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INFILTRATION CHARACTERISTICS OF SOILS AFFECTED BY GULLY EROSIONS IN GIREI LOCAL GOVERNMENT AREA OF ADAMAWA STATE NIGERIA

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Abstract: Field measurements of infiltration rateson soils associated with gully erosions in Girei Local Government Area, Adamawa State Nigeria, were conducted in 2014 to determine whether the infiltration capacity of the soils had contributed to the development and formation of the gullies. The gullies were characterized according to the guidelines for soil description of the Foods and Agricultural Organization [1]. Most of the gullies were observed to be severe and still active affecting about 10 – 25 % of the land area. The soils had a high sand content, and their surface texture was dominantly loamy sand. The cumulative infiltration curves showed that the soils can take up to 100 mm of water in just about 30 minutes. Steady state infiltration rates attained after 60 minutes were typically greater than 4 cm/hr. Soils with these values are categorized as having a high infiltration capacity (≥ 2 cm/hr.),implying that the soils infiltration capacity were adequate not to generate surface runoff that would influence gully development. A log-transformed regression analysis showed that two parameters (bulk density and organic carbon content) of the soils were significant predictors of the soils infiltration capacity. Managing these soils must therefore target practices that would enhance and sustain soil organic carbon. The dominant factors observed to be responsible for gully formation in the area were combination of natural and accelerated erosions due to human activities which included unplanned housing without recourse to drainage of catchments water, indiscriminate vehicular traction across the lands as access roads, mining of sand and late rite for construction of roads and houses, cattle grazing, and felling of trees for firewood, hence there is an urgent need for enforcement of environmental standards by regulatory agencies in agriculture and construction industries.
Keywords: Infiltration rate, cumulative infiltration, gully erosion, soil organic carbon, bulk density.

Introduction

Water erosion is the single major process responsible for the loss of billions of tonnes of soils worldwide. For example, Murck, *et al.*, [2] estimated global rate of soil loss through erosion at over 25 billion tonnes per year for both rural and urban environments. Soil erosion has been recognized in both rural and urban environments in Nigeria for many years as evident in the works of [3-4] and [5].The soil’s resistance to erosion depends on its texture, aggregate stability, shear strength, organic matter and clay content, mineralogy, infiltration capacity and

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chemical constituent [6]; [7]; and [8]. When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves downslope as runoff or ponds on the surface of flat lands and basins. When runoff occurs on bare or poorly vegetated soil, erosion takes place. Runoff carries nutrients, chemicals and soil with it, resulting in decreased soil productivity, off-site sedimentation of water bodies and diminished water quality. Sedimentation decreases storage capacity of reservoirs and streams and can lead to flooding. Water erosion is the leading factor in the development and formation gullies in Nigeria [5]. Several drainage lines and surface basins along Yola-Mubi road in Girei LGA have become affected by water erosion, which has turned them into gullies with varying degrees of severity, and hence, gully erosions have become a common site on fields in Girei.

The soils of Girei were classified as Alfisols [9]. There is a visible pressure on this particular soil due to competing interest for its utilization in crop production, infrastructure (urbanization), and grazing reserve (cattle routes). [10], stated that 'on a global level, it is estimated that overgrazing is the cause of 35% of land degradation whereas agriculture and deforestation/ forest exploitation are held responsible for 28% and 37% respectively'. A study conducted in 2012 at Bangshika in Adamawa state of Nigeria, showed that volume of soil loss in gullies range from 697 m^3 to 3,362 m^3 [11]. In the eastern parts of Nigeria, gullies created as a result of human activities could have depth, width and length of 50 m, 500 m and 2000 m respectively [12]. There is a need to ascertain whether the gully formations in Girei were due to the soils inherent property such as lack of adequate infiltration capacity, other natural causes or external factors imposed on the land by man's activities. This work was therefore conducted to characterize the gullies and evaluate the infiltration capacity of the soils affected by gully erosions in the study area.

The specific objectives were to;

i. To describe the morphology and categorize gullies according to guidelines for soil description of the Foods and Agricultural Organization [1]

ii. To measure and characterize the infiltration capacity of soils associated with the gullies

iii. To evaluate the relationship of some physical parameters to the field infiltration capacity of the soils.

Materials and Methods

Study area

The study was conducted in the year 2014, in Girei local government area of Adamawa State, a Guinea Savannah region of north eastern Nigeria. Girei lies between latitude 9º00´N and 9º 32´ N and Longitude 12º10´ E and 12º48´E at an altitude of 158.5m above sea level [13]. The annual rainfall rangeis 700-1000mm and temperature ranges from 15 to 39ºC [13]. Soil moisture regime is *Ustic*, while the soil temperature regime is *Isohyperthermic* [8]. Relative humidity varies seasonally. It is extremely low (20-30%) between January and March and increases from April to reach its peak (above 70%) in August and September.

Field techniques and soil sampling

Soils affected by gully erosions were identified and selected along the Yola-Mubi highway. The Yola-Mubi highway served as a baseline, while the Adamawa Mountains were used as reference for the direction of water flow through the gully systems. Generally, stream flows were oriented East (upstream) to West (downstream) of the baseline. Ten gully locations were identified and studied (Figure 1). At each gully system, eight (8) sampling locations were selected at least 10 meters from the gully edge, and 50 m apart along the gully channel.
Infiltration measurements were conducted at each sampling point using double ring infiltrometer method [8]. Short time intervals of 2 minutes were used during measurements of rapid initial infiltration rates for the first ten minutes, after which 5 minutes' intervals were used, and then an internal of 10 minutes until steady state was attained. Time intervals longer than 10 minutes led to emptying of the infiltration rings due to rapid water intake of the sandy textured surface soils, resulting infrequent refills of the infiltrometers, which could increase the risks of measurement errors. Steady state infiltration rates were attained after about 25 to 35 minutes, and measurements were continued until a time period of 1 hour had elapsed. A total of eighty (80) measurements were made. Eighty (80) surface soil samples were collected using soil auger to a depth of 20 cm. Core cutters were used to collect undisturbed samples for bulk density determination.

Laboratory analysis

In the laboratory, soil samples were air dried and sieved using a 2 mm mesh. The soil texture was determined using the Bouyocus hydrometer method. The soil bulk density was determined by oven drying soil cores at 105^0 C for 24 hrs. The volume of the soil core was calculated from the internal radius and the height of the core. The mass of the oven dry soil was divided by its volume to obtain dry bulk density of the soils. The soil pH and electric conductivity (EC) were measured in a 1: 2 soil to water ratio using an electrode. The organic carbon was determined by wet oxidation method [14].

Data Analysis

The mean, standard deviation and coefficient of variability were determined for soil physical properties and infiltration parameters. Graphical plots of the infiltration characteristics were made. The shape and pattern of infiltration curve provides some useful information on factors controlling the water entry into the profile [15]. The relationship of the soil physical properties to the measured infiltration rates of the soils was evaluated using a log-transformed multiple linear regression model.

Results and discussion

Morphological description and classification of the gullies

The results for gully characterization according to the guidelines [1] are presented in Tables 1 and 2. Seven of the ten sites were medium, U-shaped classic gullies (1 – 5 m deep), and affecting about 10-25% of the sites on which they occurred. Classic gullies are channels that are generally too deep to be crossed by farm equipment or filled using normal tillage operations, some type of earth moving equipment is generally required to fill them [16]. The sites identified as classic gullies include Girei river I, Angwan Hona (sites I and II), University Farm (sites I and II), and Damare (sites I and II). Two of the erosions were observed to be extreme cases, affecting about 25 – 50% of the land, and categorized as large classic U-shaped gullies (≥ 5 m deep). They include sites at the Professorial quarters and Girei River II. Only one of the gullies was categorized as a small, moderate, ephemeral gully (≤ 1 m deep), which affected only about 5-10% of the land area (Bajabure Federal Housing Estate). Erosions on all the ten sites were observed to be still active. A gully is described as active when its walls are free of vegetation, however, when walls are stabilized by presence of a vegetation cover, they are described as inactive [8].

Physical and chemical properties of the soils

Laboratory analysis (Table 3) showed an average content of sand, silt and clay fractions to be 78.30%, 8.20% and 12.40% respectively, hence a textural classification of loamy sand was applicable to surfaces of all ten locations in this study. The least coefficient of variation was observed in the sand fraction (CV < 4%). The silt fraction content was consistently in a single digit on almost all the soil samples and had the largest coefficient of variability (CV > 35%). The average bulk density was 1.56 g cm^{-3} (CV = 2%), which was slightly higher than the normal range of 1.10 to 1.50 g cm^{-3} reported for surfaces of most mineral soils [8]. Such high bulk density may be expected considering the skeletal nature of these soils with sand contents consistently approaching 80%. The results further showed that these soils were moderately acidic (pH 5.8; CV = 7.80 %), with a low organic carbon content (1.10%; CV = 10.80%).

Steady State Infiltration Rate (IR) and cumulative infiltrations (CI)

The infiltration rates and cumulative infiltrations are also presented in Tables4 and 5. Initial infiltration rates were typically between 35 and 60 cm hr^{-1} except in a few cases. Graphical plots of infiltration data for representative individual measurements are presented in Figures 2, 3, 4 and 5. The graphs suggest that the soil profile had dominant controls on infiltration rates with time [15]. The cumulative infiltration curves on the figures showed that the soils can take up to 100 mm of water in just about 30 minutes. Steady state infiltration rates attained after 60 minutes were typically greater than 4 $cmhr^{-1}$. These values exceed the limits classified as soils having a high infiltration capacity ($\geq$ 2 $cmhr^{-1}$; Table 6). Such high infiltration capacities are usually attributed to sands and sandy textured soils. Only few sampling locations at Damare I, indicated steady state infiltration capacities within the medium rates i.e. 1 – 2 cm/hr. [17] reported that texture is the predominant property controlling the soils influence on water characteristic and infiltration rate. Accurate determination of infiltration rate is essential for reliable prediction of surface runoff, design and evaluation of irrigation systems, watershed modelling [18]. It is also used in planning water conservation techniques, and in land evaluation for liquids and effluent waste disposal [19].In this study, coefficients of variability were consistently greater than 75%, and exceeding values 115% in many cases for both infiltration rates and cumulative infiltrations, and this was in agreement with [15], who described soil hydraulic properties as being highly variable spatially.

Regression Analysis

The relationship of the infiltration rate (IR) to some measured soil properties were evaluated using a multiple regression model of the form;

$Y_i = ß_{oi} + ß_{1i}X_{1i}+ ß_{2i}X_{2i}+\ldots ßp_{-1i}X_{p-1i}+ \varepsilon_i$-- (1)

Where Yi is the respondent (dependent variable), $ß_{oi}$, $ß_{1i,}$ $ß_{1i}$ and$ß_{p-1i}$ are parameters, X_{1i}, X_{2i}, X_{p-1i} are variables (independent predictors), and ε_i is error term [20].Infiltration rate (IR) was the response variable Y, while five (5) independent and predictor variables were; Organic Carbon (X_1), Bulk Density (X_2), Porosity (X_3), Clay content (X_4), and pH (X_5) respectively. Total sample size used was 80 (i.e. 8 sampling points from each of the ten gully sites studied). Diagnostic tests for normality were carried out andresults showed departure from a standard normal distribution.Collinearity was observed between Bulk Density (X_2) and Porosity (X_3), which may have been due to computations of porosity from an assumed constant particle density (2.65 g/cm^3).

Alog-transformed infiltration rate $Y_i^{'}$ was used in a second model was developed;

$Y_i^{'} = ß_{oi} + ß_{1i}X_{1i} + ß_{2i}X_{2i} + \ldots ß_{p-1i}X_{p-1i} + \varepsilon_i$-- (2)

Where $Y_i^{'}$ = ln (Y_i) i.e. natural log of Infiltration rate IR (dependent variable), $ß_{oi}$, $ß_{1i,}$ $ß_{1i}$ and$ß_{p-1i}$ are parameters, X_{1i}, X_{2i}, X_{p-1i} are variables (independent predictors) and remain unchanged as in model 1, and ε_i is error term. The collinearity observed between porosity and bulk density suggests that one of the two parameters should be dropped from the model; porosity was not included in the second model. Diagnostic tests for the second model revealed a normally distributed data with just two outliers (Figure 6). No collinearity was indicated; hence this model was adopted and a step-wise selection procedure was used. The full model was given as;

$Y^{'} = 1.09X_1 + 19.60X_2 + 0.085X_3 - 0.013X_4 - 30.60$---- (3)

The step-wise selection procedure picked two of these parameters (Organic carbon X_1; and bulk density, X_2), hence;

$Y^{'} = 1.03X_1 + 13.85X_2 - 20.60$ ---- (4)

Conclusions

The outcome of this study showed that water infiltration rates in these soils were quite adequate, and therefore could not be a significant factor in the development of the gullies studied in this work. Other soil properties such as bulk density and organic carbon contents, which had a statistically significant relationship with the infiltration rates did not exhibit trends relating to severity of gully development. On-site assessments and physical observations made during morphological description and characterization of the gullies showed that major causes of the erosions were attributed to human activities such as; indiscriminate construction of houses without recourse to necessary infrastructure for channelling run-off/run-on water, inappropriate clearing of vegetation for food cultivation, animal grazing and indiscriminate vehicular traffic across the land. Other factors observed on site include excavation of sand from the stream beds, and laterites from fields or abandoned burrow pits, which are often used for construction of houses and roads. These combined factors transformed natural drainage lines and seasonal stream channels into active accelerated erosions that broke the landscapes and formed deep gullies.

All the gully erosions in this study were observed to be still active, hence with time, the moderate ephemeral gully at Bajabure Housing Estate, will become a classic severe gully problem, while the presently severe classic gullies at seven of the study sites will transcend to extreme gullies, unless something is done to curtail the menace. Enforcement of environmental standards by regulatory agencies in construction and agricultural sectors could go a long way to mitigate these problems. Alternatively, methods such as the Conservation Reserve Program (CRP) of the United State department of Agriculture [21], which provides incentives to land owners for adoption of conservation practices on their lands could be tried and implemented at Girei.

Table 1 Morphological description and classification of gullies

S/N	Location and coordinates	Horizons	Depth (cm)	Color	Texture	Erosion and Category	Degree of erosion	Area affected	Activity
1	Girei river I 0230497 1036519 (UTM; Zone 33P)	A	0 – 16	7.5YR 4/4	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors such as inappropriate agricultural practices (cultivation of fields crops along river banks instead of maintaining a grass buffer zone)	Severe	10-25 %	Active
		Bw1	16-26	7.5YR 4/3	Sandy loam				
		Bw2	26-45	7.5YR 4/4	Sandy loam				
		C1	45-69	10YR 4/4	Sandy				
		C2	69-95	10YR 5/4	Sandy				
		Cr	95-220	10YR 5/3	Gravely				
2	Girei River II 0230302 1037169 (UTM; Zone 33P)	A	0 – 16	7.5YR 5/4	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors such as inappropriate crop cultivation and housing along river banks instead of maintaining a grass buffer zone	Extreme	25-50 %	Active
		Bw	16-90	75YR 4/6	Sandy loam				
		C	90-350	70YR 5/8	Sandy clay				
3	Angwan Hona I 0228288 1034302 (UTM; Zone 33P)	A	0-25	7.5YR 2/2	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors such as excavation of laterite and sand for construction purposes, and indiscriminate vehicular traffic across fields	Severe	10-25 %	Active
		Bw	25-62	7.5YR 5/2	Sandy loam				
		C1	62-92	7.5YR 7/1	Sandy loam				
		C2	92-250	7.5YR 5/2	Sandy loam				
4	Angwan Hona II 0227847 1035102 (UTM; Zone 33P)	A	0-30	10YR 4/2	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors such as felling of trees for fire wood and indiscriminate vehicular traffic across fields	Severe	10-25 %	Active
		Bw	30-98	10YR 5/2	Sandy loam				
		C	98-274	10YR 7/1	Sandy				
5	Professors quarters 0225285 1032864 (UTM; Zone 33P)	A	0-18	7.5YR 3/1	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors which include construction of estate buildings without recourse to proper drainage, and over grazing (cattle route)	Extreme	25-50 %	Active
		Bw	18-50	7.5YR 5/2	Sandy loam				
		C1	50-150	7.5YR 5/4	Sandy				
		C2	150-376	7.5YR 5/4	Sandy clay				

Table 2 Morphological description and classification of gullies

S/N	Location and coordinates	Horizons	Depth (cm)	Color	Texture	Erosion and Category	Degree of erosion	Area affected	Activity
6	University Farm I 0224990 1033411 (UTM; Zone 33P)	A	0-15	7.5YR 3/1	Loamy sand	Classic gully: natural and accelerated erosion due to human induced factors such as unplanned drainage and indiscriminate vehicular traction across fields as access roads	Severe	10-25 %	Active
		Bw1	15-70	7.5YR 5/2	Sandy loam				
		C	70-250	7.5YR 5/1	Sandy loam				
7	Bajabure Federal Housing 0223636 1030754 (UTM; Zone 33P)	A	0-21	10YR 4/4	Loamy sand	Ephemeral gully: natural and accelerated erosion due to human induced factors such as unplanned housing without recourse to drainage of roof water catchments and indiscriminate vehicular traction across lands as access roads	Moderate	5-10 %	Active
		Bw1	21-29	7.5YR 4/6	Sandy loam				
		Bw2	29-31	7.5YR 5/2	Sandy loam				
		C1	31-34	7.5YR 4/1	Loamy sand				
		C2	34-100	7.5YR 5/4	Loamy sand				
8	University Farm II 0224450 1033681 (UTM; Zone 33P)	A	0-15	10YR 5/6	Loamy sand	Classic gully: natural accelerated erosion due to cultivation of field crops along natural drainage lines, and indiscriminate felling of trees	Severe	10-25 %	Active
		Bw1	15-24	7.5YR 5/4	Sandy				
		Bw2	24-33	7.5YR 6/4	Sandy				
		C1	33-51	7.5YR 5/2	Loamy sand				
		C2	51-115	10YR 8/1	Sandy				
9	Damare I 0220110 1030781 (UTM; Zone 33P)	A	0-13	7.5YR 4/6	Loamy sand	Classic gully: natural accelerated erosion due to cultivation of field crops along natural drainage lines, overgrazing, and indiscriminate felling of trees	Severe	10-25 %	Active
		Bw	13-44	7.5YR 5/2	Sandy loam				
		C1	44-120	7.5YR 5/4	Sandy				
		C2	120-150	7.5YR 8/5	Sandy				
10	Damare II 0220306 1030904 (UTM; Zone 33P)	A	0-26	7.5YR 3/1	Loamy sand	Classic gully: natural accelerated erosion due to cultivation of field crops along natural drainage lines, overgrazing, and indiscriminate felling of trees	Severe	10-25 %	Active
		Bw	26-63	7.5YR 3/2	Sandy loam				
		C	63-120	7.5YR 4/3	Sandy				

Table 3: Some physical and chemical properties of the soils (each data point represents a mean of 8 replications)

Location	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)	pH	EC	OC (%)	OM (%)	Porosity (%)
Girei River I	74	12	14	1.58	5.78	0.016	1.01	1.75	43
Girei River II	78	9	13	1.56	5.70	0.011	1.07	1.85	41
Angwan Hona I	81	8	10	1.59	6.21	0.013	1.18	2.03	40
Angwan Hona II	86	5	8	1.62	5.98	0.010	0.93	1.59	39
Professorial Quarters	80	8	12	1.56	6.67	0.029	1.30	2.24	41
University Farm I	75	10	15	1.52	5.13	0.078	1.25	2.15	43
University Farm II	76	11	13	1.56	5.45	0.013	1.22	2.10	41
Bajabure Housing Estate	79	9	12	1.55	5.73	0.015	1.13	1.94	41

Damare I	79	8	14	1.50	5.40	0.035	1.06	1.83	42
Damare II	75	12	13	1.54	5.44	0.020	1.28	2.19	42
Mean	**78.3**	**9.20**	**12.40**	**1.56**	**5.75**	**0.024**	**1.14**	**1.97**	**41.30**
SD	**3.59**	**2.15**	**2.07**	**0.03**	**0.45**	**0.020**	**0.12**	**0.21**	**1.25**
CV	**4.59**	**23.37**	**16.66**	**2.20**	**7.80**	**85.95**	**10.82**	**10.74**	**3.03**

Note: BD- bulk density, SD- standard deviation, CV- coefficient of variability, EC- electric conductivity, OC- organic carbon, OM- organic matter

Table 4: Steady state infiltration rates (cm hr^{-1}) attained after 60 minutes of measurement

Replications	GR I	GR II	AH I	AH II	PQ	UF I	UF II	FHE	DM I	DM II
IR 1	1.8	25.6	7.8	6.0	47.6	53.6	10.2	9.6	6.0	25.2
IR 2	6.8	1.2	11.6	8.4	17.8	18.6	34.8	11.6	4.2	1.2
IR 3	9.0	6.6	12.6	15.0	12.0	1.2	36.0	1.2	3.0	0.5
IR 4	8.8	7.2	7.0	27.6	5.8	14.1	30.2	18.0	1.2	3.0
IR 5	2.4	22.6	6.6	12.0	17.4	4.8	6.6	6.6	8.8	14.4
IR 6	20.0	1.2	3.0	1.3	12.4	46.6	2.4	6.0	6.0	2.4
IR 7	5.0	11.0	31.6	13.2	17.8	44.8	16.2	1.8	36.0	20.6
IR 8	0.6	2.4	24.0	30.0	46.8	36.4	7.8	1.8	12.0	44.5
Mean	6.8	9.7	13.0	14.2	22.2	27.5	18.0	7.4	9.7	13.6
SD	6.20	9.52	9.81	10.02	15.95	20.32	31.61	5.86	11.16	15.89
CV	91.2	97.9	75.3	70.6	71.9	73.9	75.5	79.5	115.7	116.5

***Key*:** Infiltration rate (IR), Girei River (GR), Angwan Hona (AH), Professorial Quarters (PQ), University Farm (UF), Federal Housing Estate (FHE), Damare (DM)

Table 5: Cumulative infiltrations (cm) after 60 minutes of measurement

Replications	GR I	GR II	AH I	AH II	PQ	UF I	UF II	FHE	DM I	DM II
CI 1	2.7	30.1	8.2	6.7	57.3	58.1	11.8	12.4	7.8	40.0
CI 2	8.8	3.4	13.1	11.0	21.9	25.2	39.8	16.8	4.7	1.7
CI 3	12.6	7.4	15.2	17.3	14.1	1.5	44.2	1.2	3.2	0.5
CI 4	11.1	7.6	8.3	40.8	6.4	18.5	34.8	22.7	1.5	1.6
CI 5	3.3	28.9	10.0	13.9	19.0	5.0	9.1	12.5	11.1	19.1
CI 6	24.0	1.9	3.7	2.6	21.0	53.0	3.2	9.8	8.0	4.2
CI 7	6.9	13.6	35.1	19.1	22.9	53.3	19.2	2.6	66.9	23.5
CI 8	0.8	2.7	28.0	39.0	48.4	39.7	9.6	1.6	14.0	59.1
Mean	8.8	12.0	15.2	18.8	26.4	31.8	21.5	10.0	14.7	18.7
SD	7.4	11.5	10.8	14.1	17.4	22.4	15.8	7.8	21.5	21.5
CV	84.6	95.9	71.2	74.9	65.8	70.6	73.8	78.1	146.8	114.8

***Key*:** Cumulativeinfiltrations (CI), Girei River (GR), Angwan Hona (AH), Professorial Quarters (PQ), University Farm (UF), Federal Housing Estate (FHE), Damare (DM)

Table 6: Classification of Field Infiltration Rates (cm hr^{-1})

Rates	Classification	Soil type
> 2.0	High	Sands
1.0 – 2.0	Medium	Sandy and silty soils
0.5 – 1.0	Moderate	Loams
0.1 – 0.5	Low	Clayey soils
< 0.1	Very low	Sodic clayey soils

Source: Scott, 2000

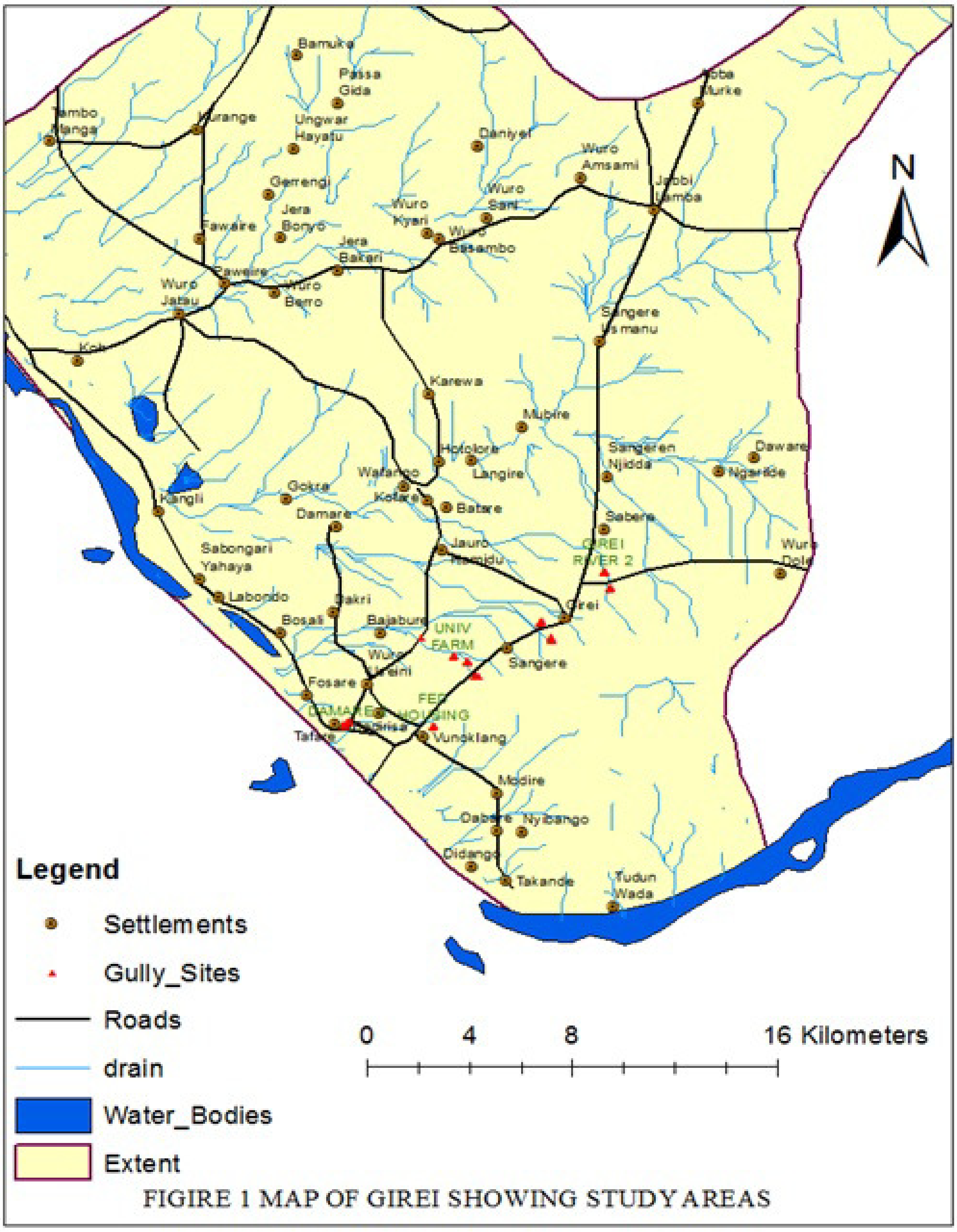

Figure 1: Map of Girei LGA in Adamawa State Nigeria showing study sites (red triangles)

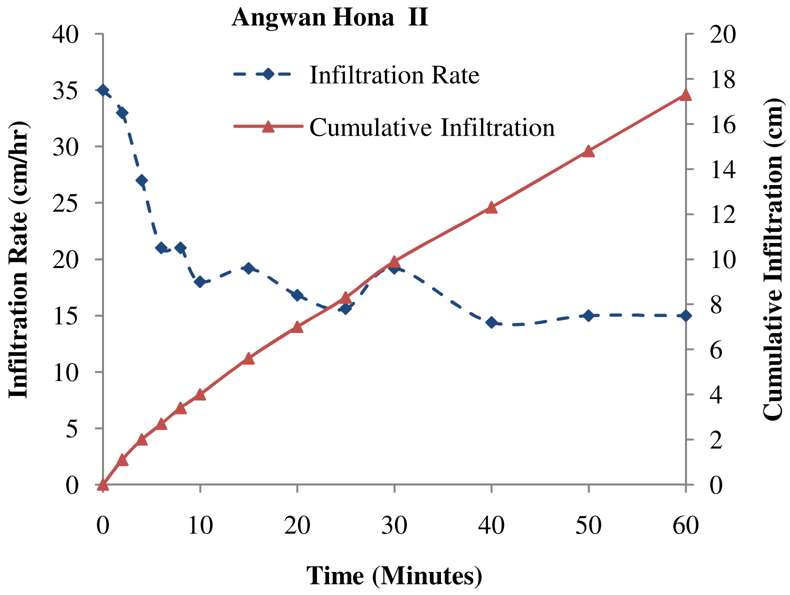

Figure 2: Infiltration curves for one of the eight points sampled at Angwan Hona II (Severe gully)

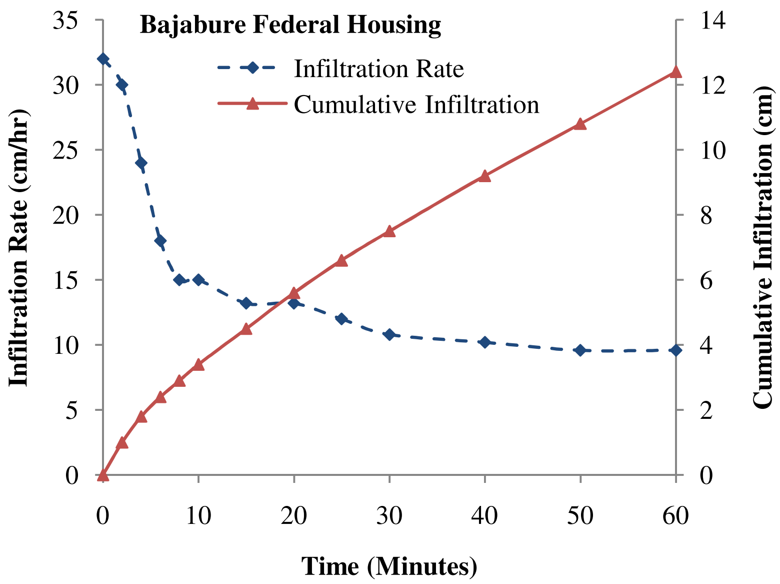

Figure 3: Infiltration curves for one of the eight points sampled at Bajabure Federal Housing Estate (Moderate gully)

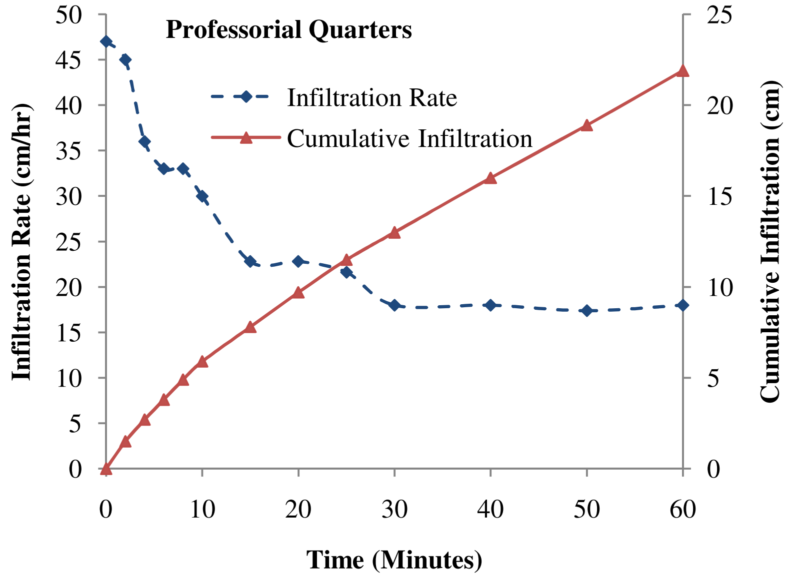

Figure 4: Infiltration curves for Professorial quarters (Extreme gully site)

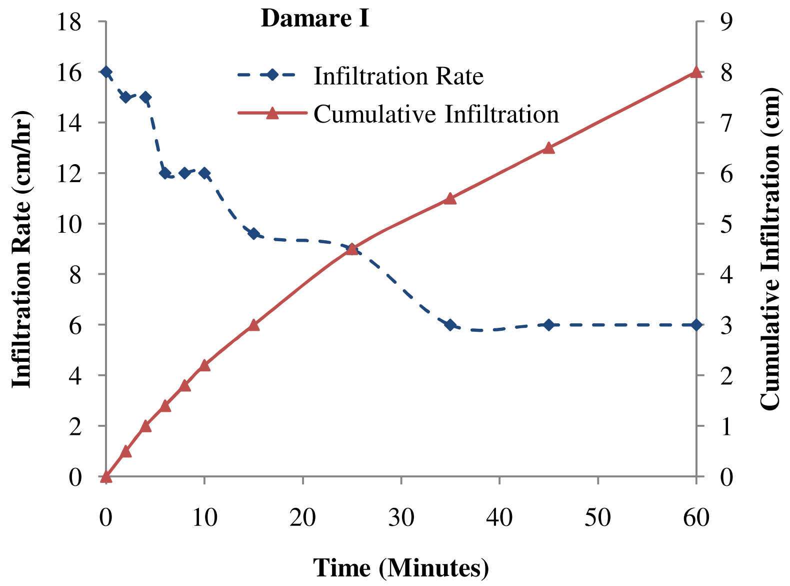

Figure 5: Infiltration curves for Damare I (Severe gully site)

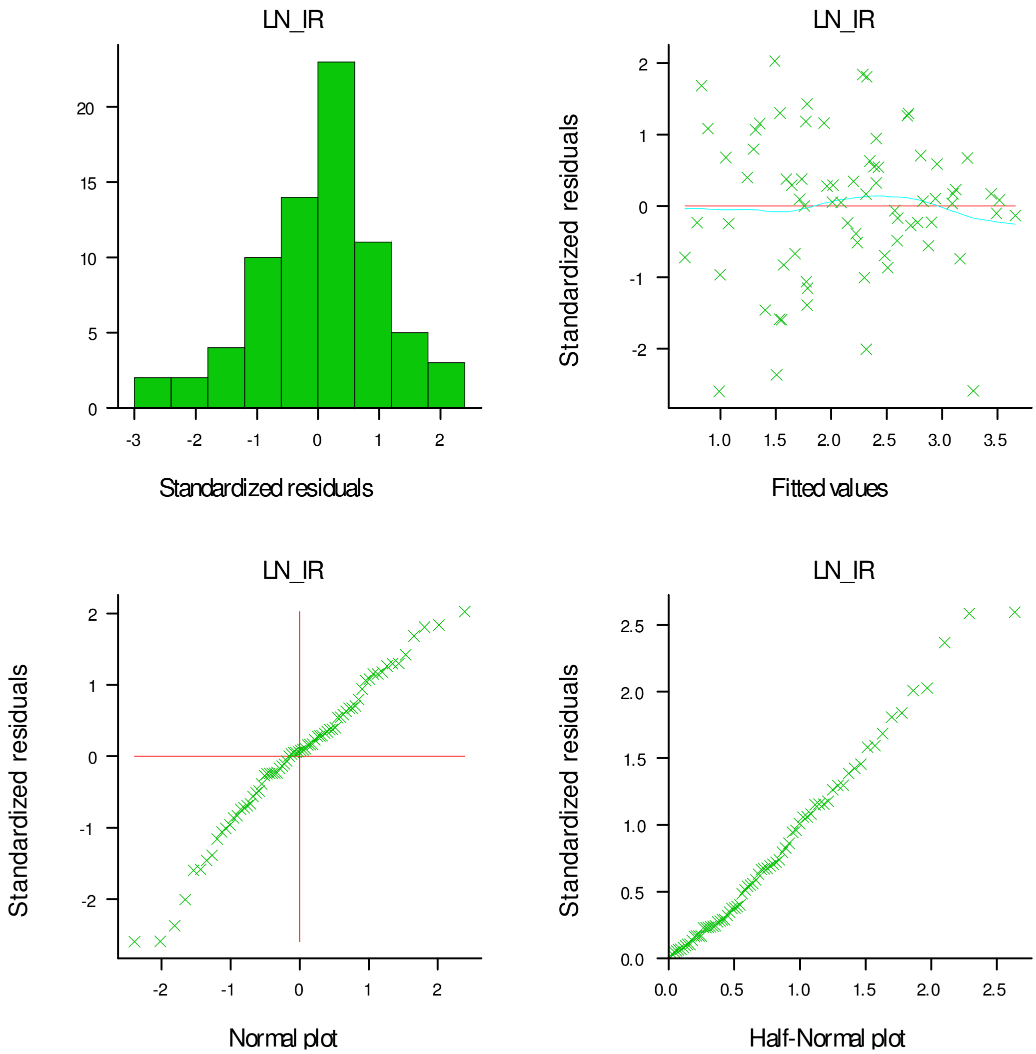

Figure 6: Diagnostic analyses of regression data (test of normality)
Note: LN - natural log, IR- infiltration rate

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