QUANTITATIVE ANALYSIS OF RELIEF CHARACTERISTICS USING SPACE TECHNOLOGY

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Abstract

The study analyzes seven topographic parameters namely absolute relief, relative relief, dissection index, slope, aspect, drainage density and ruggedness index, for better understanding of local relief characteristics with some observation of structural landscape pattern .The advanced application of Remote Sensing (RS) and Geographic Information System (GIS) techniques have lead to estimation of above parameters based on Digital Elevation model and satellite imagery. The entire Morobe province of Papua New Guinea has been selected for this study. The study area is bounded within 145° 30' to 148° E longitude and 5° to 8° S latitude. Higher the value of dissection index is calculated over the region, indicating larger undulation and instability of the terrain. The topographic ruggedness index also indicates the extent of instability of land surface and it is found northern and south-centre part of the province.

Keywords: Remote Sensing, GIS, Digital elevation model, morphometric analysis

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1. Introduction:

Relief characteristics are the leading factor of the human environment. Between the relief and cartography on one side and the sciences dealing with the earth's surface on the other, there exists the very closest, reciprocal rapport. The topographic map of the last hundred years made up the basis for widespread geographic-thematic mapping of all types (Imhof, 2007). However, many large scale topographic maps, new as well as old, contained poorly formed contour lines or unrealistic pattern. The increasing availability of digital elevation models (DEMs) has provoked rapid advances for regional-scale characterization and numerical modeling of mountain landscapes (Bishop et al., 2003; Riquelme et al., 2003; Jamieson et al., 2004). Employ of earth observation data and GIS techniques in morphometric analysis have emerged as powerful tools in recent years particularly for remote areas (Sharma et al., 2012; Nongkynrih and Husain, 2011; Koshak and Dawod, 2011). Such analysis aided in understanding the hydrological, geological and topographical characteristics of the very complicated and unique Morobe Province, Papua New Guinea.

Geomorphometry provides an ideal tool for assessing the relief characteristics of a region. Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms (Clarke, 1966). Among many other methods, geomorphometric parameters (Rasemann et al., 2002; Schmidt and Dikau, 1999; Hovius, 2000) have been used to characterize, the regional relief characteristics of an area. Morobe province region consists of surfaces of varying elevation and reveals configuration of varying altitude, dimension and magnitude. The relief needs interpretation, examination, and analysis of its slope, altitude and existing expression. However, no such study has been carrying out in this regard.

Therefore our key objective is to derive from a DEM of the regional topography any characteristics or patterns that may be used for interpreting the geomorphic history of the Morobe province in the context of rapid uplift and erosion.

2. Site description:

The Morobe Province lies within the southeast corner of Papua New Guinea (PNG), and extended from 145° 30' to 148° E longitude and 5° to 8° S latitude (Figure 1). The Province has nine districts and covers an area of 33,933 km^2, accounting for 7% of the total land area in PNG. The study site is characterized by rugged terrain and high rainfall; where as much as two thirds of the land is covered with undisturbed moist tropical forest. The topography ranges from sea level to over 4000 meter above sea level and plate tectonics are active in this region. The major leading soils are Humitropepts, Dystropepts, Troporthents and Rendolls (Bleeker, 1983).

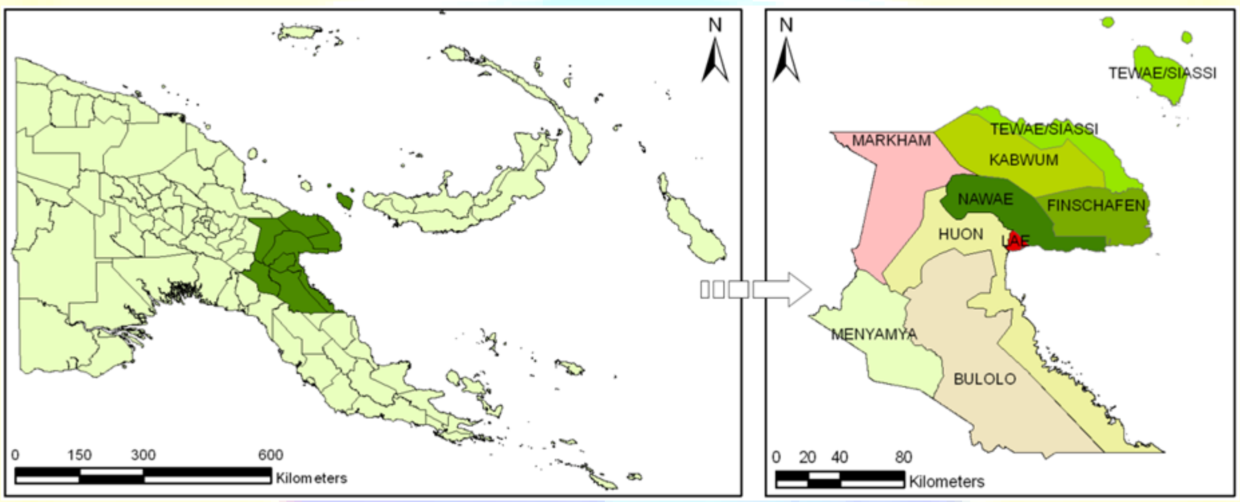

Figure 1. Location map of the study area

3. Methodology:

Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) is downloaded from GLCF website (Global land Cover Facility, 2000) Maryland, which is in Tagged Information File Format (TIFF) format with 90 meter ground resolution. Convert raster derived from USGS DEM to Triangulated Irregular Network (TIN) surface model to remove points within an area of interest from one or more embedded feature classes. The study site is clipped based o the administrative boundary. Based on this clipped image, area is divided into 370 square grids of 100km x 100km and detailed altitudinal and drainage characteristics for morphometric analysis are derived for each grid. Out of the various morphometric attributes, some important ones are selected for the present study, like absolute relief, relative relief, dissection index, ruggedness index, drainage density and slope.

While different slope algorithms correlate highly, they fabricate different outcome. Because slope and aspect provide the raw input to the eigenvector algorithm, the slope algorithm might affect the organization calculations. Guth (1995) suggested using a steepest adjacent neighbor algorithm, while the most popular algorithm appears to be the four nearest neighbors (Hodgson, 1998; Jones, 1998), although Evans (1998) makes a convincing case for the superiority of an eight neighbor's algorithm. A detailed analysis of the steepest adjacent neighbor and four nearest neighbors differences highlights the effect of slope algorithm on geomorphic parameters. Eight partial slopes were calculated with an eight point neighborhood about the central point, in each of the eight principal cardinal directions. Four are to the north, south, east and west and, four approximately northeast, southeast, southwest, and northwest. Slope algorithm is to use these values to estimate a single slope at the central point. Queens aspect ratio were also calculated to estimate the low relief and short DEM spacing relative to the vertical resolution. MICRODEM http://www.usna.edu/Users/oceano/pguth/website/microdem/microdem.htm) and ARC GIS v9.3 (ESRI, Redlands, CA, USA) software was used to carry out the present work.

4. Results and Discussion:

Based on the automatic morphometric analysis using SRTM DEM, the results are presented. In general, the relief characteristics of Morobe province shows interesting characteristics, and their geographical distribution are described below.

4.1 Absolute relief characteristics

Absolute relief gives the elevation of any area above the sea level in exact figure. The topography of this region varied from 0-4094m (figure 2). The highest elevation zone was found in northern and southern part of the province while, lowest elevation observed in the north-central and coastal part of the study area. A simple line diagram was plotted to delineate the elevation against percentage of area. However, maximum area of this region was covered by less than 500 meters.

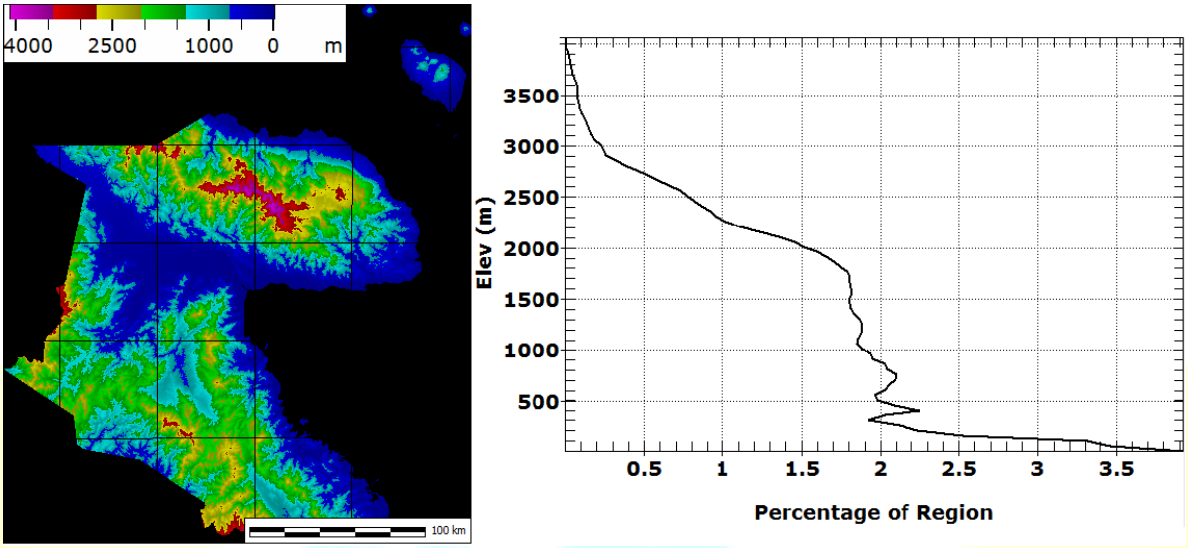

Figure 2. Absolute relief of Morobe province, PNG. The graph shows relation between area of percentage and corresponding absolute relief in Morobe province.

4.2 Slope

Slope represents the loss or gain in altitude per horizontal distance in a direction. Slope map was prepared from SRTM data as shown in figure 3. However, the maximum slope of the study area is 65.50º (219.82%), whereas, average slope was 18.30º (32.98%). Steep slope was found mainly in north-west part of the province, some tracts were also persisted in south east and central region. In the north-central area has flat topography, some tracts were also found in northern part of the province. Most of the part is as hilly terrain having moderate to steep slope.

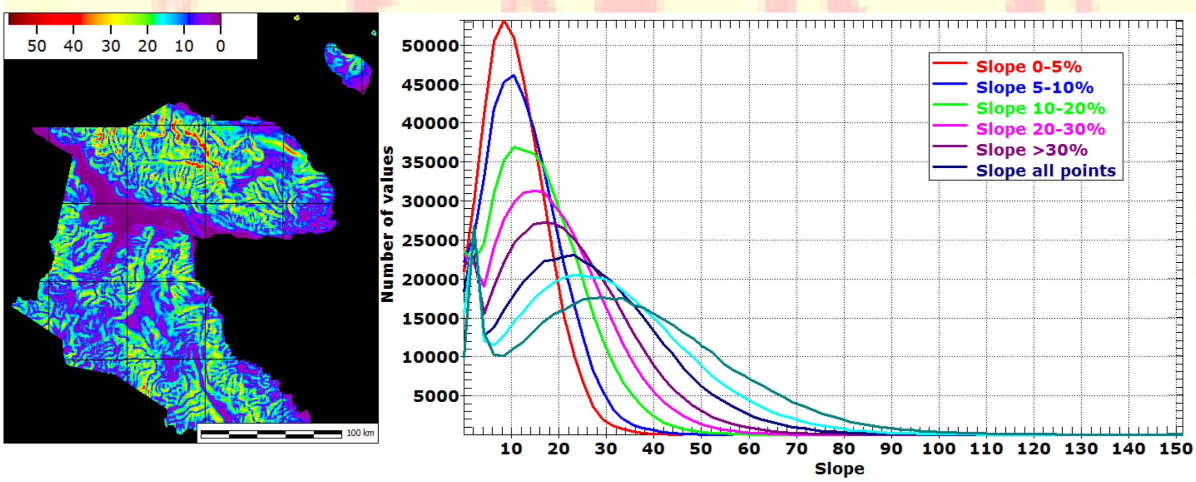

Figure 3. Spatial distribution of slope in Morobe province. Line graph shows the slope vs. pixels in the Morobe province.

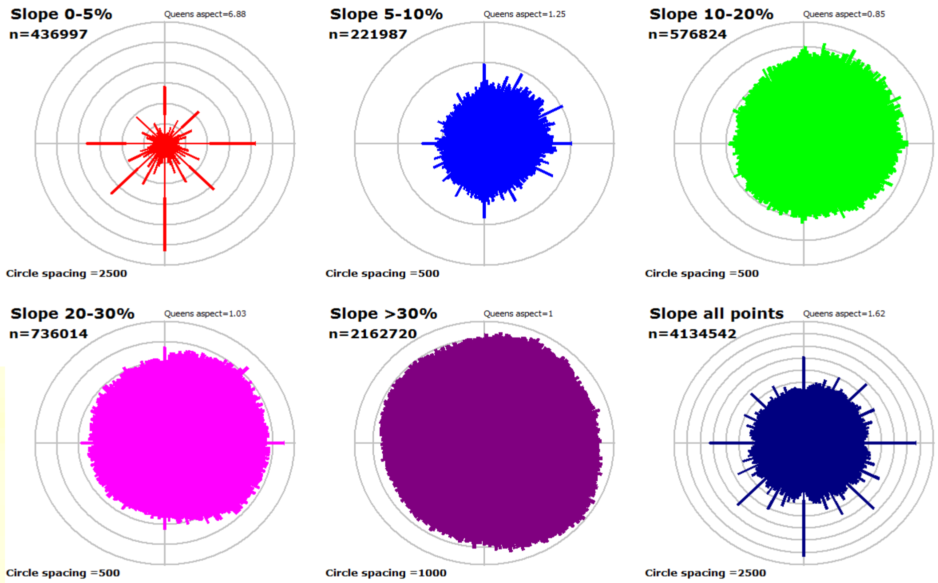

Figure 4. Slope distributions of the Morobe province for the 30 m DEM, divided by slope class. This DEM has elevations in meters.

Figure 4 shows the series of rose diagrams of slope of Morobe province for a 90 m SRTM DEM. The circles are radii of constant numbers of values to get different numbers depending on the maximum frequency. It depends on the isotropy/anisotropy of the distribution and the total number of points in the slope interval. However, it is observed that the spikes in the slope distribution, especially prominent for the lower region of Morobe province. Slope varies from 5% - 10%, showed maximum spikes in the northwest direction. Furthermore, majority of spikes were illustrated in the eastern direction, slope varies from 10% - 30%.

4.3 Slope vs. elevation

Figure 5 diagrams shows where generally steep and generally flat areas occur in terms of elevation. The computer also plots the standard deviation for slope in each elevation bin, showing the relative variability of slope at different elevations. The thin green and blue lines show one standard deviation above and below the average elevations.

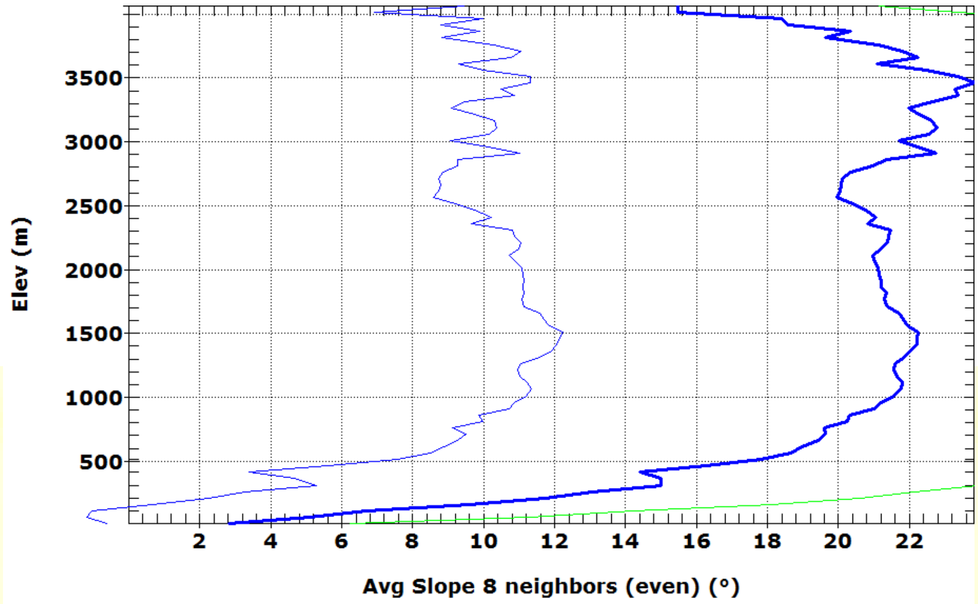

Figure 5. Slope *vs*. elevation of Morobe province

The result of this analysis showed that there is less than 15º slope up to an altitude of about 500 meters. However, within the study area, maximum slope variation was found between altitudes of 3000 – 3500 meters (more than 22º). The zones higher than about 1500 meters illustrate a less slope angle in respect to the elevation about less than 1500 meters.

4.4 Aspect

Figure 6 represents the aspect distribution of Morobe Province of 90 meter DEM. This allows slope values to change by 1/100, and in this case the algorithm appears to produce uniform and natural aspect distributions if the slope is steeper than 10%. The spikes in the aspect distribution were prominent for the eastern parts of the Morobe province. The value of 1 means that the Queens neighbor aspect arise equally to other aspects; values less than 1 (probably not likely), represents that the Queens aspect neighbors are less frequent, and values greater than 1 (probably very likely), means that the Queens aspect neighbors are less frequent. In Morobe Province, largest Queens's aspect ratio was found in 4 neighbor's weight distance. Therefore, it would be said that larger values of the Queens aspect ratio probably lead to low relief and short DEM spacing relative to the vertical resolution.

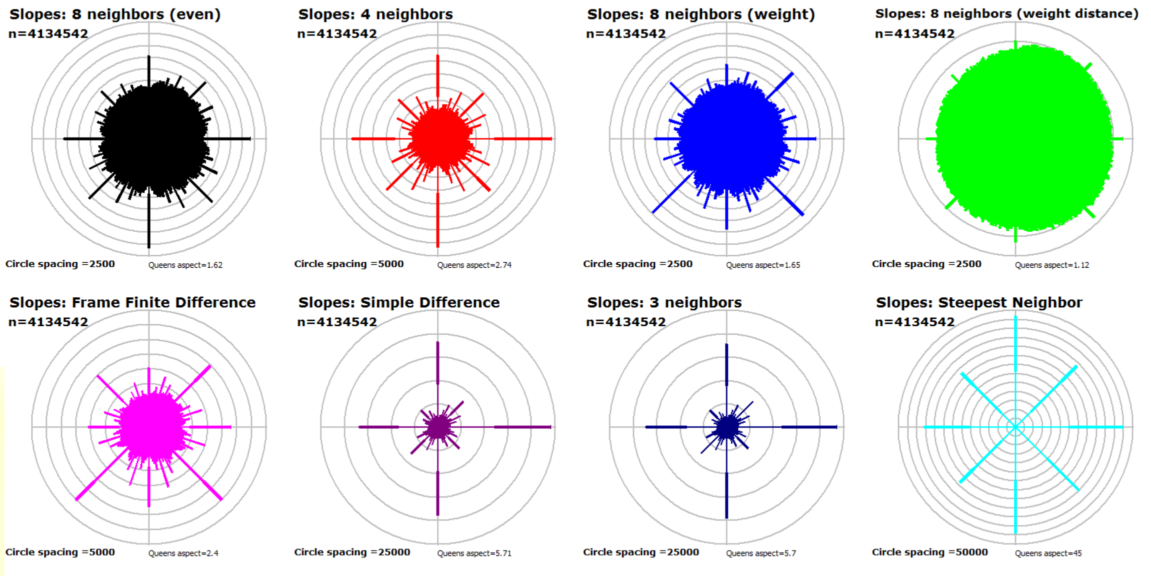

Figure 6. Aspect distributions for 30 m DEM of Mrorbe province.

4.5 Relative relief

The relative relief (RR) represents actual variation of altitude in a unit area with respect to its local base level. The RR does not take into account the dynamic potential of the terrain but as it is closely associated with slopes and it is more expressive and also useful in understanding the morphogenesis of this region. It is defined as the difference in height between the highest and the lowest points in 100 km^2 grid areas. The relative relief map of this region (Figure 7) gives a clear picture of the nature and amount of local relief of Morobe province. Isopleths of 500 meters relative relief demarcates the undulating surfaces of the Morobe province.

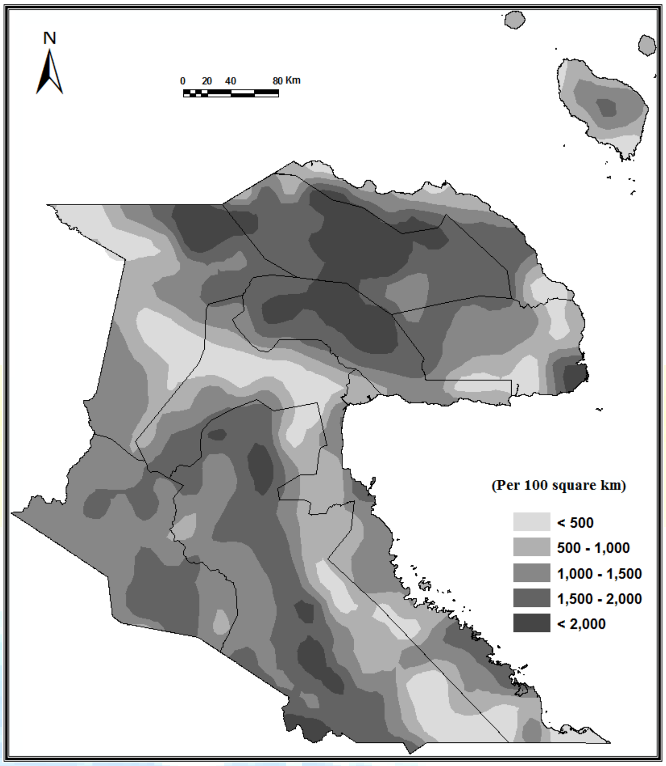

Figure 7. Spatial distribution of relative relief per 100 km^2 of Morobe province

The whole area is divided into five categories which are as follows: (1) low relative relief (<500m), (2) moderate to low relative relief (500-1000m), (3) moderate relative relief (1000-1500m), (4) high relative relief (1500-2000m), and (5) very high relative relief (>2000m). The geometrical characteristic of each class is shown in table 1.It also shows that high relative relief in Kabwum and Markham district, located at the northern part of the Morobe province. Some small pockets of high relative relief were also illustrated in the estern and central part of the study area. However, the lowest relative relief was found in the Nawae and southern region of the Bulolo.

Table 1. Geometrical characteristics of relative relief in Morobe province

Classes	Frequency of classes	Area (km^2)	Perimeter (km)	Thickness
Very low	<500	3880.66	1451.60	9461.71

Low	500-1,000	6549.49	3131.60	11050.00
Moderate	1,000-1,500	10569.73	3883.00	11192.906
High	1,500-2,000	9026.08	3161.20	13501.899
Very high	>2,000	3694.92	1108.40	14768.706

Mean= 1264.40 metres, Median= 1290.70 metres, Mode= 380 metres, Standard Deviation- ±634.43, Kurtosis- -0.64, Skewness- -0.08

The two variables, i.e., absolute relief and relative relief correlated statistically show the coefficient of correlation (+0.83) is not perfect looking into the age of the study area. It might be attributed to the impact of various upheavals particularly the tertiary movements, responsible for volcanic orogeny and upliftment of this area causing its rejuvenation. The positive value of correlation co-efficient suggests that the value of relative relief increases in accordance with the absolute relief as is also clear by the regression coefficient (R^2=0.69).

4.6 Dissection index

Dissection index (DI) is expressing the ratio of the maximum relative relief to maximum absolute relief. It is an important morphometric indicator of the nature and magnitude of dissection of terrain (Singh, 2000). The value of DI varies from zero (complete absence of dissection) to one (vertical cliff). Generally, low DI corresponds with the subdued relief or old stage, and with low relative relief. Conversely, the areas with high DI indicate high relative relief where slope of the land is steep (Deen, 1982). Based on DI values, the area has been classified into five major classes, such as, (1) low DI (<0.20), (2) medium to low DI (0.20-0.40), (3) medium DI (0.40-0.60), (4) high DI (0.60-0.80), and (5) very high DI (>0.80) (Figure 8). The geometrical characteristic of each class is shown in table 3. In our study area, larger part is covered with the high DI value (> 0.80). Very small pockets of low DI value (< 0.20) spread throughout the province, and the topography of the region rules out the deposition of lean sediment that ensures thin layer of soil. The detail geometrical characteristics of DI of Morobe province is shown in Table 2. DI is related to active tectonics and concave drainage profile development along the profile at lower altitude. Furthermore, it does not active mobilization of the weathered material mobilization is quick at lower altitude. Such topography assures constricted irrigation because of high gradient. The workings of fields such as tillage, spading, hoeing, weeding, sowing and harvesting are difficult task.

Table 2. Areal coverage of dissection index in morobe province

Classes	Frequency of classes	Area (km^2)	Perimeter (km)	Thickness
Very low	<0.20	19.75	20	1950
Low	0.20 – 0.40	916.50	532	6850
Moderate	0.40 – 0.60	6189.25	2272	12527.306
High	0.60 – 0.80	11370.75	3733	15577.699
Very high	> 0.80	15220.50	2551	18910.711

Mean= 0.75, Median= 0.80, Mode= 0.93, Standard Deviation= ±0.20, Kurtosis= -0.34, Skewness= -0.69

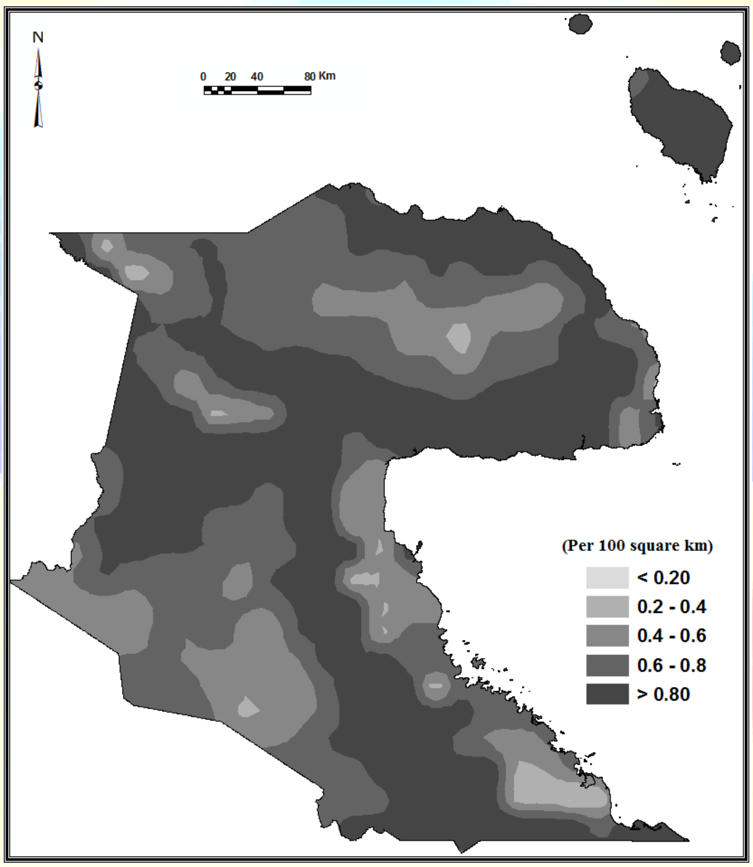

Figure 8. Spatial distribution of dissection index per 100 km^2 of Morobe province

4.7 Ruggedness index (RI)

RI is an appraise of surface jaggedness, representing sharpness of local relief and the amplitude of available drainage density and other environmental parameters. RI is measured by taking into account both relief and drainage (Chorley and Kennedy, 1971). The result of our analysis shown that the high frequency classes of RI are found in north and south central region of the province. But moderate and moderate to low value of frequency classes are found in the valley and its peri-domestic area (Figure 9). The details of geometrical characteristic of each class of ruggedness index are shown in table 4. Moreover, frequency classes of DI value shows very low value is observed in almost valley except few places at own stream.

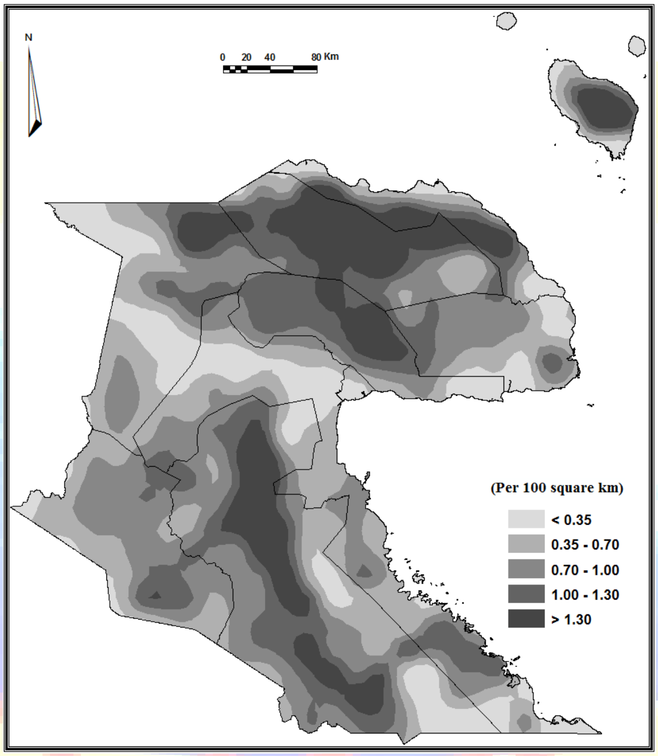

Figure 9: Spatial distribution of Ruggedness index per 100 km^2 of Morobe province

Table 4. The geometrical characteristic of Ruggedness index of Morobe province

Classes	Frequency of classes	Area (km^2)	Perimeter (km)	Thickness
Very low	Below 0.35	5033.13	2215.80	10419.10
Low	0.35 – 0.70	7882.41	3817.40	9447.70
Moderate	0.70 – 1.00	9202.99	3964.40	11426.1
High	1.00 – 1.30	6409.61	2984.20	12850.00
Very high	Above 1.30	5192.74	1073.80	15337.51

Mean= 0.79, Median= 0.77, Standard Deviation= ±0.46, Kurtosis= -0.61, Skewness= 0.29

4.8 Drainage density (DD)

Drainage density is measured by the length of stream channel per 100 km^2 unit area. It is generally influenced by several factors like, geology, climate, permeability of soil etc (Morisawa, 1968). Five categories of drainage density observed in the study area, such as (1) very low DD (Below 0.25 per $100km^2$), (2) low DD (0.25-0.50 per $100km^2$), (3) medium DD (0.50-0.75 per $100km^2$), (4) high DD (0.75-1.00 per $100km^2$), (5) very high DD (above 1.00 per $100km^2$) (Table 5, Figure 10).

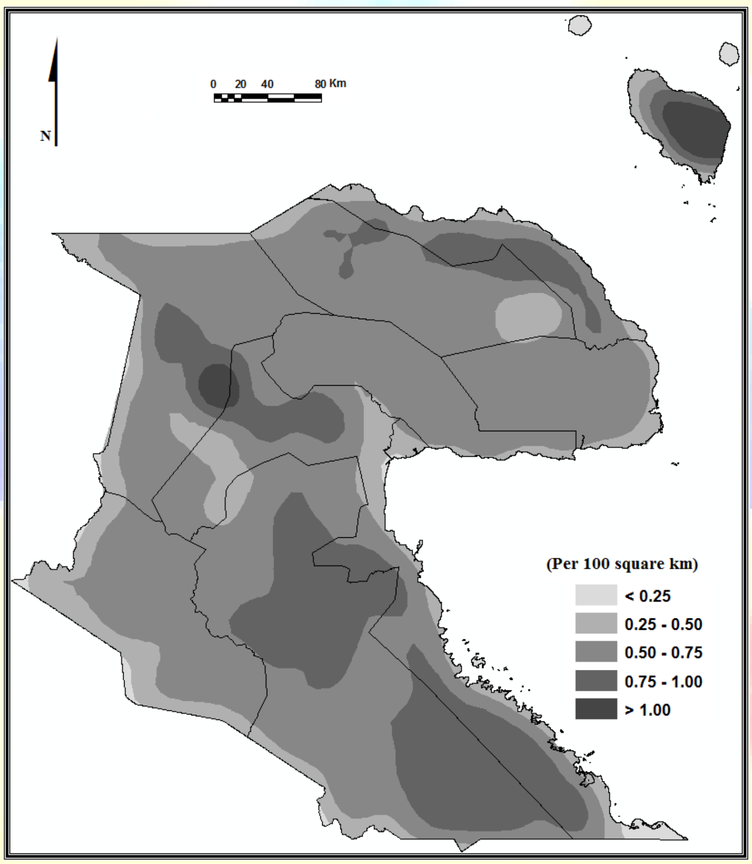

Figure 10. Spatial distribution of drainage density per 100 km^2 of Morobe province

Table 5. The geometrical characteristic of drainage density of Mrobe province.

Classes	Frequency of classes	Area (km^2)	Perimeter (km)	Thickness

Very low	Below 0.25	343.25	539.00	3357.29
Low	0.25 – 0.50	4761.25	2741.00	8950.00
Moderate	0.50 – 0.75	20123.75	2995.00	26005.52
High	0.75 – 1.00	7881.25	1594.00	23577.52
Very high	Above 1.00	607.25	189.00	9150.00

Mean= 0.62, Median= 0.63, Mode= 0.93, Standard Deviation= ±0.20, Kurtosis= 1.51, Skewness= -0.04

About 60 per cent of the total area is covered with moderate drainage density. It may be due to the structural control as predominance of volcanic and igneous rock formation.

5. Conclusion:

Based on the automatic morphometric analysis using SRTM DEM, the results show that the local relief characteristics with some observation of structural landscape pattern of the Morobe province. It is shown that the high absolute relief area is surrounded in the northern region. Spatial distribution of relative relief at some location indicates asymmetrical distribution, which indicates active tectonic in the area. Low value of dissection index is found almost whole valley except few places at downstream and at junction of the tributaries with main stream. Higher the value of dissection index and the topographic ruggedness indexes are calculated over the region, indicating larger undulation and instability of the terrain/land surface, found northern and south-centre part of the province. Therefore, it is recommended that the attained results be utilized in hydrological, physical characteristics, and environmental management in Morobe Province, PNG.

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