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GEOLOGICAL AND GEOTECHNICAL ASSESSMENT OF SELECTED GULLY SITES, YOLA AREA, NORTHEAST NIGERIA

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A geological and geotechnical assessment of selected gully sites in the Yola area, northeast Nigeria, is presented. The geotechnical results indicate a mean plasticity index of 6.0 percent and a mean silt/clay content of 4.0 percent. Maximum dry density ranges from 1.48 mg/m^3 to 1.56 mg/m^3. An optimum moisture content ranging from 9.80 percent to 11.40 percent was recorded. The shear strength test indicated values of cohesion ranging from 1.60 mg/m^2 to 2.40 mg/m^2 in an angle of internal friction ranging from 26^o to 29^o. The soil is thus not compact but loose because it is highly weathered. The fractive force due to runoff and seepage flux are resisted mainly by the angle of internal friction, since the value of cohesion is low. The hydraulic properties of the upper aquifer were analyzed and used to infer the surface and subsurface processes that contribute to the formation and continued expansion of existing gullies in the area. A specific discharge value of 79.81 m/yr and an average linear groundwater velocity of 207 m/yr were recorded, indicating high pore pressures and seepage fluxes. From the geotechnical analysis recommendations for erosion control were suggested.

INTRODUCTION

Gully erosion is an environmental hazard that is ravaging the landscape of parts of Yola, as in many parts of the country, especially southeastern part of Nigeria. The dangers of gully erosion have been discussed by many workers in standard textbooks and scientific journals, but few people understand its real impact on the agricultural, infrastructural and socioeconomic aspects of both urban and rural development of a country.

It was in the light of the above consideration that hydrogeological and soil test analyses were done in the area with a view of providing hydrogeological and geotechnical information on the genesis and expansion of gullies in Yola and its environs. The information from this study will help suggest appropriate measures to control gully development.

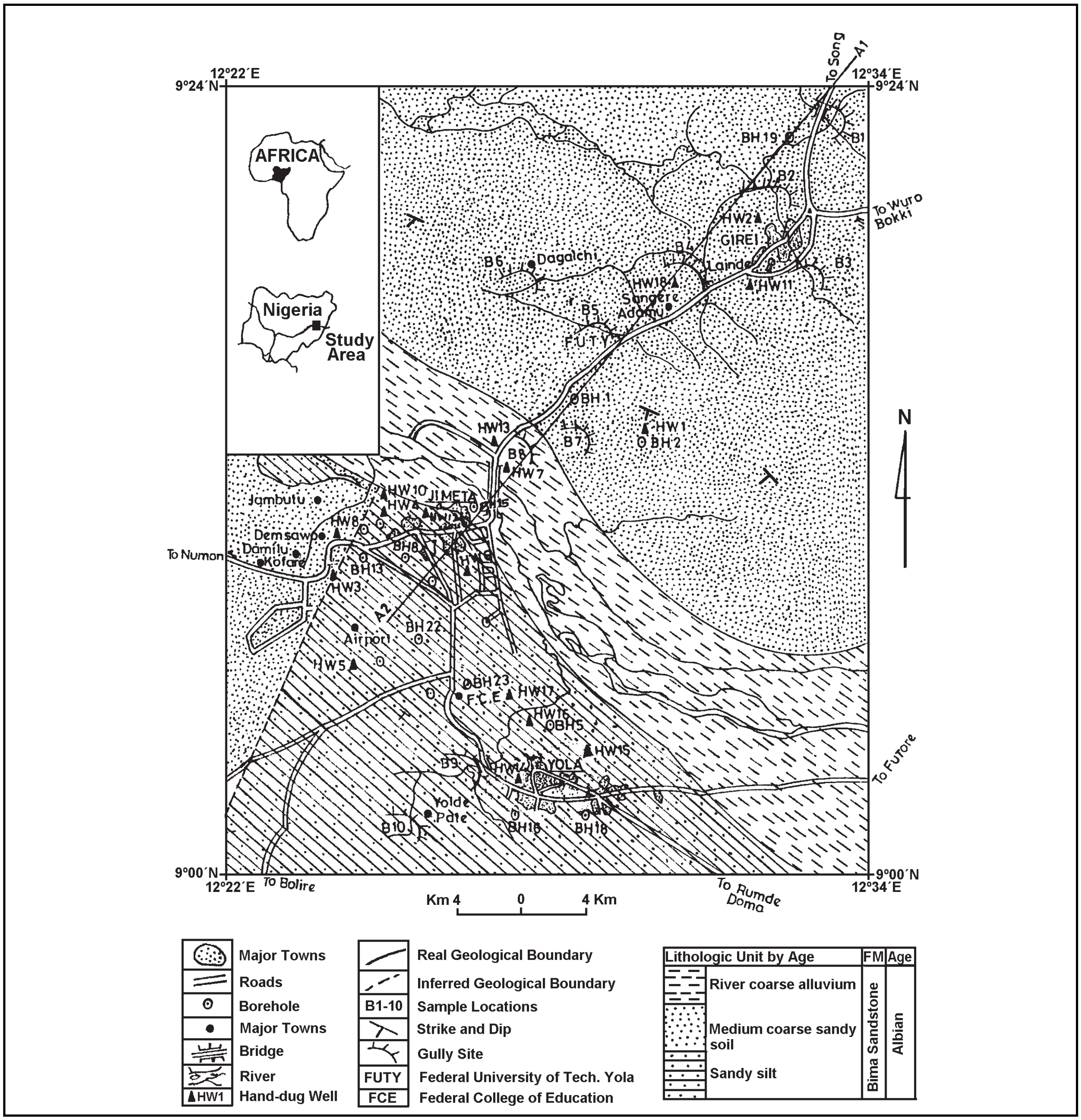

Figure 1. Geologic map of the study area.

The study area falls within latitudes 90º10' N and 9º24' N and longitudes 12º22' E and 12º34' E with an areal extent of about 8086 km^2. The prominent landform is the Adamawa highlands characterized by high relief, and surrounded by scarp slopes and plains. The relief of the Adamawa highlands ranges between 550 to 950 meters above mean sea level. The western, northern and southern parts consist of plains and scarp slopes with scattered patches of Bima sandstone outcrops. The eastern portion is characterized by chains of highlands that extend to the Cameroon Republic (Figure 1).

The area is drained by the Benue River, which is the largest and the only perennial river in the area. The Benue River is fed by a number of smaller streams such as the Karlahi, Chouchi, Lumo, Mayo-Ine and Balaje, which are mainly seasonal. These streams traverse the area in a predominantly east-west direction. In addition to these streams, there are small inland lakes such as Geriyo, Mbulirgo and Niuwa.

Most of the previous work done in the area was mainly regional (Falconer, 1911; Wilson, 1925; Wilson and Bain, 1928) and described the geology of the Upper Benue Trough in terms of its sedimentary and stratigraphic aspects. Subsequently Carter et al. (1963), Cratchley and Jones (1965), Dupreeze and Barber (1965), and Kiser (1968), gave some details on the geology, geological structure, hydrogeology and water quality of the former Northern Nigeria in which the study area is included. Finally, Jackson, 1995 wrote on the hydrogeology of the Upper Benue Basin around the Yola area.

The main objective of this study is to assess the results of the geotechnical parameters obtained from soil tests. These revealed that the surface and subsurface processes are the main contributors to the formation and continued expansion of gullies in the area.

GEOLOGICAL ASSESSMENT OF BIMA SANDSTONE

The study area is underlain by sedimentary deposits (Figure 1) which consist of two stratigraphic units (Ezeigbo et al., 1992). These are the quarternary river coarse alluvium and the feldspathic Bima sandstone. The alluvial deposits, which occur mainly along the banks of the river Benue and its tributaries, consist of sands, clays, silts, silty-clays and pebbly-sands. The sands are usually loose, moderately sorted and relatively permeable

The Bima sandstone is generally fine to medium grained in texture, crystalline indurated, compact and well cemented when fresh. The fabric or structure is lineated since the elongated or sometimes tabular grains are arranged parallel to one another. They have a preferred orientation within the rock thus making it anisotropic. They are fracture foliated since the rock has a set of parallel planes of weakness, such as bedding planes. The spacing of these bedding planes varies from less than 6 mm to 8 mm; they are thus thinly to thickly laminated. They are stratified, moderately jointed and capable of supporting vertical walls without support, and are thus competent. However, field study of the gully sites revealed that the Bima sandstone has been moderately weathered, moderately sorted, is loose, and contains a small proportion of clays.

According to Folk and Ward (1957), the sorting characteristics of a rock sample can be evaluated using the following equation:

$$\Theta 1 = \frac{\Phi 84 - \Phi 16}{4} + \frac{\Phi 95 - \Phi 5}{6.6} \tag{1}$$

Where

$\Theta 1$ = inclusive graphic measure (sorting),

$\Phi 84$ = quartile 84 (84 percent of the particles are finer), and

4 and 6.6 = mathematical constants.

Using equation (1) sorting values ranging from 0.95 to 1.70 were obtained for samples collected at the gully sites (Table 1), which correspond to moderately sorted samples. This indicates that the fine grained materials such as clays and silts that can provide cohesion are of moderate composition. A comprehensive explanation of the geological assessment of the Bima sandstone will be given in the discussion that follows.

Table 1. Values of Sorting Estimated for the Gully Sites

Sample No.	Location	Sorting Value	Description
B4	Sangere Adamu	1.00	Moderately sorted
B7	Vinikilang	1.60	Poorly sorted
B8	Vinikilang	1.70	Poorly sorted
B1	Girei	1.01	Moderately sorted
B2	Girei	1.05	Moderately sorted
B3	Girei	0.95	Moderately sorted
B7	Bagale	1.10	Moderately sorted
B9	Chouchi Bridge	0.97	Moderately sorted

GEOTECHNICAL ASSESSMENT

Incipient gullies were observed in different parts of Yola and environs where the moderately weathered Bima sandstone outcrops. Badland devastation was found in Yola town (Yolde Pate and the Chouchi bridge site), Vinikilang, the Federal University of Technology, Yola, Sangere-Adamu and Girei areas, where gully systems with very prominent slip scars are developing. Locations of the above mentioned gullies are shown in Figure 1.

The average depth of incision of these gullies is about 4.5 m whereas the average width is about 4.2 m. A typical example of such gullies taken at Girei is shown in Plate 1. It is the geotechnics of these areas that determine their susceptibility to gully erosion.

The geotechnical parameters of the soil mechanics laboratory tests, such as the liquid limit and plastic limit, the grain-size analyses, the permeability test, the shear strength test, and the compaction test, were carried out. Tables 2a and b summarize the test results. The liquid and plastic limits were measured and were used to obtain the plasticity index, which is a measure of the plasticity of the soil. The plasticity index ranges from 4.70 to 7.20 with a mean value of about 6.0 which shows that the soil is slightly plastic. This indicates that the soil has slight dry strength and hence can easily be crushed with fingers. Also the grain-size analyses revealed that the percentage of silt/clay content ranges from 3.40 to 4.50. The compaction test shows that the optimum moisture content ranges from

Plate 1. Bad-land devastation (Gully) taken at Girei.

9.80 to 11.40 percent, while the maximum dry density ranges from 1.48 mg/m^3 to 1.65 mg/m^3. Permeability was measured, and the values range from 2.48 x 10^{-3} cm/s to 8.99 x 10^{-3} cm/s with a mean value of 3.45 x 10^{-3}cm/s, which is relatively high according to the Bell (1983) classification.

Table 2a. Summary of Soil Tests

			Atterberg Limit				
Gully Location	**Depth (m)**	**Width (m)**	**Plastic Limit %**	**Liquid Limit %**	**Plasticity Index**	**Silt/Clay Content**	**Soil Classification**
B1 Girei	6.00	8.00	21.50	27.50	6.00	4.00	Sandy-Silt
B2 Girei	2.60	3.20	21.50	28.00	6.50	4.10	Sandy-Silt
B3 Girei	1.50	1.80	22.00	27.50	5.50	3.90	Sandy-Silt
B4 Sangere-Adamu	19.60	8.20	20.50	27.00	6.50	4.00	Sandy-Silt
B5 Futy	2.10	1.80	22.00	28.00	6.00	4.50	Sandy-Silt
B6 Bagale	1.30	2.10	21.50	26.50	5.00	3.40	Sandy-Silt
B7 Vinikilang	1.60	2.00	20.00	26.50	6.50	4.00	Sandy-Silt
B8 Vinikilang	1.80	2.30	21.80	27.40	5.60	3.80	Sandy-Silt
B9 Chouchi	4.80	6.20	22.10	29.30	7.20	4.20	Sandy-Silt
B10 Yolde-Pate	3.80	6.40	23.70	28.40	4.70	3.80	Sandy-Silt
Mean	4.51	4.20	21.65	27.61	5.95	3.97	Sandy-Silt

Table 2b. Summary of Soil Tests

			Compaction		Shear Strenght		
Gully Location	**Depth (m)**	**Width (m)**	**Optimum Moisture Content %**	**Maximum Dry Density mg/m^3**	**Angle of shearing resist. Θ^0**	**Cohesion kg/m^2**	**Permeability cm/sec**
B1 Girei	6.00	8.00	10.00	1.52	26.00	0.16	$2.96x10^{-3}$
B2 Girei	2.60	3.20	10.20	1.56	28.00	0.18	$2.89x10^{-3}$
B3 Girei	1.50	1.80	11.40	1.63	27.50	0.23	$2.93x10^{-3}$
B4 Sangere-Adamu	19.60	8.20	10.00	1.53	27.00	0.18	$2.99x10^{-3}$
B5 Futy	2.10	1.80	10.10	1.50	28.50	0.19	$2.68x10^{-3}$
B6 Bagale	1.30	2.10	11.40	1.62	27.00	0.23	$2.79x10^{-3}$
B7 Vinikilang	1.60	2.00	10.00	1.56	28.00	0.19	$2.89x10^{-3}$
B8 Vinikilang	1.80	2.30	11.20	1.65	26.50	0.24	$2.48x10^{-3}$
B9 Chouchi	4.80	6.20	10.10	1.50	29.00	0.19	$8.99x10^{-3}$
B10 Yolde-Pate	3.80	6.40	9.80	1.48	28.50	0.18	$2.89x10^{-3}$
Mean	4.51	4.20	10.42	1.56	27.60	0.20	$3.45x10^{-3}$

The shear strength of thesoilsamples was also determined. Shear strength is the maximum internal resistance of the soil to movement of its particles by sliding or slipping. The forces that resist shear are the intergranular friction and cohesion. The values of cohesion range from 0.16 kg/cm^3 to 0.24 kg/cm^3, which is relatively low. The angle of internal friction ranges from26°to 29°. The significance of this test is that the fractive force due to runoff and the seepage flux are only resisted by the angle of internal friction since the value of cohesion is low.

The mean annual precipitation occurring as rainfall over a ten water year period (1984/85 to 1993/94) amounted to 899.66 mm or 7.26×10^9 m^3 of precipitation over an area of about 8,068 km^2 (Table 3). Ezeigbo et al. (1996) have suggested that about 65 percent of the total precipitation is lost through evapotranspiration, about 15 percent is lost as surface runoff, while the remaining 20 percent can be taken as infiltration. Accordingly we have estimated a total runoff of about 1.09×10^9 m^3, which is relatively high.

We have identified two aquifer systems, namely the upper unconfined and lower confined (Figure 2). This investigation is confined to the upper unconfined aquifer system since all the gullies identified are located within this aquifer. It varies in thickness from 0-90 m, whereas the depth to static water level varies from 1.26 to 19.6 m. Table 4 shows the hydraulic head values in the study area.

Two groundwater flow directions were identified; to the northeast, showing that the recharge area is from northeast towards the Benue River, and from west to east (Figure 3). It occurs generally at a depth below 20 m. The hydraulic properties as determined from statistical methods (Hazen, 1893, Harleman et al., 1963, and Uma et al., 1989) indicate a mean hydraulic conductivity, K, of $8.19x10m^{-4}$ m/s and a transmissivity, T, of $4.85x10^3$ m^2/s (Table 5). Comparisons were made for K to the Todd (1980) and T to the Gheorghe (1978) classifications. The values of K and T are relatively high.

Table 3. Yola Monthly Rainfall Data (mm)

W.Y.	May	June	July	Aug.	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
84/85	138.1	76.2	243.1	183.0	168.3	54.3	0.0	0.0	0.0	20.9	87.3	971.2
85/86	159.0	131.8	200.6	173.6	173.6	10.8	0.0	0.0	0.0	54.0	40.0	943.4
86/87	155.4	107.3	312.2	117.5	78.7	98.6	11.6	0.0	0.0	0.0	19.1	900.4
87/88	34.6	105.2	162.5	199.7	127.3	44.1	0.0	0.0	0.0	5.0	0.3	678.4
88/89	113.3	142.4	185.5	164.0	353.9	97.3	0.0	0.0	0.0	0.0	45.1	1102.
89/90	137.3	62.9	235.8	339.7	55.4	4.0	0.0	0.0	0.0	0.0	20.8	855.9
90/91	92.4	143.5	259.6	159.0	90.7	38.9	6.6	0.0	0.0	0.0	78.5	869.2
91/92	161.6	70.9	128.0	168.5	179.0	27.7	0.0	0.0	0.0	0.0	12.5	745.2
92/93	166.7	67.8	216.4	299.5	132.8	29.2	7.0	0.0	0.0	13.1	23.1	955.6
93/94	129.1	84.0	169.7	262.8	192.0	41.7	0.0	0.0	0.0	26.1	70.4	975.8
M.V.												899.7

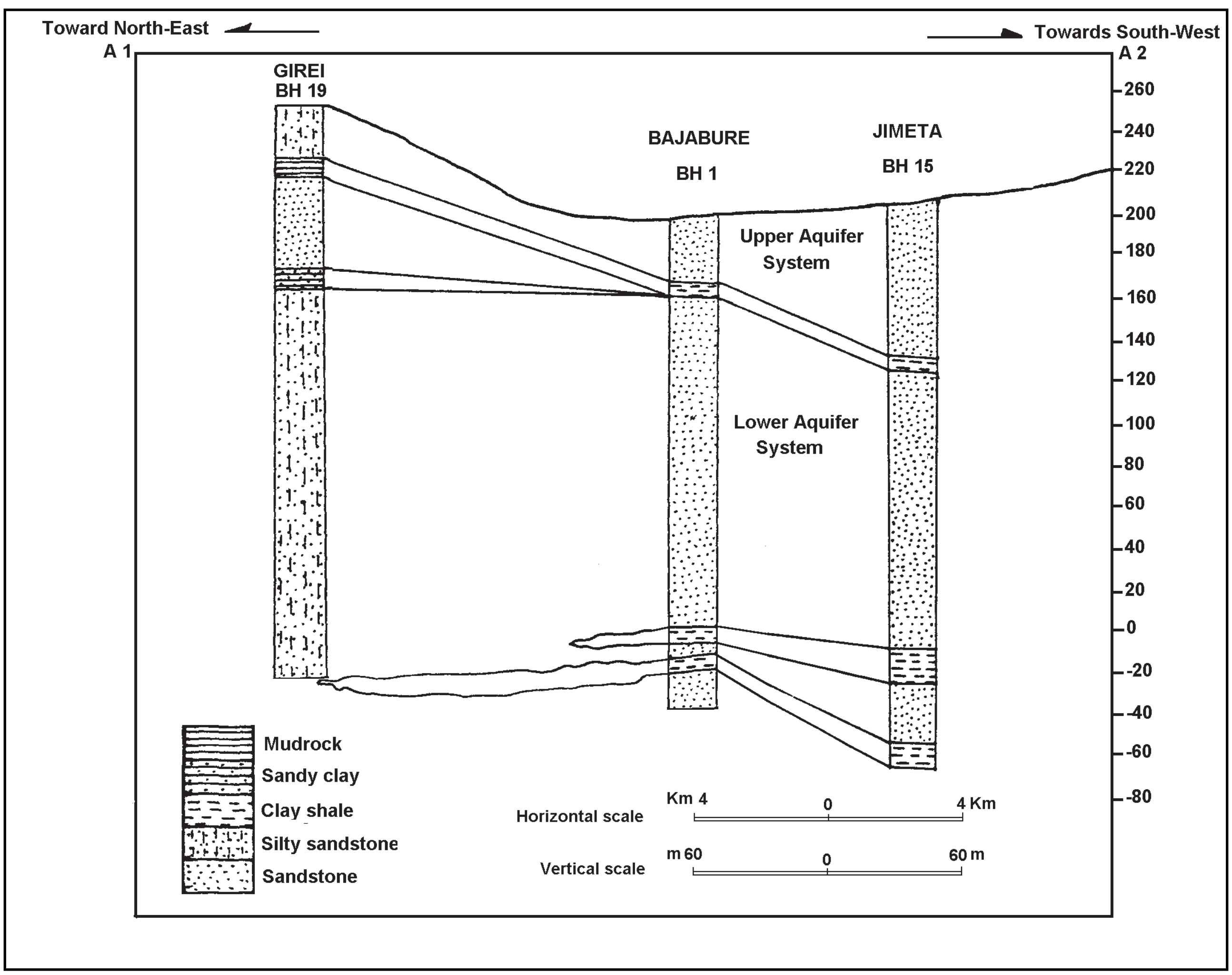

Figure 2. Cross section showing aquifer systems.

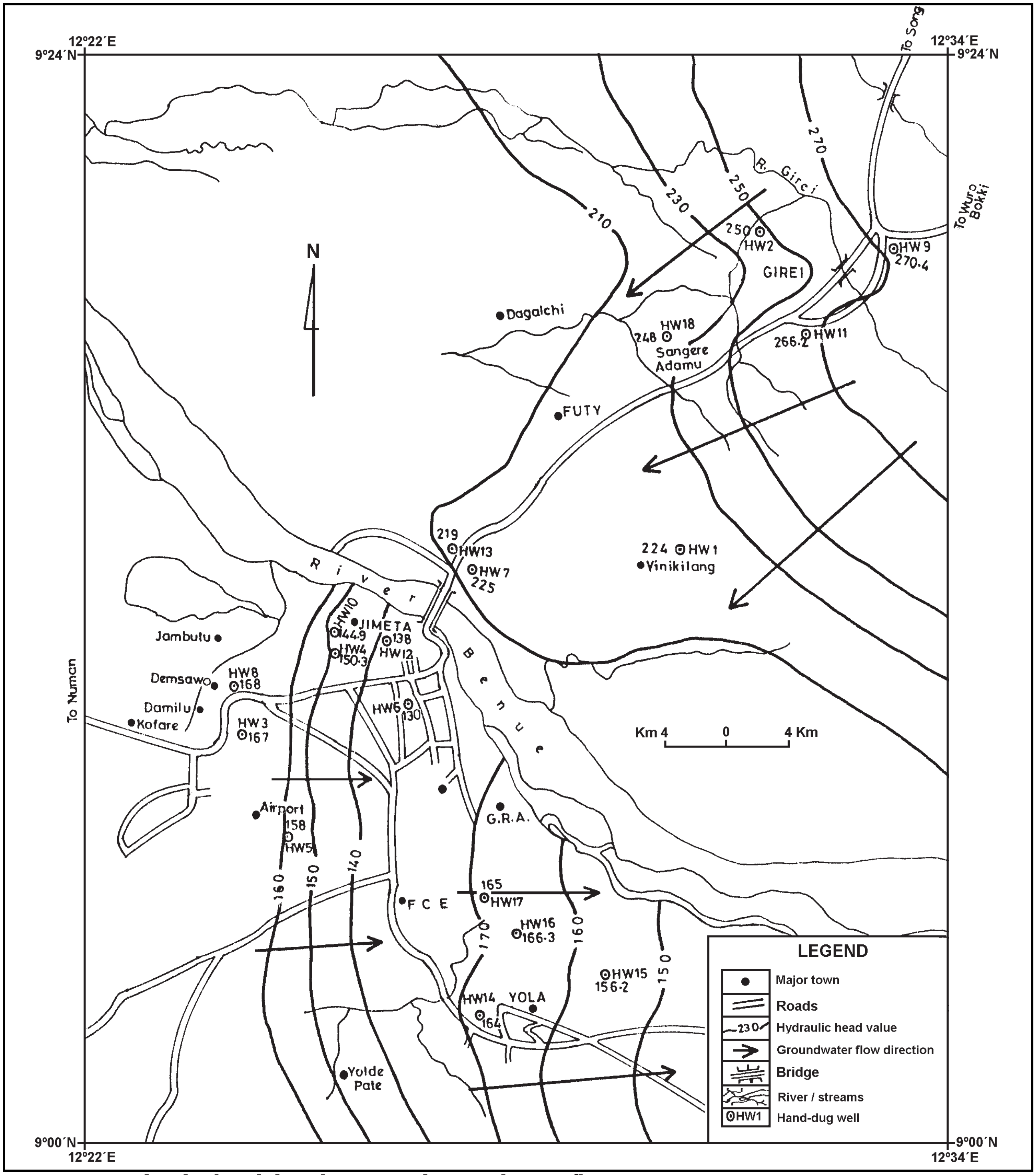

Figure 3. Hydraulic head distribution and groundwater flow.

The specific discharge is developed in overcoming friction on the joint surfaces and in pore spaces. It is also called the Darcy velocity (V_d) and equals the product of hydraulic conductivity, and hydraulic gradient (i). It is based on Darcy's law and expressed mathematically as:

$$V_d = Ki \tag{2}$$

Where

V_d = specific discharge, and

i = hydraulic gradient.

Table 4. Hydraulic Head Values for the Upper Aquifer

Hand-dug Well No.	Location	Elevation	Depth to Static Water Level (m)	Hydraulic Head (m)
HW1	Vinikilang	226.60	2.60	224.00
HW2	Girei	257.00	7.00	250.00
HW3	Jimeta	169.28	2.28	167.00
HW4	Jimeta	151.50	1.26	150.30
HW5	Airport	175.94	17.94	158.00
HW6	Nassarawo	131.70	1.70	130.00
HW7	Bajabure	229.40	4.40	225.00
HW8	Demsawo	169.26	1.26	168.00
HW9	Girei	277.10	7.10	270.00
HW10	Jimeta	146.10	1.20	144.90
HW11	Girei	273.04	6.84	266.20
HW12	Jimeta	139.58	1.58	138.00
HW13	Bajabure	228.00	8.70	219.30
HW14	Tola-town	168.45	4.45	164.00
HW15	Tola-town	175.36	19.36	156.20
HW16	Tola-town	169.70	3.40	166.30
HW17	Tola-town	169.17	4.17	165.00
HW18	Sangere	254.50	6.50	248.00

The mean hydraulic conductivity value for the upper unconfined aquifer is computed as 8.19×10^{-4} m/s. This value, when multiplied by the average hydraulic gradient which was computed as 0.0038, gave a specific discharge value of 98.15 m/year. These values indicate high seepage forces, which agree with the high K and T values recorded.

The average linear groundwater velocity is a measure of the speed with which water moves through the pores or joints; and is obtained by dividing the specific discharge by the real or volumetric (average) porosity. The average linear groundwater velocity (V_a) as given by Todd (1980) is

$$V_a = \frac{V_d}{n} \tag{3}$$

Where

n = Porosity of the aquifer,

V_d = specific discharge, and

V_a = Average linear groundwater velocity.

The porosity of the upper aquifer is estimated based on Pettijohn (1975) at a value of 0.43. Using

Table 5. Hydraulic Properties of Samples Gully Sites

	Hydraulic Conductivity (m/s)				Transmissivity (m^2/s)				
Location	**Hazen (1893)**	**Harleman, et al., (1963)**	**Uma, et al., (1989)**	**Average**	**Hazen (1893)**	**Harleman, et al., (1963)**	**Uma, et al., (1989)**	**Average**	**Thickness (m)**
B4 Sangere-Adamu	$1.5x10^{-3}$	$1.0x10^{-3}$	$6.0x10^{-5}$	$8.5x10^{-4}$	$2.9x10^{-2}$	$2.0x10^{-2}$	$1.2x10^{-3}$	$1.7x10^{-2}$	19.60
B3 Girei	$1.2x10^{-3}$	$7.5x10^{-4}$	$4.9x10^{-5}$	$6.7x10^{-4}$	$1.8x10^{-3}$	$1.1x10^{-3}$	$7.4x10^{-5}$	$1.0x10^{-3}$	1.50
B5 Futy	$3.7x10^{-3}$	$2.8x10^{-3}$	$9.8x10^{-5}$	$2.2x10^{-3}$	$7.7x10^{-3}$	$5.8x10^{-3}$	$2.1x10^{-4}$	$4.6x10^{-3}$	2.10
B7 Vinikilang	$6.7x10^{-4}$	$4.7x10^{-4}$	$3.2x10^{-5}$	$3.9x10^{-4}$	$1.1x10^{-3}$	$7.5x10^{-4}$	$5.1x10^{-5}$	$6.3x10^{-4}$	1.60
B9 Chouchi	$3.2x10^{-5}$	$9.1x10^{-6}$	$5.6x10^{-7}$	$1.4x10^{-5}$	$1.5x10^{-4}$	$4.4x10^{-5}$	$2.8x10^{-6}$	$6.7x10^{-5}$	4.80
Mean	$1.4x10^{-3}$	$9.9x10^{-4}$	$4.8x10^{-5}$	$8.2x10^{-4}$	$8.4x10^{-3}$	$5.9x10^{-3}$	$2.8x10^{-4}$	$4.9x10^{-3}$	5.92

equation (3), an average linear groundwater velocity of 228 m/year was calculated, which further confirms the high seepage fluxes and pore pressures.

DISCUSSION

Seven samples were selected and their slides prepared and observed under a polarizing microscope. From the study of the rock samples under both plane polarized and cross polarized lights the following minerals were observed: quartz, orthoclase, muscovite and iron-oxides. Quartz is generally anhedral in crystal form, has weak birefringence and shows grey to white first order interference. It has low relief, shows parallel as well as undulose extinction and is colorless under plane polarized light. Orthoclase is colorless under plane polarized light, sub-hedral in the norm and shows low relief and weak birefringence. It is also non-pleochroic and shows grey to white first order interference, parallel extinction and carlsbad twinning.

Muscovite is pale yellow to colorless under plane polarized light, anhedral in crystal form and shows moderate relief and moderate birefringence. It is very weakly pleochroic, shows purple to red interference colors and cleaves in one direction. Iron-oxide is opaque under plane polarized light, anhedral in crystal form, of high relief and non-pleochroic.

Table 6 is the summary of the mineralogical composition and percentages. The presence of clay in the gully samples, though in low percentages, may have originated from the weathering of feldspars.

Blyth and De Freitas (1992) pointed out that cementation can occur in two ways namely:

1) by the enlargement of existing particles. Rounded quartz becomes enlarged by the growth of ‘jackets’ of additional quartz, derived from silica-bearing solutions, the new growth being in optical continuity with original crystal structure of the grains, and

2) by the deposition of interstitial cementing matter from percolating waters.

The chief types of cement are:

1) silica in form of quartz,

2) iron-oxides, and

3) carbonates e.g. calcite, magnesite, witherite.

Table 6. Summary of Mineralogical Composition of Bima Sandstone

Location	Sample No.	Mineral Under Plane Polars	Mineral Under Cross Polars	Mineral %
Vinikilang	B7	--	Orthoclase Quartz	20 80
Vinikilang	B7	--	Orthoclase Quartz	30 70
Futy	B5	Muscovite	Muscovite Orthoclase Quartz	20 40 40
Sangere-Adamu	B4	Muscovite	Muscovite Orthoclase Quartz	10 40 50
Bagale	B6	Muscovite	Muscovite Orthoclase Quartz	10 40 50
Girei	B3	Iron-oxide	Iron-oxide Orthoclase Quartz	30 30 40
Girei	B2	Muscovite	Muscovite Orthoclase Quartz	20 40 40

The petrographic studies show that silica in form of quartz and iron-oxide are the predominant cementing materials for the Bima sandstone. Cementing materials can be affected by pH values (acidity), and chloride and sulfate contents of the groundwater that comes in contact with them. Table 7 shows that the pH values of the groundwater are generally less than 6.5, which is an indication of acidic water. It is capable of dissolving cementing material, especially calcium carbonate. The chloride concentration shows a mean value of 137 mg/l, which is relatively high and capable of causing corrosion and incrustation of metallic objects and structures. Thus any erosion control structure should be made with anti-corrosion materials. The sulfate content of the groundwater indicates a mean value of 30 mg/l and hence a paucity of sulfate bearing minerals such as pyrite, anhydrite or marcasite.

The investigation has provided the hydrogeological characteristics of the upper aquifer in the area in terms of depth to water table, recharge and discharge areas and groundwater flow directions. This will serve as a useful guide in prospecting for groundwater resources in the area.

The susceptibility of the soil materials to gully formation in the area is due to the low silt/clay content of the gully sites. The plasticity index is generally low, indicating that the soil has slight dry strength and hence can easily be crushed with fingers. Therefore it offers little resistance to gully erosion.

The relatively high values of permeability, seepage discharge, and average linear groundwater velocity suggest high seepage forces and pore pressures. These will tend to reduce the shear strength of the soil and enhance its erodibility. Also, since the relatively high seepage forces and pore pressures

Table 7. Chemical Analysis of Water Samples from Hand-Dug Wells (mg/l)

Hand-dug Well (Project No.)	**Sulfate (SO_4^{2-})**	**Chloride Cl^-**	**pH**
HW1	11.0	125.0	6.7
HW2	43.7	10.0	6.2
HW3	14.0	150.0	7.2
HW4	35.0	410.0	4.0
HW5	38.0	270.0	5.9
HW6	15.0	310.0	5.6
HW7	28.0	17.0	6.1
HW8	52.0	245.0	5.8
HW9	60.0	90.0	6.2
HW10	13.0	140.0	6.3
HW11	21.0	12.6	6.5
HW12	12.0	295.0	6.2
HW13	60.0	90.0	6.2
HW14	39.0	10.0	7.1
HW15	21.0	12.8	6.5
HW18	28.0	5.9	6.4

reduce the angle of internal friction for a given total stress, liquefaction of the soil can occur. Hence the soil will tend to lose all strength and will flow like a liquid resulting in the creation of the deeply incised gullies observed in the area.

CONCLUSION

The investigations provided geological, geotechnical and hydrogeological characteristics which were used to infer the surface and subsurface processes that contribute to the formation and continued expansion of gullies in the Yola area.

The engineering aspects of soil erosion control should be geared towards changing the slope characteristics of the area so that the amount and velocity of runoff are decreased. Other soil stabilization techniques such as grouting, dewatering and construction of concrete ripraps should be applied where pore pressures and seepage forces are high.

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REFERENCES

Bell, F.G.; (1983). Fundamentals of Engineering Geology, Butterworth publishers, London. pp. 488-524.

Carter, J. O., W. Barber, E. A. Tait and G. P. Jones; (1963). The geology of parts of Adamawa, Bauchi and Borno provinces in Northeastern Nigeria. Geol. Surv. of Nigeria, Bull.,30, pp. 35-53.

Cratchley, C.R., and G. P. Jones; (1968). An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. Overseas Geophys.Paper, Geol. Surv. London. No.1

Dupreeze, J. W. and W. Barber; (1965). The distribution of chemical quality of groundwater in Northern Nigeria. Geol. Surv. of Nigeria. Bull.36, pp. 19-33.

Ezeigbo, H. I., A. G. Iliya and D. K. Zira; (1996). Water Resources of Jimeta-Yola Metropolis, Adamawa State, Nigeria. Jour. of Min. and Geosci. (in press).

Falconer,J. O.; (1911). The geology and geography of Northern Nigeria. Macmillan Pub. London, pp. 295.

Folk, R. L., and K. C. Ward (1957). Brazos River Bar : A study of the significance of grain-size parameters. Jour. of Sed. Petrology vol.27, pp. 3-26.

Gheorghe, A.; (1978). Processing and synthesis of hydrogeological data, Abacus Press, Turnbridge Wells Kent.

Harleman, D. R. E., P. E. Mehborne and R. A. Rumer; (1963). Dispersion, permeability correlation in porous media. Jour. Hydraulic Div. Amer. Soc. of Civil Engineers. No.HY2, vol.89, pp.67-85.

Hazen, A.; (1893). Some physical properties of sands and gravels. Mass State Board of Health 24th Annual Report.

Jackson, M. I.; (1995). Hydrogeology of Yola area in the Upper Benue Basin, Northeast Nigeria (Unpubl.) M.Sc. Thesis University of Nigeria, Nsukka.

Kiser, A. T. (1968). Chemical quality of water in Northern Nigeria, Geol. Surv. of Nigeria. Open file Report.

Pettijohn, F. J.; (1975). Sedimentary Rocks (3rd Ed.) Harper and Row, New York.

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