SPATIAL DISTRIBUTION OF INSELBERGS IN THE BASEMENT COMPLEX TERRAIN OF WESTERN NIGERIA

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ABSTRACT
The study examined the spatial distribution pattern of inselbergs on a granitic landscape located in Igbajo District in the central part of the Western Nigerian Basement Complex region. The goal of the study was to infer the plausible evolutionary pathway of inselbergs in the study area, and in related parts of the tropical landscape. The study employed the Poisson Probability Distribution (PPD) technique and the Nearest Neighbour Analysis (NNA) to evaluate the spatial distribution of the inselbergs in the study area. Inselbergs were defined as point features and enumerated following the imposition of regular grid cells on the entire inselberg landscape. Analysis was carried out principally in a Geographic information System (GIS) environment with ArcGIS 10.3 software. The results of the spatial pattern analysis indicated a clustered distribution of inselbergs in the study area. It was thus established from the study that spatial distribution of inselbergs was not sufficient to unravel the underlying process behind their evolution. Hence recourse must be made to other important factors pertaining to structure and lithology of the underlying rocks.

Keywords: Spatial pattern; inselbergs; Nearest Neighbour Analysis; Poisson Probability Distribution; Western Nigeria.

INTRODUCTION

Inselbergs have attracted the interest of tropical geomorphologists over the years and were the focus of numerous studies in the last century e.g. Linton (1955) in Britain; Doornkamp (1968) in Uganda; Jeje (1973) and Faniran (1974) in Nigeria; King (1975) in South Africa; Selby (1977) among others. They are viewed as residual uplands which stand above the general level of a surrounding plain mantled with weathered regolith of variable thickness (Faniran, 1974; Migon, 2006). Also, they believed to be remnants of the denudation of formerly extensive rock body shaped at the weathering front and later exposed following the stripping of regolith (Migon, 2006). With regards to evolution, two contrasting theories have dominated the literature on inselbergs and other related residual landforms (Thomas, 1978). First is the theory of pediplanation and pedimentation propagated by King (1975) while the second is the two-stage hypothesis of etching and stripping of weathered mantle advanced by tropical geomorphologists such as Jeje (1973); Thomas (1978) and Twidale (1998).

One important area of geomorphic enquiry into inselberg morphology and evolution pertains to their spatial pattern of distribution (Faniran, 1974; Romer, 2005). This is because there is great prospect of drawing useful inferences on evolution from observed spatial pattern of inselbergs. The first attempt documented in this regard was by Faniran (1974). His argument was that if inselbergs were the results of pediplanation and scarp retreat as espoused by King (1975), they should be located in clusters around and along major drainage divides in a region. If on the other hand, inselbergs were the results of two-stage process of etching and stripping (Thomas, 1978), they would be expected to occur with no obvious physiographic inclination, thus showing a random pattern of distribution.

These hypotheses became the research questions in Faniran (1974) research conducted on the Western Nigerian Basement terrain. The results which indicated patterns ranging from random to regular led to the affirmation of the two-stage hypothesis for evolution of the residual landforms in the area. It is important to note that Faniran (1974) covered the entire basement region of Nigeria. However, inselbergs are not everywhere distributed across the region but are located in distinct districts where the underlying rocks are closely related to the granite family or its metamorphic equivalents. It is thus argued in this study that scale may have played some role in the findings of the aforementioned spatial pattern analysis. This is more so given the outcome of Romer (2005) in which a similar spatial pattern analysis was attempted.

The result of this study in Zimbabwe revealed some tendency towards clustering which according to the researcher did not invalidate the two-stage hypothesis in any way (Romer, 2005). This research therefore attempts to contribute to the debates as to whether scale exert significant influence on spatial pattern analysis and also whether observed spatial pattern of inselbergs have any bearing on evolutionary pathway. Igbajo inselberg landscape located in the central Western Nigeria Basement terrain was selected for this study for various reasons. The selected region is known for its abundance of inselbergs (Burke and

Durotoye, 1970; Thomas, 1994) formed on the Igbajo granitic pluton (de Swardt, 1953). It is also a subset of the Western Nigerian Basement region which was the focus of the earlier reported study (Faniran, 1974). This study employed two classical techniques of point pattern analysis to examine the spatial distribution of inselbergs on the Igbajo granitic pluton of central western Nigeria with a view to drawing inferences on their evolution.

METHODS AND MATERIALS

Research principles and hypothesis

One major area of interest of geographic enquiry is the distribution of phenomena over space (Silk, 1979). Two techniques have featured prominently in spatial pattern analysis. Quadrat analysis which requires enumeration of points per cell and the nearest neighbour analysis which entails direct measurement of spacing between points (Silk, 1979). The main thrust of these analyses is the concept of random distribution (Silk, 1979; Rogerson, 2001). A random distribution is that in which for a set of points located over a defined area, any point has had equal chance of occurring in any sub-area as any other point, and the placement of a point on a particular sub-area has had no influence on the occurrence of another point in any other sub-area (Clark and Evans, 1954). Other patterns of distribution are clustered (characterized by a set of closely packed points in few locations), and regular forms (characterized by equidistant pattern of points) (Shaw and Wheeler, 1994).

The Poisson Probability Distribution (PPD) technique has long been identified as a veritable method of point pattern analysis. Svedberg (1922) cited in Clark and Evans (1954) is attributed with the first application of PPD as a tool for spatial analysis of point patterns. The method entails the application of the Poisson formula to determine probability of points per quadrat following the imposition of a number of equal-sized quadrats on the area of interest. Additionally, the χ^2 technique is normally employed to test the significance of the departure of observed distribution from that generated by random occurrence. The notation of the Poisson probability and the χ^2 are given as follows:

$$P(X=k) = e^{-\Lambda} \Lambda^k / k! \qquad (1)$$

where P(X=k) represents the probability of 'X' number of quadrats receiving 'k' number of points; 'Λ' is the density of points per quadrats over the entire area denoted by $\Lambda = \frac{n}{m}$ *with 'n' and 'm' respectively representing number of points and number of quadrat cells. 'e' = 2.71828 is a constant and the base of natural logarithms.*

The application of the formula to all number of points scenarios starting from zero would yield the **expected number** of quadrats containing appropriate number of points when the probability values are multiplied by the total number of quadrats as given below:

$$E(X = k) = P(X = k) * m \quad (2)$$

where E (X = k) is the expected number of quadrats containing k points.

The results in columns for observed and expected number of quadrats containing 'k' number of points can thereafter be subjected the χ^2 test to evaluate the significance of the departure of observed distribution from a random pattern using the formula outlined below:

$$X_v^2 = \sum_{i=1}^{n} \left(\frac{(o_i - e_i)^2}{e_i}\right) \quad (3)$$

where X_v^2 *is the notation for chi square at 'v' degree of freedom;*
'o_i*' and '*e_i*' respectively the **observed** and **expected** number of quadrats with 'k' number of points.*

A major concern of the quadrat analysis is the challenge of determining the optimum size of quadrats (Silk, 1979, Rogerson, 2001). In essence, if the cell size is too small, there could be many empty cells such that if clustering exists on all but the smallest spatial scales, such a pattern might be missed. Conversely, if the cell size is too large, certain patterns that occur within cells may be missed (Rogerson, 2001). Silk (1979) averred that the quadrat should be small relative to the size of the study area and suggested an optimum number of between 50 and 100 grid cells. Rogerson (2001) suggested an optimal quadrat size of two points per quadrats. A suggestion that quadrat analysis be carried out at variety of cell sizes to ensure comparison of results was also made (Silk, 1979). Whereas the highlighted quadrat size issue considerably limits the application of the Poisson technique in point pattern analysis, the same cannot be said of the nearest neighbour analytical technique.

The Nearest Neighbour Analysis (NNA) has a rich literature to back up its application in the analysis of spatial point pattern (Clark and Evans, 1954; Faniran, 1974). The introduction of the technique into analysis of the spatial point pattern was propagated by Ecologists with Clark and Evans (1954) providing fundamental conceptual background and relevant statistical notation. In essence, the NNA employs distance in two-dimensional space from one individual point to another within a particular area of interest. This ensures that the required variable for pattern analysis is distance and not square quadrats, and consequently eliminates the impact of quadrat size on the outcome of spatial point pattern analysis. The outcome of NNA is usually the determination of the value of R which ranges from 0 - 2.15. The value '0' implies a situation in which all points are altogether coincident at the same location while the other extreme i.e. 2.15 implies a perfect regularity of points where points are set up in a hexagonal form (Faniran, 1974). A value of '1' implies randomness and is usually the reference value of the statistical test. The technique, denoted with 'Average Nearest Neighbour' in the ArcGIS environment has a number of notations as highlighted below:

The average nearest neighbour ratio is given as: ANN = $\frac{\overline{Do}}{\overline{De}}$ *(4)*

Where $\overline{Do}$ *is the **observed mean distance** between each feature and its nearest neighbour and* $\overline{De}$ *is the **expected mean distance** between each point and its nearest neighbour.*

The z-score for the statistic is calculated thus: Z = $\frac{\overline{Do} - \overline{De}}{SE}$ *(5)*

where SE, the standard error is estimated thus: SE = $\frac{0.26136}{\sqrt{n^2/A}}$ *(6)*

where 'n' corresponds to the total number of points and 'A' denotes area of region of interest.

For the present study, the null hypothesis was set up as follows:

H_0: *Location of inselbergs is random and independent;*
H_1: *Location of inselbergs not random or independent.*

The hypothesis was tested using the Poisson technique and the Nearest Neighbour Analysis. The underlying principle for this spatial point pattern analysis is hinged on the proposition articulated in Faniran (1974) which presupposes a random distribution of inselbergs as the clue to their evolution via the tropical processes.

Study Site

The study was carried out in Igbajo District in of Western Nigeria. It is situated approximately 49 km north of Ilesa and 50 km northeast of Osogbo, two major settlements in the region. The area lies between Latitudes 7^0 53' and 7^0 57'N, and Longitudes 4^0 41' and 4^0 52'E (Figure 1). The topography is a rugged one characterised by hills of various configurations whose local relief is in excess of 60 m in certain locations. The landscape comprises of inselbergs and other convex rock outcrops with some extensive weathered surface which has been variably dissected by surface drainage. In plan view, the drainage network is dendritic in pattern though it has rectangular components (Burke and Durotoye, 1970; Thomas, 1994).

The geology of the area comprises of rocks of plutonic origin referred to as the Igbajo granitic pluton which forms part of the Precambrian Basement Complex of Western Nigeria (de Swardt, 1953; Rahaman, 1976). The Igbajo granite is bounded to the west by granite-gneiss; to the southeast by migmatite and gneiss undifferentiated; while it is bounded to the northeast by schist and epidiorite complex (Fig 2). The granites are coarse grained and slightly porphyritic although some gneissic foliation is noticeable in the marginal areas (de Swardt, 1953). The pluton formed a discrete body (as observed from the satellite data) of about 120 km^2 in areal extent. From hand specimen, alkali-feldspars, quartz and biotite were observed as the main mineral constituents. This observation is also supported by petrographic analysis which revealed the preponderance of biotite, quartz, plagioclase (oligoclase variant) and microcline as main mineral constituents (Afolabi et al., 2013). The plutonic body outcropped in several places as inselbergs with elevation reaching about 670 m above sea level in Igbajo settlement.

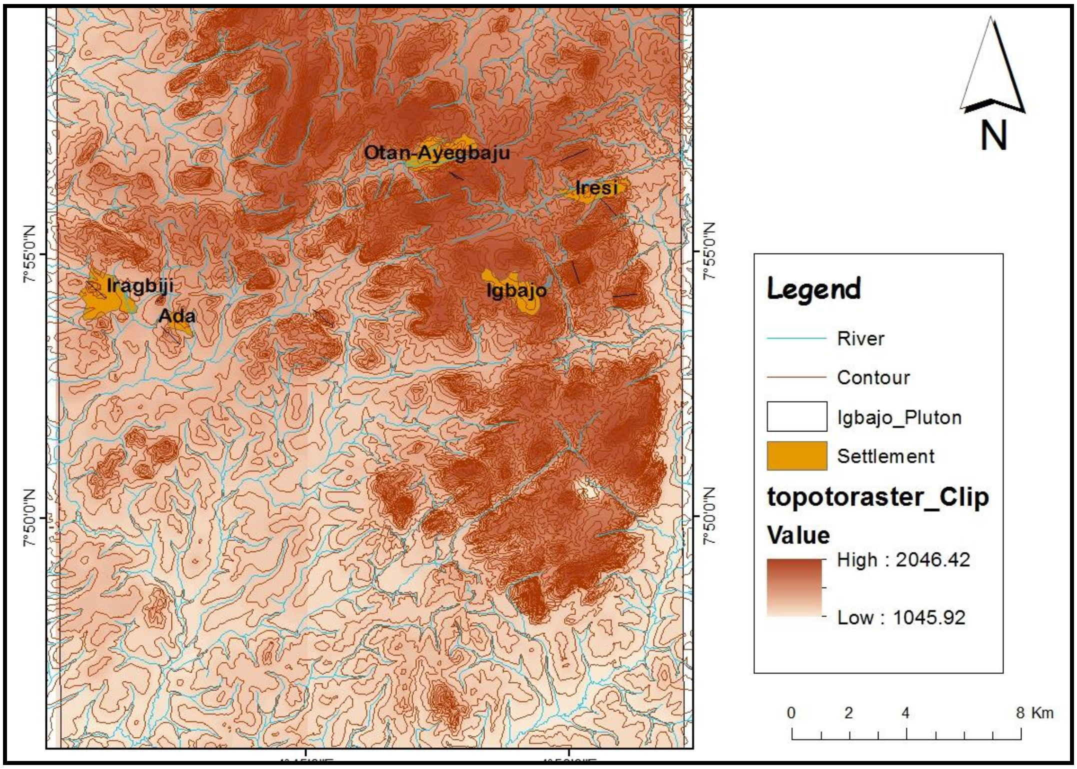


Figure 1: The study site

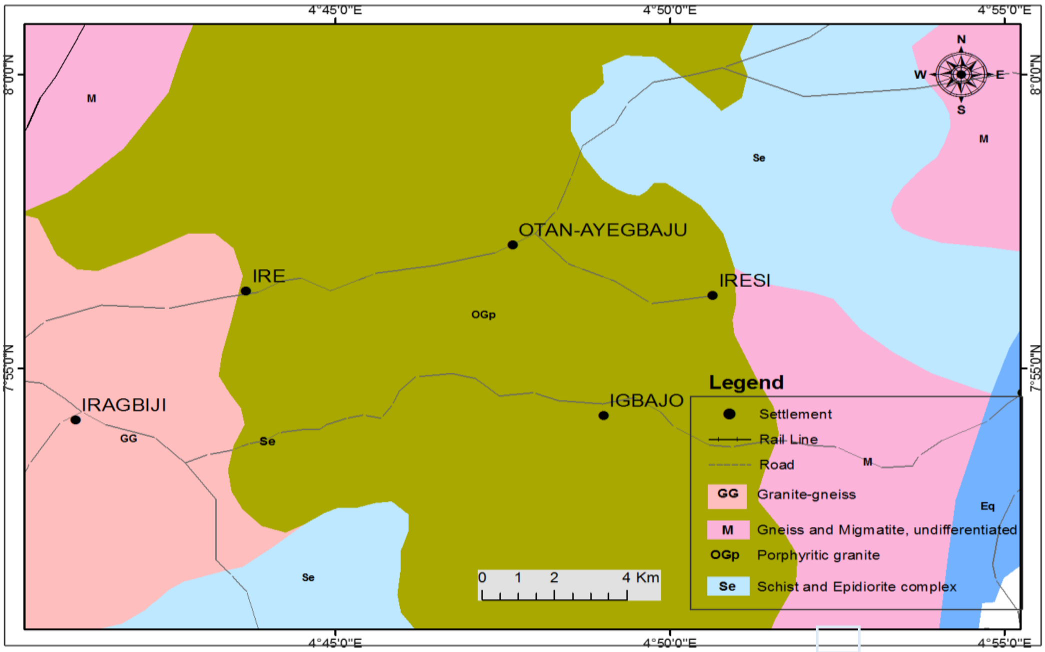


Figure 2: Geology of the study site is dominated by porphyritic granitic rocks with other metamorphic variants making up the marginal areas.

Data Analysis

The study employed two-point pattern analytical techniques to facilitate the determination of the spatial pattern of distribution of inselbergs in the study area: the Poisson Probability technique and the Nearest Neighbour Analysis. The satellite image (LANDSAT) and topographic data of the area formed the baseline information for this study.

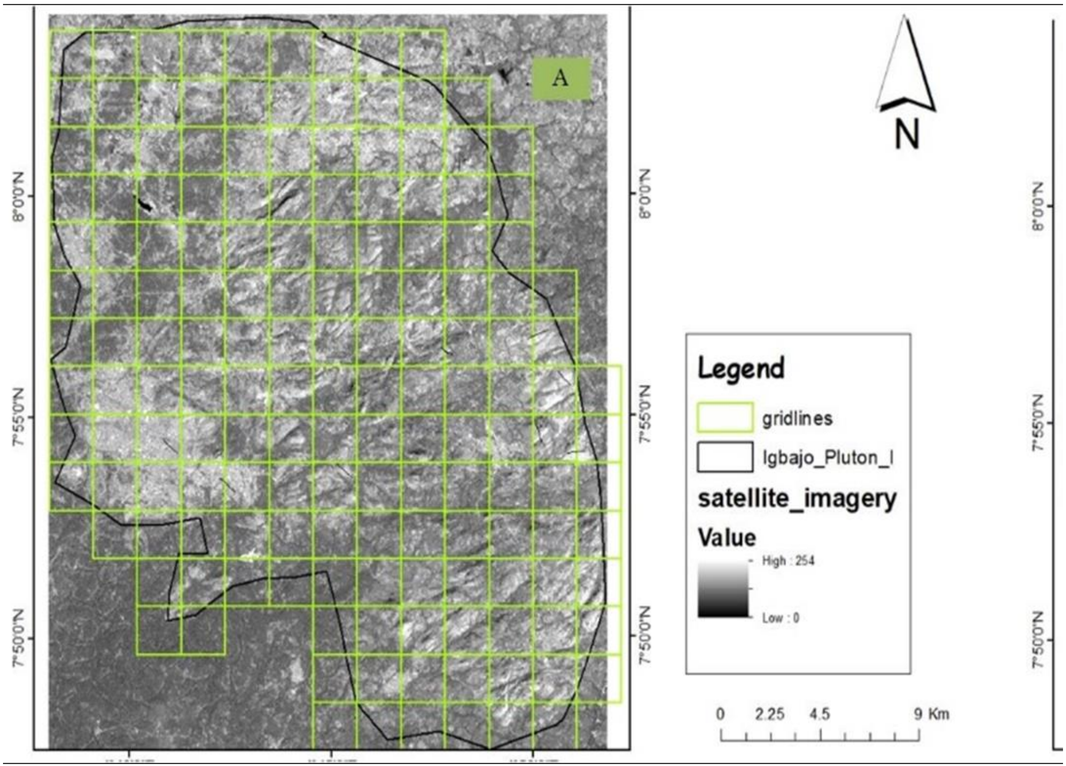
For the quadrat analysis with Poisson probability technique, a number of steps were followed:

i. The topographic map of the study area was processed in the Geographic Information System (GIS) environment.
ii. ArcGIS tool was used to impose a set of regular grid lines on the study area.
iii. Square grid measuring 2 km x 2 km were imposed on the study area in first instance while grid cells measuring 1.5 km x 1.5 km were imposed in the second scenario (Figure 3 and Figure 4).
iv. Inselbergs were defined as landforms represented by minimum of 4 closely spaced contour lines. The topographic map has contour interval of 10 m. This implies a minimum relative relief of about 30 m and is largely in conformity with previous studies in the area (Faniran, 1974; Afolabi and Ogunkoya, 2018).

v. The identified inselbergs were defined as points (Figure 4) and the number of points per quadrat were enumerated for the each of the grid cells created.
vi. Some inselbergs extended across the boundary of two contiguous grid cells. The point was carefully emplaced in the cell where the crest or peak of the landform is situated as validated with the satellite data.
vii. On inselberg's area, given that the term is a general name for a group of residual landforms of variable areal extent ranging from very small-sized knoll to large eminences covering over 1 square kilometre. A minimum area value of 0.1 km^2 was selected for this study and any landform of less areal extent was left out. To arrive at the above minimum value, I relied on the lowest value for areal coverage reported in a recent study in the area (Afolabi and Ogunkoya, 2018).
viii. A frequency distribution of the number of quadrats with no (zero) point, 1 point, 2 points, and etc. was computed. This generated a table of frequency distribution (Table 1 and 2) with the counts forming the observed points per quadrats.
ix. Poisson probability formula was thereafter employed to determine the expected number of points per quadrat under a random distribution.
x. Finally, chi square (X^2) technique was applied to determine the significance of the departure of observed inselbergs' distribution from the hypothetical scenario generated by a random and independent distribution (Table 3 and 4).

Secondly, the Nearest Neighbour Analysis (NNA) was used to test the randomness of location of inselbergs in the study area:

i. The inselberg points defined on the topographic data, in the GIS environment formed the input data.
ii. The distance from an individual point (inselberg) to its nearest neighbour provided the baseline data for the analysis.
iii. Distance between points was measured in Euclidean format.
iv. The value of mean distance to nearest neighbour was obtained (observed mean distance).
v. The mean distance to the nearest neighbour under a random distribution was determined (expected mean distance).
vi. The ratio (R) of the observed mean distance to the expected mean distance was determined, and this became the index of randomness (cf. Clark and Evans, 1954).
vii. The analysis was carried out with the aid of the 'spatial statistic tool' of 'Average Nearest Neighbour' in ArcGIS 10.3 with the results presented in (Figure 5) while the Getis-Ord General (Figure 6) analysis was employed to examine the degree of clustering of the inselbergs.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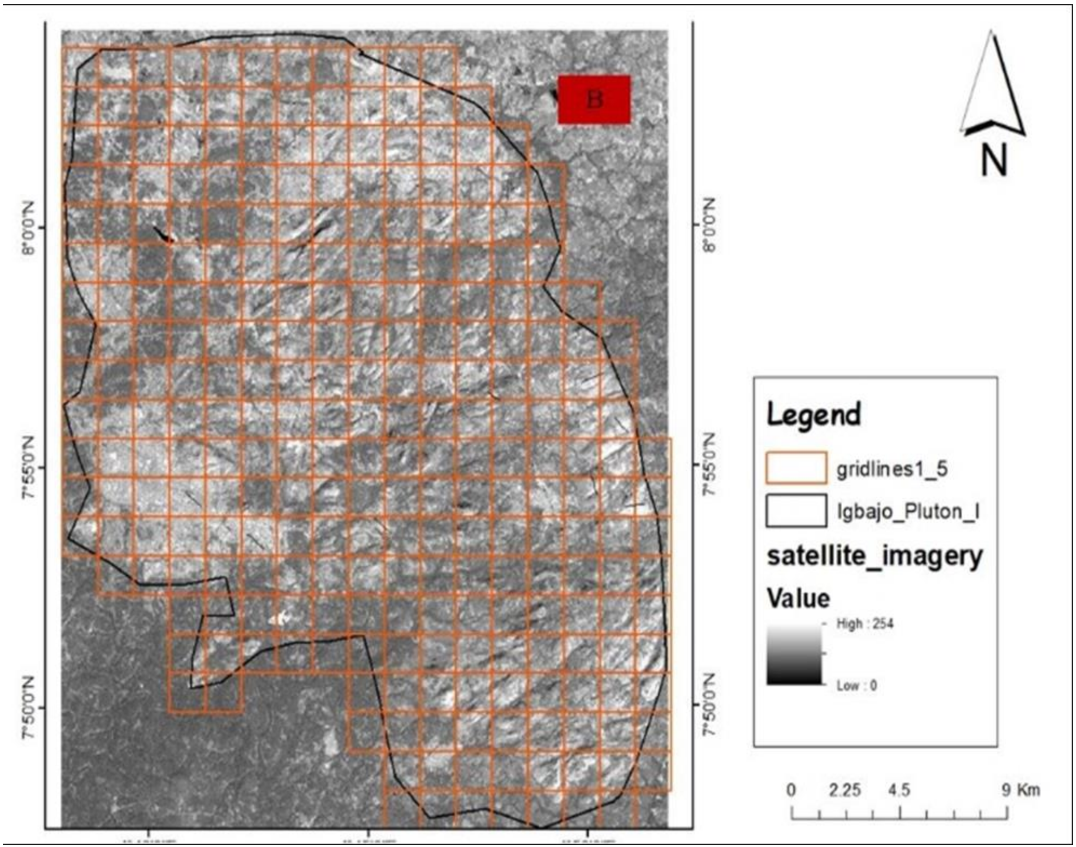
(A)



(B)

Figure 3: The granitic pluton in the Earth Imagery after the imposition of regular gridlines 2 x 2 km² (A) and 1.5 x 1.5 km² (B)

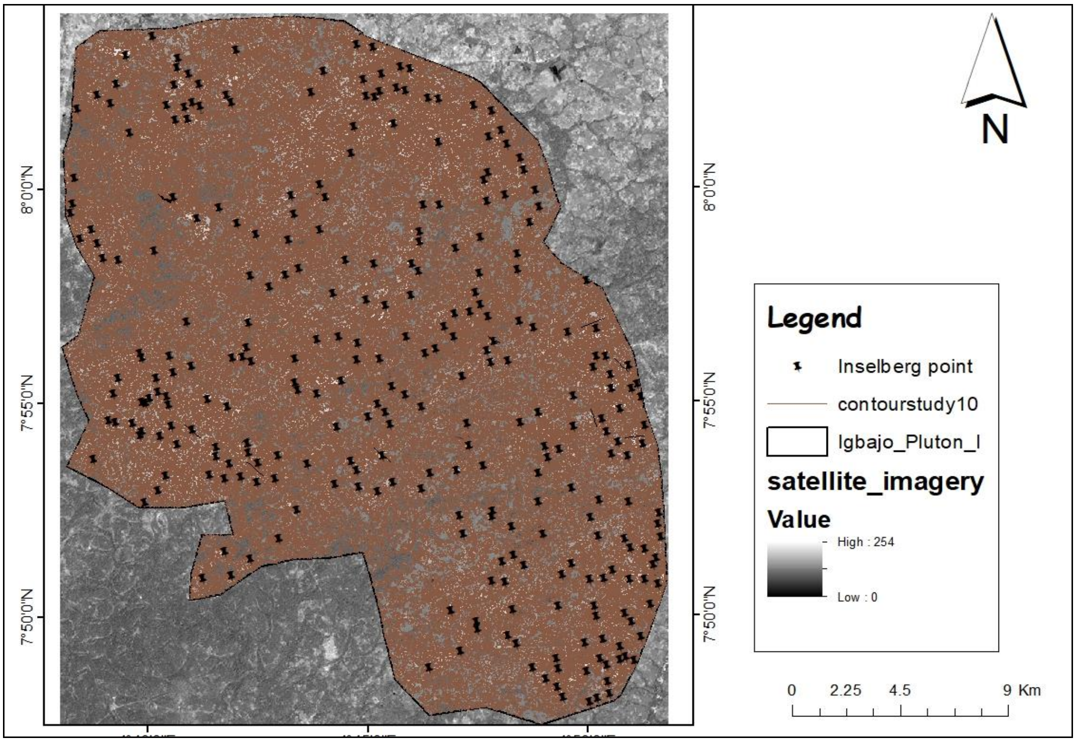


Figure 4: Inselbergs were thereafter defined as point features on granite pluton

Table 1: Frequency distribution of inselbergs points per quadrats with 2 x 2(km^2) gridlines

Number of points (n)	Number of quadrats (o*i*)	Expected number of quadrats (*ei*)
0	44	26
1	38	47
2	31	43
3	21	26
4	11	12
5	9	4
≥6	6	1
n: 292	**m: 160**	**ʎ: 1.825**

Table 2: Frequency distribution of inselbergs points per quadrats with 1.5 x1.5(km^2) gridlines

Number of points (n)	Number of quadrats (o*i*)	Expected number of quadrats (*ei*)
0	110	92
1	85	100
2	41	54
3	22	19
4	7	5
≥5	6	1
n: 292	**m: 271**	**ʎ: 1.077**

Table 3: Poisson and Chi-square statistical analysis of distribution of inselbergs with 2*2(km^2) gridlines

Number of Points	*Oi*	*Ei*	$(Oi-ei)^2/ei$
0	44	26	12.46
1	38	47	1.72
2	31	43	3.35
3	21	26	0.96
4	11	12	0.08
5	9	4	6.25
≥6	6	1	25.0
∑n: 292	m: 160		$\chi_6^2 = 49.82$
ʎ = 1.825		χ_6^2 (Table) = 12.59 (0.05) and 16.81 (0.01)	

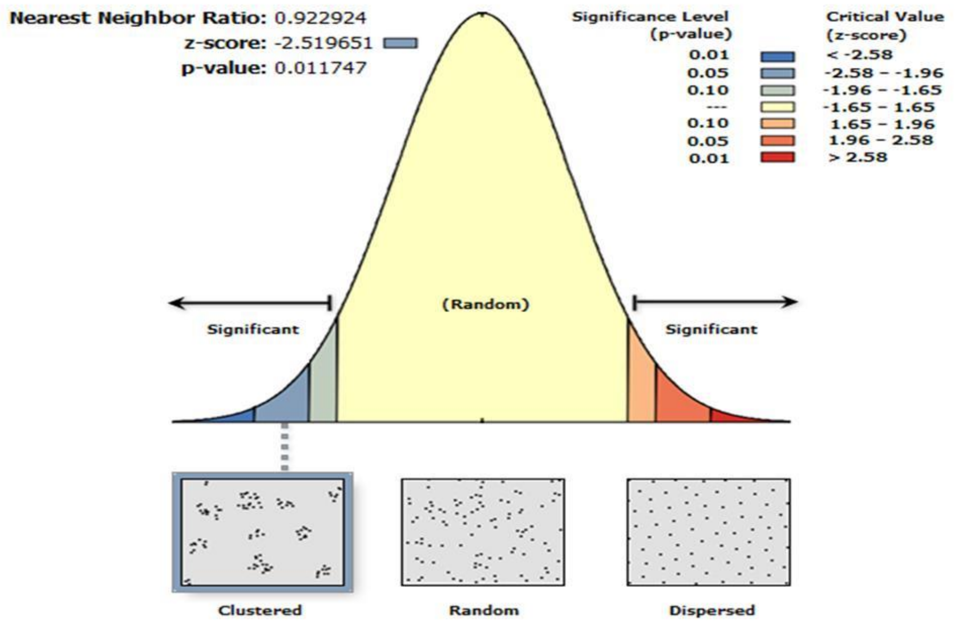
$X_6^2 = 49.82 > \chi^2$ (α= 0.05 and 0.01, 6 df) = 12.59 and 16.81 respectively
Decision: Reject H_0

Table 4: Poisson and Chi-square statistical analysis of distribution of inselbergs with 1.5*1.5(km^2) gridlines

Number of Points	*Oi*	*Ei*	$(Oi-ei)^2/ei$
0	110	92	3.52
1	85	100	2.25
2	41	54	3.13
3	22	19	0.47
4	7	5	0.8
≥5	6	1	25.0
∑n: 292	m: 271		$\chi_5^2 = 35.17$
ʎ = 1.077		$\chi 5^2$ (Table) = 11.07 (0.05) and 15.09 (0.01)	

$X_5^2 = 35.17 > \chi^2$ (α= 0.05 and 0.01, 5 df) = 11.07 and 15.09 respectively
Decision: Reject H_0

Average Nearest Neighbor Summary



Given the z-score of -2.5196508132, there is a less than 5% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	716.0364 Meters
Expected Mean Distance:	775.8344 Meters
Nearest Neighbor Ratio:	0.922924
z-score:	-2.519651
p-value:	0.011747

Figure 5: Nearest Neighbour Summary

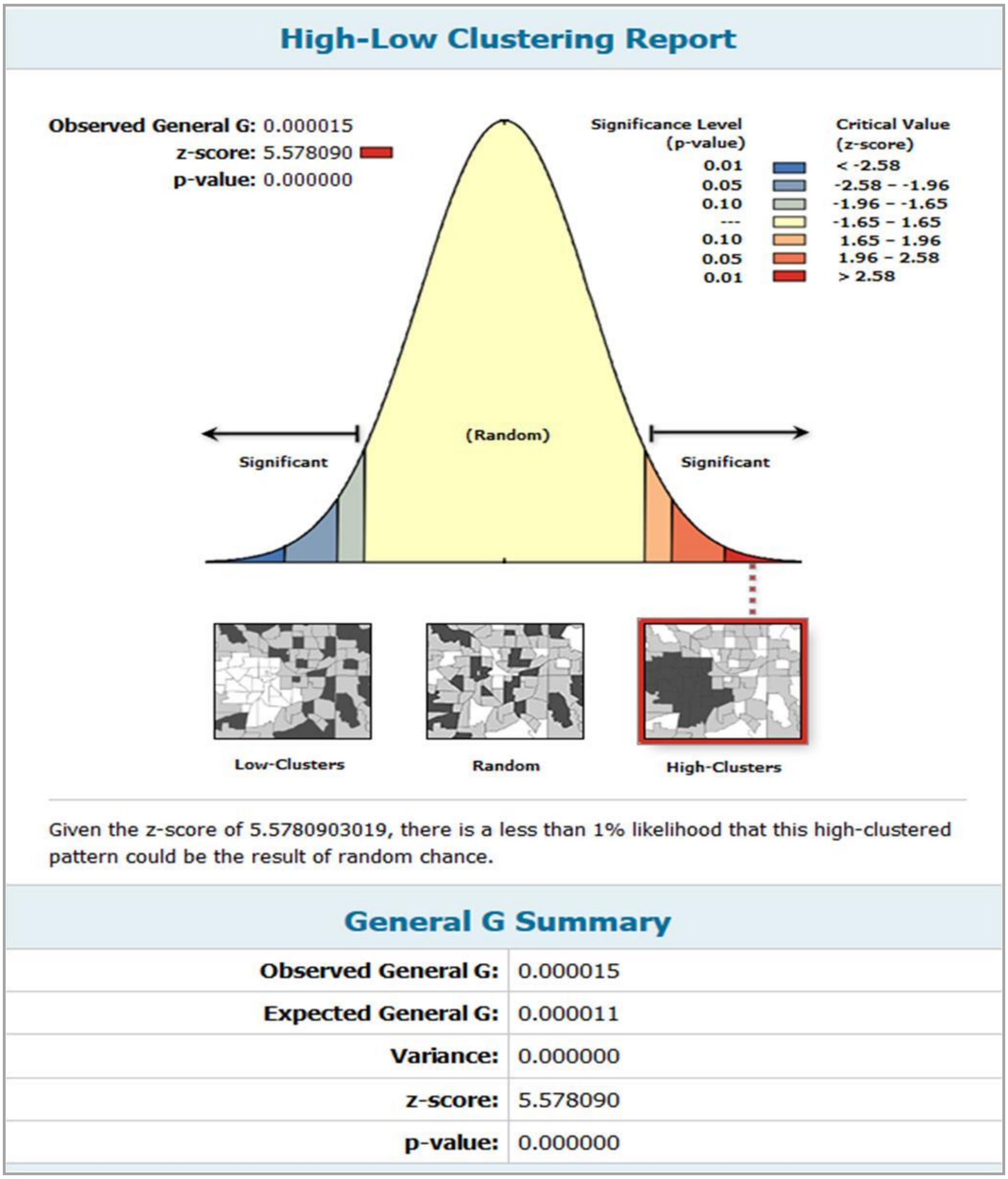


Figure 6: High-Low Clustering (Getis-Ord analysis)

RESULTS

In order to achieve the objective of this study two classical analytical techniques were employed in the evaluation of the pattern of distribution of inselbergs and other residual landforms in the study area. Quadrat analysis using the PPD and χ^2 methods was carried out at two scales. These involve the imposition of 2 x 2 km^2 and 1.5 x 1.5 km^2 grids on the study area (Figure 3). The inselberg points were thereafter enumerated and the result formed the tables of frequency distribution (Tables 1 and 2). The Poisson formula and the χ^2 analysis were thereafter employed to generate the expected frequency of points in a random distribution, and to determine the deviation of the observation from a random distribution. The results are presented in Tables 3 and 4.

Highlight of the results for the 2*2 km^2 grid showed that the test statistic, X_6^2 (49.82) is greater than χ^2 (α= 0.05 and 0.01, 6 df) = 12.59 and 16.81 respectively. Similarly, the results of 1.5*1.5 km^2 grid cells showed that the test statistic, X_5^2 (35.17) is greater than χ^2 (α= 0.05 and 0.01, 5 df) = 11.07 and 15.09 respectively. Hence H_0 was rejected. The rejection of H_0 is informed by the fact that the χ^2 values 49.82 and 35.17 are extreme values whose probability of occurrence is less than 0.01 or 1%. This therefore implies that the occurrence of inselbergs in the study area is neither random nor independent. The fact that similar results were obtained from the both tests more or less eliminates the impact of grid size on the results obtained.

The second part of the analysis involves the application of the Nearest Neighbour Analysis (NNA) to evaluate the pattern of distribution of inselbergs in the study area. The result is shown in Figure 5. Test results obtained from the NNA include Do (716.0364 m); De (775.8344 m); NNR or R (0.9229); z-score (-2.519651); and p-value (0.011747). In an NNA, p-value is the probability that observed pattern was created by random processes and when it is very small (i.e. < 0.5), it indicates the unlikelihood of an observed pattern being the result of a random process. Similarly, a higher value of z (i.e. $> \pm 2.50$) indicates a tendency towards clustering. The result of the study with a R of 0.9229 therefore indicates a clustered distribution of the inselbergs in the study area. The pattern analysis was further advanced with the application of the Getis-Ord cluster analysis (Fig. 6). Highlight of the results show Observed G (0.000015); Expected G (0.000011); z-score (5.578090) and p-value (0.00). The high value of the z-score and low value of p in this test indicate a clustered pattern of distribution in the study area. The NNA and cluster analysis thus agree with the PPD and χ^2 methods highlighted earlier and showed that results have not been influenced by the technique of spatial analysis employed.

DISCUSSION

The study had attempted an evaluation of the spatial distribution pattern of inselbergs and other residual landforms in Igbajo district of the Western Nigerian Basement region. Of essence to this study is the understanding that the spatial distribution of residual landforms like inselbergs is usually controlled by the structure and lithology of the underlying geology as well as the intricate evolutionary processes undergone by the landforms. Also critical to the study is the belief that observed pattern of distribution of inselbergs can provide some elucidation on issues pertaining to the evolution of the landforms. Given the foregoing background, this study therefore employed two point pattern analytical techniques to examine the pattern of distribution of inselbergs over the region.

The desire was to ensure a comparison of results as per methods as well as to enable the determination of the impact of scale on quadrat analysis via the Poisson technique.

Overall, the results obtained indicated a clustered distribution of inselbergs on the Igbajo pluton of the central Western Nigeria Basement Complex region. The present result is at variance with the result obtained in a similar analysis over the entire basement region of Western Nigeria (Faniran, 1974). However, the results agree largely with a recent study on the Zimbabwe inselberg landscape (Romer, 2005). The observed pattern of distribution thus presents an interesting challenge. This is more so as it should imply scarp retreat and pedimentation for the evolution of the landforms (Faniran, 1974). This is in contrast to the general belief in tropical geomorphological circles that evolution of inselbergs on many a tropical landscape is via the two-stage process of deep weathering and stripping (Jeje, 1973; Thomas, 1978, 1994; Twidale, 1998). In this regard, the distribution of the landforms over space is expected to be random as it was controlled by the structure and lithology of rocks (Jeje, 1973) as against the idea that they are remnants of a retreating scarp and thus form clusters around/along regional drainage divides.

What then is the implication of the findings from this study for inselberg evolution. It shows that spatial pattern alone may not be adequate to lead to ascription of evolutionary pathways for the landforms. This argument is validated by the clustered pattern observed in another study (Romer, 2005). The author attributed clustering to the complex relationship between structure and evolutionary processes. This may also be the case with the present study area. Although the landforms were all built on the Igbajo pluton, it has been observed earlier that even within a single granite pluton, major unconformities tend to occur in rock chemistry, mineralogy, grain size and rock texture (Pye et al., 1984). These variations have important ramifications for the rate and progress of weathering and erosion on such rocks. It was established in an earlier study (de Swardt, 1953) that the geology of the present study area is characterised by progressive gradation between the coarse grain granite of the central area and gneissic granite equivalent in the marginal areas. Additionally, another study also reported that the marginal rocks appeared to give rise to fewer and less massive inselbergs than those close to the centre of the pluton (Afolabi and Ogunkoya, 2018). Given the preceding, it is therefore highly plausible that structural and lithological differences within the pluton had played a definitive role in the distribution of its residual forms.

Moreover, Romer (2005) stated that clustering of inselbergs could be indicative of the two-stage model of evolution. In this regard, observed cluster could be related to structural and lithological differences, and associated with specific plutonic bodies. The evolutionary pathways of these kinds of residual outcrops according to the author should involve differential weathering and erosion, the twin processes of the two-stage model of inselberg evolution (Romer, 2005). Observations during a recent field study to the landscape are in agreement with the argument of structurally controlled etching and stripping evolution processes. The observed forms include regolith-fresh rock interface observed along road cuts; coexistence of boulders and corestones in profiles which is indicative of on-going exhumation; and stream dissection into fresh granite beds (Afolabi and Ogunkoya, 2018). These are all indicative of the fact that the inselbergs were form deep beneath the surface (Thomas, 1994) and later exhumed, while some are still being exhumed at present time in accordance with the progressive exhumation idea (Thomas, 1978). The significance of the foregoing is that spatial distribution on its own does not reveal details about evolution of inselbergs.

CONCLUSION

The spatial distribution of inselbergs formed the focus of point pattern analysis carried out in this study. This was in the attempt to validate the agelong supposition that pattern of distribution provides clues necessary to unravel the underlying processes behind evolution of the landforms. The results obtained in this study revealed a clustered pattern of distribution of inselbergs in the study area. The study also highlighted the fact that results did not vary significantly owing to the spatial analytical techniques employed. It is therefore concluded that statistical analysis of spatial distribution is insufficient to reveal the evolutionary process of inselbergs. Recourse must therefore be made to relevant structural, lithologic and historical information before a precise statement can be made pertaining to the evolution of inselbergs.

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