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Analyzing the spatial relationship between land surface temperature and elevation in three gullies locations in southeastern Nigeria

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Abstract

Gully erosion is a dangerous phenomenon that threatened human existence, plants and animals communities. Families are being separated from their ancestral home and livelihood due to gully erosion. Also, available agricultural lands to combat food insecurity are contently depleted on yearly basis across the globe as a result of gullies menace. Southeastern Nigeria is highly vulnerable to gully erosions due to it geology and studies on spatial relationships between gully LST and elevation has not been carried out, particular by applying remote sensing and GIS technique to investigate it variations. Available studies where limited to mapping and causes of gully erosion in the region. The study applies LST and elevation data to investigate correlation on three gullies locations. LST was derived from Landsat data and was first converted to radiance image while the elevation data was obtained from Google Earth image. Elevation data was used to produce raster surface in that cell values equivalent to LST at every point can be extracted. Three sets of paired sample points of LST and elevation was extracted from the three gullies locations and used to compute correlation coefficient (r). The study observed at Nanka gully a strong negative correlation of -0.665. This implies an increase in LST correspond to decrease in elevation within the gully. At Ekwolobia and Aguluezechukwu gullies sites, positive correlation coefficient of 0.692 and 0.910 were obtained. The positive correlation coefficients implied that LST and elevation increase or decrease within the gullies. This might be due to unequal distribution of radiation within gully surface as a result of three canopies. For further study, it is recommended that improve elevation data source like LiDAR elevation data should be use to investigate spatial correlation between LST and elevation at gully location.

Keywords: Correlation Analysis; Elevation; Gully Erosion; Land Surface Temperature; Remote Sensing; Southeastern Nigeria

1. Introduction

Gully erosion is one of the world serious hazards that threatened human lives and causing varying degrees of impacts. Gully erosion affects roads, bridges, buildings, farmlands and degrades ecosystem [1]. Valuable agricultural lands are rendered unprofitable due to gully menace. In addition, top soil layers are also destroyed in the process. Gully erosion occurs as a result of mass movement of fluid materials down the hill slope [1], occasioned by intense precipitation [2], [3]. [4] in their study showed that surface runoff was the significant factor for gullies development in Iran. According to experts, other causes of gully erosion are lack of vegetation cover, soil texture, overgrazing, and abuse of land use planning. [5] summarized causes of gully into natural and anthropogenic causes. The greatest impacts were on human population and valuable agricultural land. The occurrences of gully erosion displaced inhabitants of the affected locality.

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Gully locations are characterized by different in elevation and land surface temperature (LST). [6] observed that gullies depth in Queen Ede catchment, Benin City varies from 0.5 to 13.8m. In their studies, gullies elevations were obtained using total station observation. Ideally, as gully advances, the elevation at the bottom and along the slope side defers.

LST is the remote sensing derived using satellite imageries with thermal infrared band [7], [8]. Remotely sensed LST was selected due to wide areal cover. Several remote sensing data has been used to derive LST. [9] used MODIS data to derived LST in Northwest Vietnam. Similarly, [10] used Landsat data to derived LST in Abuja, Nigeria. MODIS and Landsat data are optical remote sensing systems that operate in the visible, near-infrared (NIR) and short-wave infrared (SWIR) regions of the electromagnetic spectrum to form images of the earth's surface by detecting the reflected radiation from targets [11]. They have been used to carry out studies relating to climate, urban, and environment. In analyzing spatial relationship between LST and elevation, Landsat data was selected for the study.

LST varies with change in elevation. An increase in elevation leads to corresponding decrease in LST for a balance atmosphere [9]. Studies on these variations have been carried out in gully, and complex terrain like mountainous and hilly regions of the globe. [9] studied variation of LST and elevation in Northwest Vietnam and observed that LST dropped with increase in elevation. [12] used digital surface model to estimate difference in elevation at various locations in gully and compute their volume. [13] compared accuracy of different DEM data sources obtained in gully in Loess Plateau. In Southeastern Nigeria studies on elevation and LST relationships has not been carried out. Available studies in the region were limited to determining causes of gully formations [2], [14]. Little was done in terms of analyzing spatial relationship between LST and elevation in gullies in Southeastern Nigeria. Hence, this study was structured in using remote sensing derived LST from Landsat data and elevation data obtained from GE image to analyzed correlation between them in three gullies locations.

1.1. Study Area

The study area for the investigation of the spatial relationships between gullies elevations and land surface temperature is in Anambra State, South-East Nigeria. It is located on longitude 07° 03'mE - 07° 11'mE and latitude 05° 59'mN – 06° 08'mN. The study area lies in two Local Government Area, they are; Orumba North and Aguata in Anambra State. This study considered three (3) gully sites located in Nanka, Ekwolobia and Aguluezechukwu communities. These gullies sites were selected due to their areal extent and their proximity. Nanka gully is the largest of the three considered for the study with an area of 903.02ha. Table 1 summarized the approximate areas and the coordinates of the three gullies used in the study.

Table 1 Coordinates and area in hectares of the gullies in the study area

GULLY	EASTINGS(m)	NORTHINGS(m)	AREA (ha)
Nanka	286793.74	672119.34	903.02
Ekwolobia	288596.73	667008.95	80.96
Aguluezechukwu	291272.90	662921.13	18.17

The study area is under Anambra sedimentary basin and is made-up of sedimentary rock [15], [14]. Study has shown that sedimentary rocks are more vulnerable to gully erosion menace. The basin annual precipitation as at 2009 was 2,273.4mm and mean minimum temperature was 23.2° [16]. [14] reported annual rainfall of 2,500mm with the peak in July and October. The elevations in the gullies vary depending on the size and duration of occurrence. The minimum and maximum elevations in the gullies sites ranges from 65.38m at the bottom to 311.10m at the boundary of the high slope. Studies have shown that gully development is frequent on the steep slope. Other land use and land cover in the research areas are vegetation, water bodies, bare land and built-up. It has been reported that human activities on the vegetation have also increased the incidence of gully erosion. Agricultural activities exposed the soil to rainfall intensity thereby initiating gully formations. This study adopts remote sensing and GIS technique to investigate the relationship between elevation and land surface temperature in gully erosion impacted sites.

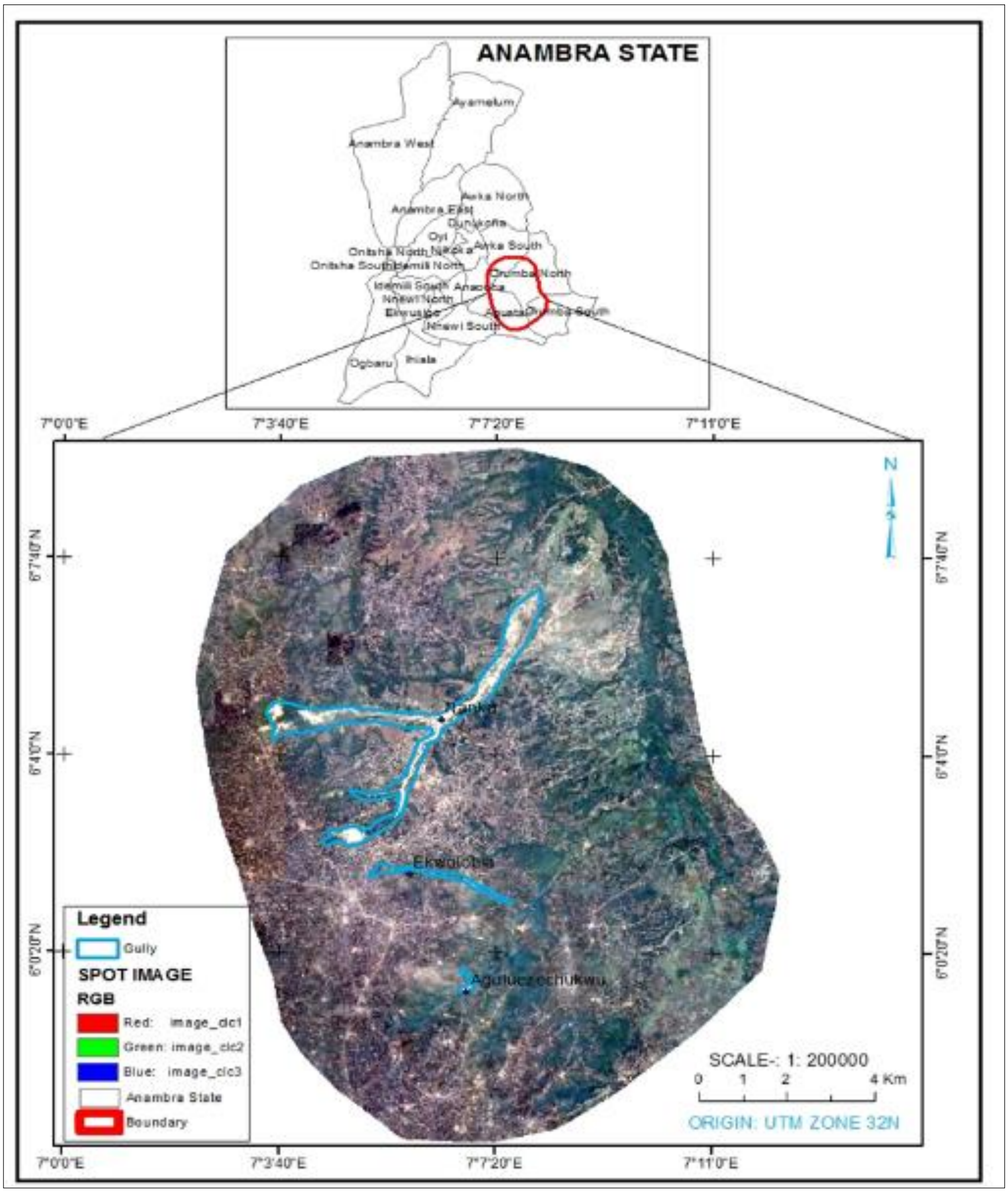

Figure 1 Study area map showing Anambra State as inset and the three gullies sites

2. Methodology

2.1. Datasets and Software used

This study was carried out using datasets and GIS software. Datasets used for the study include; Landsat OLI image of 02/05/2022, elevation data, and Nigeria shape file. Landsat data was downloaded from its website at no cost using the data link http://glovis.usgs.gov/. The OLI Landsat image was downloaded using path 188 and row 56 in zip file. The level 1 downloaded Landsat data was the high-quality, radiometrically and geometrically corrected image data [17]; [18]. Landsat data was used to derive land surface temperature (LST) of the gully erosion sites.

Elevation data for the gully erosion sites were obtained from GOOGLE ERATH (GE) via GPS Visualizer link http://www.gpsvisualizer.com/convert_input. The online link provided an interface for the extraction of elevation data from GE image. Also, Nigeria shape file was collected from the Office of the Surveyor General of Rivers State (OSGRV) through application to the GIS laboratory. Table 2 summaries datasets used for the study.

Table 2 Summary of datasets used in the study

Data	Date	Resolution (m)	Source	Data Type
Landsat OLI	02/052022	30 x 30	http://glovis.usgs.gov/	Raster
Elevation	23/02/2023	NA	GOOGLE EARTH	Vector
Nigeria Shape File	NA	NA	OSGRV	Vector

Selected GIS and statistical software package used for the study are; ESRI's ArcGIS 10.3.1 and Statistical Packages for the Social Sciences (SPSS). ESRI's ArcGIS is powerful vector software produced by the United States of America. It was used for the conversion of raw image to radiance image and for the derivation of LST of the gullies erosion sites. SPSS is computational program designed for analyzing and presenting results for structured data [19]. SPSS was used to perform linear regression between LST and elevation of the three gullies sites.

2.2. Data Processing

Prior to derivation of land surface temperature, Landsat data was in digital number (DN) which does not represents any physical quantity [20]. It was converted from digital count (DC) to surface radiance (actual reflection from the surface features). Thermal band used in the derivation of LST is the band 10. The algorithm for the conversion to surface radiance is given by;

$$L_\lambda = M_L \text{ x } Q_{cal} + A_L \text{ -- } 1$$

Where, M_L is the radiance multiplicative scaling factor for the band, Q_{cal} is the L1 pixel value in DN and A_L is the radiance additive scaling factor for the band [20].

The computed radiance image was used to calculate LST. The general equation for calculating LST is given by:

$$T = K2/ \text{In}(K1/ L_\lambda + 1) \text{ -- } 2$$

Where, T is the TOA brightness temperature in Kelvin, L_λ is the spectral radiance in $Wm^{-2}Sr^{-1}$, K1 and K2 are the thermal constant for band 10. The parameters M_L, A_L, K1, and K2 are obtained from the Landsat OLI metadata. The computed temperature in Kelvin scale was converted to Celsius scale using the algorithm,

$$C = T – 273.15 \text{-- } 3$$

Where, T is the temperature in Kelvin scale, and C is the Celsius temperature. The value 273.15°C is the absolute zero temperature for converting Kelvin scale to Celsius scale - standard for presenting temperature by NiMET.

Elevation data generated from GE was used to model Triangulated Irregular Network (TIN) surface of the gully sites. Elevation data described the general topographic surface of the gully erosion sites. TIN model produced was converted to raster surface of cell size 30m x 30m. Raster model enables cell values to be extracted and used as point data.

2.3. Linear Regression of Variables

Linear regression provides a means of measuring the strength of relationship between variables (dependent and independent) that are quantitative. Linear relationship is measure using correlation coefficient (r) which provides standardized measure of linear association between variables [21]. The degree of the relationship ranges from -1 to +1 [22]. Value of -1 indicates perfect negative correlation while value of +1 indicates perfect positive correlation between measured variables. Several software packages are available for computing correlation coefficient, for example, SPPS, excel spread sheet, IDRISI software etc. This study utilized SPSS for the computation of spatial relationships between LST and elevations of the three gullies erosion selected for this study.

Gullies erosion sites were gridded at 100m interval. The grid lines were controlled to depict the geometry of the gullies. Point shape file was created in ArcGIS for the purpose of generating point data at the grid intervals. The points were created to emanate from the gully head to the foot of the gully down slope. Using extract values to points in the ArcGIS Spatial Analyst Tool, the cell values of LST and elevation of the raster data were extracted. For the purpose of linear regression this method allowed for equal values of LST and elevation to be extracted. Total number of points extracted for Nanka gully erosion site was 96, Ekwolobia was 33, and Aguluezechukwu was 11. The size of gully determined the numbers of points to extract. The paired data were used to perform linear regression with gully LST chosen as dependent (y-axis) variable while gully elevation selected as independent (x-axis) variable.

The correlation coefficient (r) is given as,

$$r = \sum(x - \bar{x})(y - \bar{y}) / (n - 1)SxSy \text{---------------------------------} 4$$

Where, x is the independent variable, y is the dependent variable, n is the number of sample, Sx and Sy are the sample standard deviation of measured variable x and y [21].

3. Results

This section presents results of the processed elevation and LST at the respective gullies sites. Minimum elevation in Nanka gully site down slope is 65.38m and the maximum elevation at the gully head is 259.06m. The foot of the Nanka gully is towards northeast direction which proceeded to the stream. For the Ekwolobia gully, the minimum elevation at the gully down slope is 100.92m and the maximum elevation at the gully head is 252.60m. The foot of Ekwolobia gully is towards east and flows to the stream with lower elevation. Similarly, Aguluezechukwu gully has minimum and maximum elevations as 110.05m and 193.11m respectively. Maximum elevation was located at the gully head northward while minimum elevation was located eastward. Figure 2 presents surface elevation of the three gullies sites.

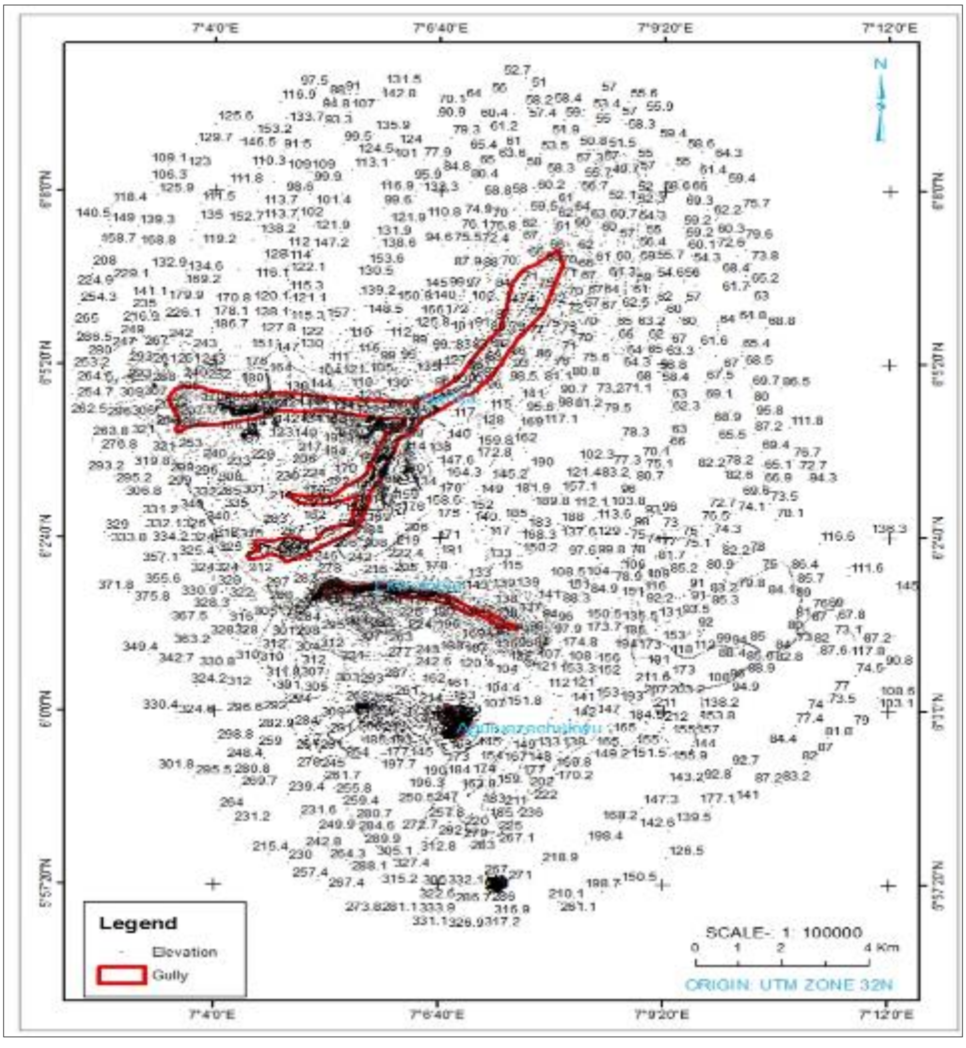

Figure 2 Elevation of the three gullies sites used in the correlation analysis.

Gullies LST also varies within the surface. For the Nanka gully, minimum LST of 26.67° and maximum LST of 35.33° were recorded. Lower LST where recorded at the gully head while higher LST where observed at the gully foot northeastward. Similarly, for the Ekwolobia's gully, minimum and maximum LST were 28.33° and 30.73° respectively. Minimum LST was observed at the foot of the gully eastward while maximum LST was observed at the gully head located westward. Also, for the Aguluezechukwu gully, minimum and maximum LST obtained were 27.37° and 32.50° respectively. Higher LST was recorded at the gully head while lower LST was observed southward. Figure 3 shows derived LST of the gullies.

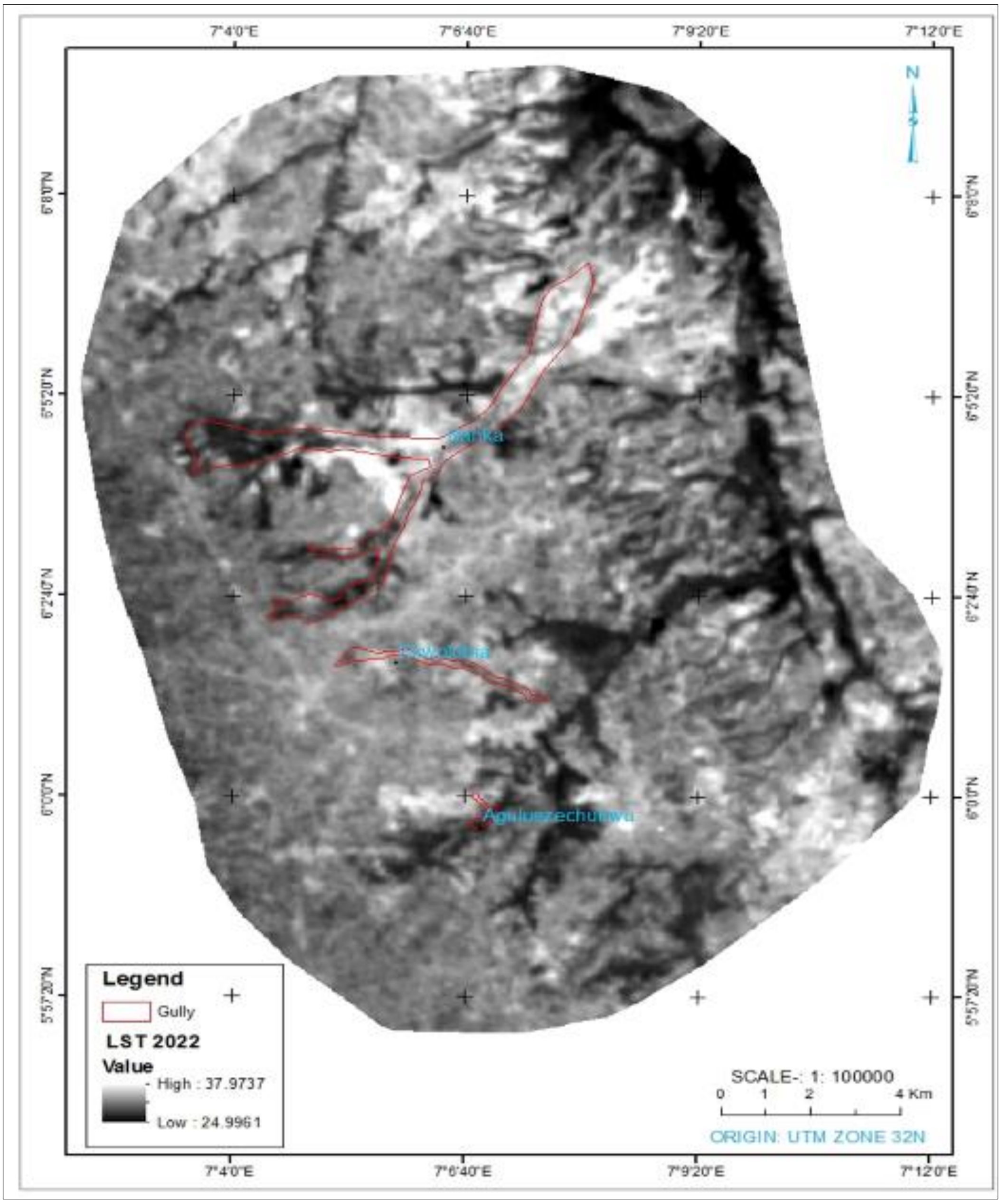

Figure3 Derived LST of the gullies sites

Linear regression was computed using paired LST and elevation data for each gully location. Total of 96 sample paired points of LST and elevation were extracted in Nanka gully location. Table 3 shows derived LST and elevation data obtained from the Nanka gully location.

Table 3 Paired points of LST and elevation at Nanka gully used for the linear regression analysis

ELEV(m)	TEMP(°c)	ELEV(m)	TEMP(°c)
259.11	26.84	102.44	33.43
259.11	27.12	101.06	32.35
243.14	27.69	96.43	30.88
239.90	28.11	96.81	30.21
231.08	28.27	97.10	29.91
203.18	27.16	97.10	29.75
186.99	27.58	96.44	29.43
172.41	27.32	93.08	29.33
162.81	27.27	93.98	29.10
145.71	27.29	91.58	29.69
134.55	27.49	93.83	30.14
131.19	27.44	91.09	29.89
128.09	28.12	91.63	29.75
126.02	27.62	93.09	30.39
125.44	27.34	90.13	30.31
122.28	26.67	89.35	30.89
121.55	26.69	86.98	31.91
118.90	26.98	85.73	31.39
119.90	26.90	85.11	32.49
120.67	27.96	85.54	33.55
120.94	29.60	82.92	32.80
121.74	30.18	82.05	32.48
121.44	29.66	82.92	33.36
118.90	28.36	82.36	34.22
115.48	27.79	81.91	34.36
115.49	27.67	80.86	34.06
113.98	27.38	79.53	34.07
113.52	27.91	79.78	33.59
115.61	28.69	81.24	33.42
120.74	29.13	78.93	31.33
117.11	30.29	78.11	32.18
119.69	29.75	77.32	33.61
118.20	29.49	76.09	32.61
112.55	30.55	75.17	33.56
113.47	31.62	74.28	32.61

113.35	31.46	75.06	33.67
108.94	31.41	74.50	33.22
105.56	31.68	75.47	32.51
105.08	33.15	72.74	34.06
104.56	33.74	71.58	35.14
103.07	34.05	70.27	35.33
101.89	33.93	69.90	34.87
101.74	34.14	68.84	33.94
101.12	34.03	67.62	33.45
100.98	33.64	67.71	33.59
100.70	34.96	67.48	33.50
100.92	34.55	66.83	33.12
102.34	33.95	65.38	32.07

Correlation coefficient (r) of -0.665 was obtained, indicating strong negative spatial relationship between LST and elevation at the Nanka gully location. The coefficient of determination and the standard error of the estimate are 0.442 and 1.972 respectively. The linear regression model showing best-fitting straight line through the set of paired points for the Nanka gully is shown in figure 4.

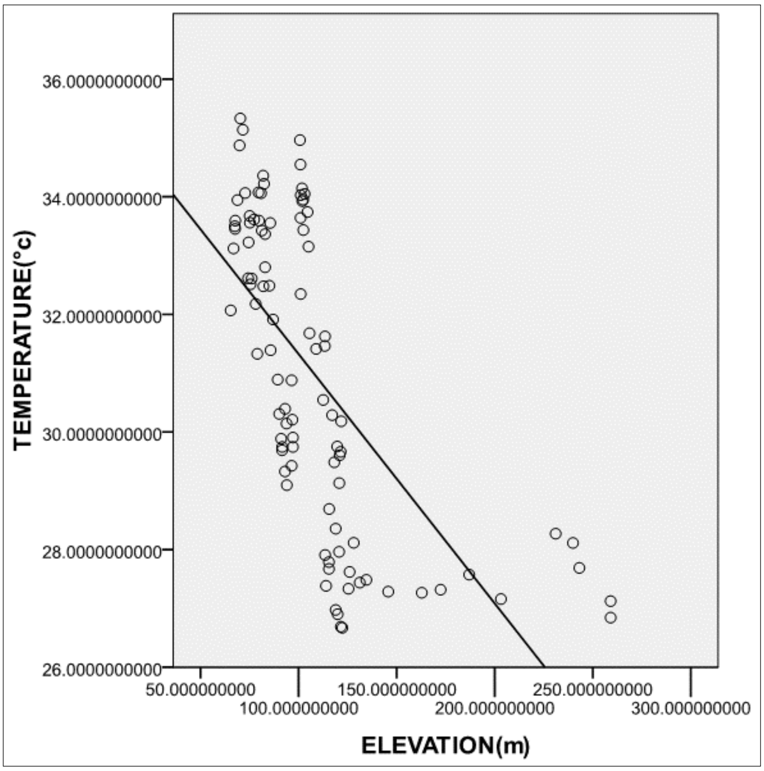

Figure 4 Best-fitting line through paired LST against elevation

Computing linear regression model for the Ekwolobia gully location using 33 paired points, the correlation coefficient of 0.692 was obtained. The model shows moderate positive spatial relationships between LST and elevation in the gully. The square of the correlation coefficient and the error of the estimate are 0.479 and 0.898. Figure 5 shows the graph of best-fitting line for Ekwolobia gully location. Table 4 is the paired LST and elevation data obtained at the Ekwolobia gully.

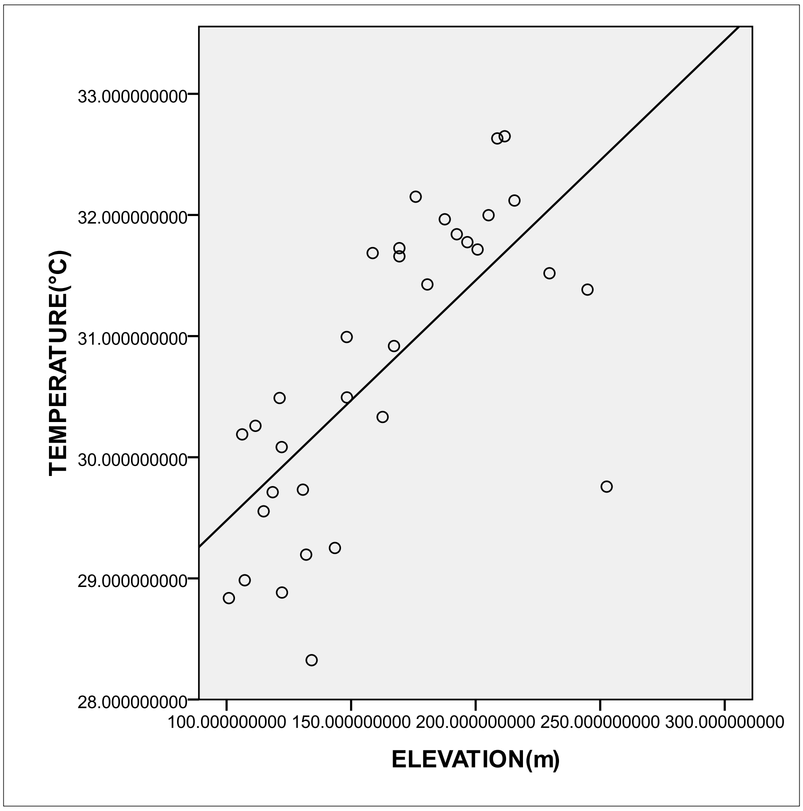

Figure 5 Graph of best-fitting line for Ekwolobia gully location

Table 4 Paired LST and elevation data at Ekwolobia gully used for the linear regression analysis

ELEV(m)	TEMP(°c)
252.60	29.76
244.91	31.38
229.64	31.52
215.58	32.12
211.65	32.65
208.68	32.63
205.18	32.00
200.77	31.71
196.67	31.78
192.41	31.84
187.60	31.96
180.61	31.43
175.92	32.15
169.36	31.73
169.37	31.66
167.22	30.92

162.64	30.33
158.64	31.69
148.23	30.99
148.31	30.49
143.49	29.25
134.14	28.32
131.94	29.20
130.63	29.73
122.12	30.08
121.29	30.49
118.50	29.71
122.24	28.88
114.87	29.55
111.58	30.26
106.26	30.19
100.92	28.84

At Aguluezechukwu gully site, the number of paired points used in the analysis was 11. The correlation coefficient 0.910 was obtained, indicating strong positive spatial relationship between LST and elevation data. The coefficient of determination and the standard error of the estimate are 0.828 and 0.839. Figure 6 shows best-fitting line for the Aguluezechukwu gully. Table 5 represents LST and elevation for Agulueechukwu gully.

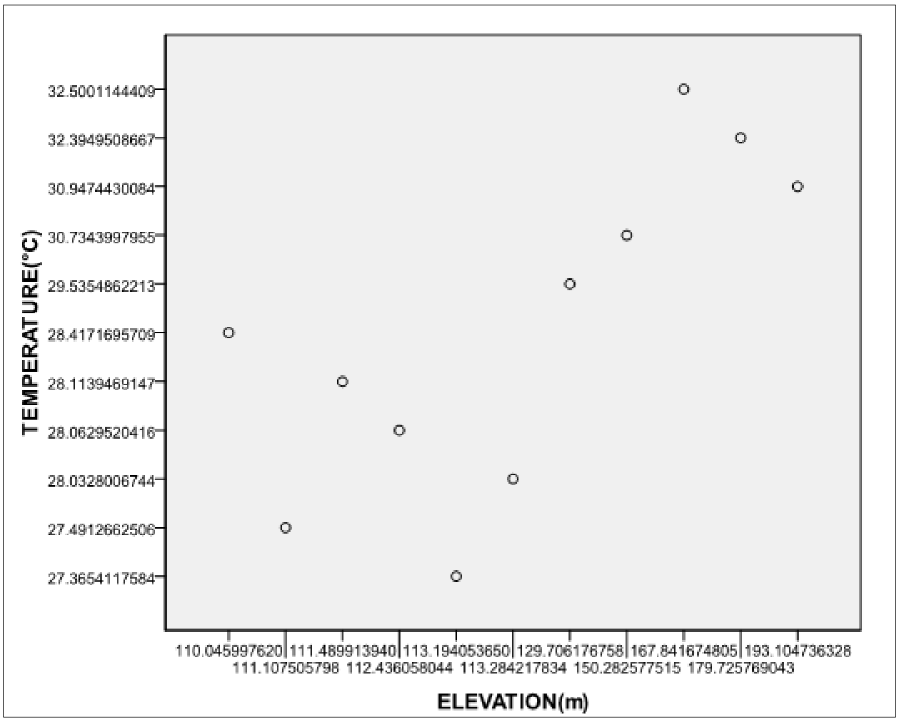

Figure 6 Graph of best-fitting line of the Aguluezechukwu gully location

Table 5 Paired LST and elevation data at Aguluezechukwu gully used for the linear regression analysis

ELEV(m)	TEMP(°c)
193.10	30.95
179.73	32.39
167.84	32.50
150.28	30.73
129.71	29.54
110.05	28.42
111.49	28.11
112.44	28.06
111.11	27.49
113.19	27.37
113.28	28.03

4. Discussions

There was an agreement with the observed values of LST and elevation of the Nanka gully, in that, an increase in elevation corresponds to decrease in LST. Locations with maximum elevation from 203.18m to 259.11m, the observed LST at that location ranges from 26.84° to 28.11°. As the elevation decrease to 120.74m, the LST observed increase to 29.60°, indicating an increase in LST by 1.49°. Down the foot of the gully with lowest elevation 65.38m to 70.27m, LST increased to a range of 32.07° to 35.14°. Nanka gully LST increased by 8.30° with a decrease in gully elevation. This increased in LST with the corresponding decreased in elevation produced strong negative spatial relationship of -0.665 between the variables. [23] also obtained strong negative relationship of -0.61 between LST and elevation in their study in Gilgit-Baltistan, Pakistan. In addition, the work of [24] also obtained correlation coefficient of -0.55 between LST and elevation in their study carried out in Hangzhou city China. The negative spatial relationship ideally obeys the natural law of the higher you go the cooler it become. That is, at high elevation, lower LST was reported while at lower elevation, high LST was recorded in the gullies. These observations and confirmation of the universal law of temperature and elevation was due to even exposure of the gully surface to solar radiation.

This situation was reversed in the case of Ekwolobia and Aguluezechukwu gullies locations. The study observed spatial positive correlation coefficients Higher LST was recorded at higher elevation and lower LST was recorded at lower elevation on both gullies. For the Ekwolobia with elevation of 252.60m, the equivalent LST recorded was 29.76°C and at elevation of 107.29m, LST recorded was 28.98°C. In the case of Aguluezechukwu gully, location with elevation of 193.10m, LST observed was 30.95°C and at elevation of 113.28m, LST observed was 28.03°C. It was this variations that give rise to moderate and strong spatial positive relationship observed at Ekwolobia and Aguluezechukwu gullies. These deviations from the natural law governing elevation and temperature can be attributed to the nature of the gully surface. The two gullies were narrow with tree canopies and these can prevent incoming radiation to be fully transmitted within the gullies surfaces [24].

5. Conclusion

Like other disasters, gully erosion is a deadly catastrophes and environment phenomenon causing havoc to the ecosystem. It leads to loss of top soil, soil nutrients (fauna and flora) and agricultural land. Gully erosion may also leads to loss of land value because the impacted land will no longer be attractive to the investor. Spatial distributions and areal extent of gullies has been widely studied in Southeastern Nigeria but information on spatial relationships between LST and elevation at gullies sites has not been fully studied in the region. The study applied remote sensing derived LST from Landsat data and elevation data to study their correlation in three gullies locations (Nanka, Ekwolobia and Aguluezechukwu). The observation at Nanka gully agreed to the universally accepted relationship that LST drop with increase in elevation. Hence, negative correlation coefficient was obtained at Nanka gully site. At Ekwolobia and Aguluezechukwu there was a deviation, yielding strong positive spatial relationships. This implies that the variables increase or decrease within the two gullies. Remote sensing data and GIS software can provide up-to-date study of gullies variables (LST and elevation) and other associated parameters. It is recommended that ground-base survey like the use of Differential Global Positioning System (DGPS) should be employ to map gully topography and correlate with LST to see if an improve result can be obtain.

Compliance with ethical standards

Disclosure of conflict of interest

The article originated from the authors and they have declared that no conflict of interest with any individual or group.

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