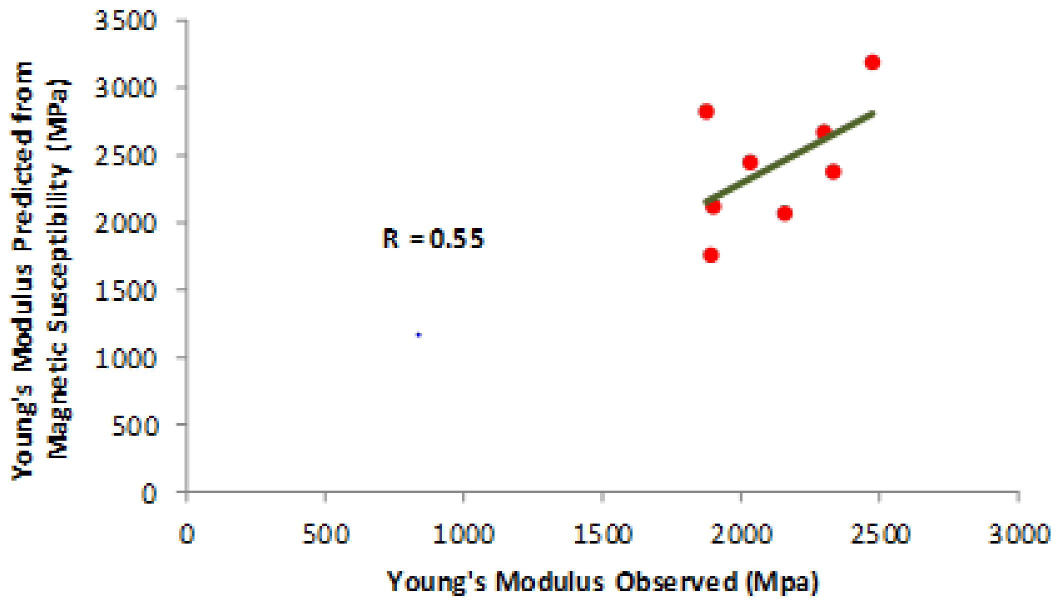

Figure 6d. Crossplot of the observed and predicted results of young's modulus from result of magnetic susceptibility.

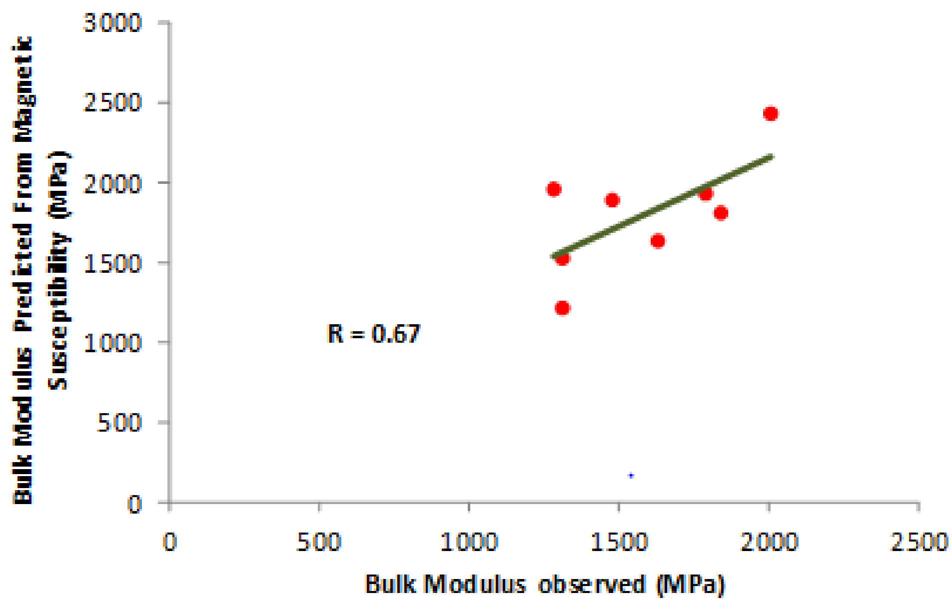

Figure 6e. Crossplot of the observed and predicted results of bulk modulus from result of magnetic susceptibility.

Basement rocks can be determined using magnetic susceptibility measurements by adopting the established empirical equations for each of the determined parameters. A very strong correlation exists in the cross plot of uniaxial compressive strengths (UCS), Poisson's ratio and bulk modulus. The esterblished magnetic susceptibility relationships with Young's and Shear Modulus are relatively weak with coefficient of correlation (R) of 0.44 and 0.47 respectively. This implies that, magnetic susceptibility may not be reliably applicable in the determination of the stiffness of rocks and the rate of resistance of rocks to prevailing shearing loads.

The study shows that the mechanical strength of rock is a function of its magnetic susceptibility. The migmatiteand granite possess more mechanical strength as foundation bedrock than the other principal rock types that characterise the study area. The results of the study further affirmed that, highly magnetic-susceptible rocks which indicates a possible high amount of iron content have reliable correlation with the level induration, stiffness, soundness, resistance to confining and shear loads as subsurface foundation bedrocks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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