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Application of Geographic Information Systems in Analyzing Topographic Roughness for Nyanga District in Zimbabwe

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Abstract

The Topographic Ruggedness Index (TRI) is one of the essential measurement in topographic analysis, as well as in explaining biodiversity and geo-diversity. This study demonstrate how to utilize Geographic Information Systems (GIS) to generate TRI for Nyanga District using Digital Elevation Model (DEM). Though the TRI strongly depends on a local scale slope derived from an average adjacent neighbor slope algorithm, and selection of different lag distances in the computation of spatial variability, the measurement demonstrated that areas of higher altitude have higher ruggedness index. The TRI model was generated by computing focal statistics to determine focal sum of DEM and of the square of DEM (DEM^2). The final TRI was computed using Math Algebra (Raster Calculator) to generate layers of different ruggedness suitable for topographic and biodiversity analysis. The algorithm presented could also be used for smaller areas with high quality data and corrected DEMs. Despite widespread adoption, ruggedness metrics require thorough testing using both artificial landscapes and real world applications.

Keywords: *Topographic Roughness Index, Geographic Information Systems, Digital Elevation Model, Focal Statistics*

1. Introduction

Topographic variations supports a various patterns and processes in climatology, hydrology, and ecology, among other disciplines and is key to understanding the variation of the earth's phenomena (Amatulli *et al.*, 2018). The Topographic Ruggedness Index (TRI) continue to be utilized by experts in various fields of study as the measurement has often known for providing a relatively accurate view of the vertical change taking place in the terrain model from cell to cell (Esri, 2020). TRI is a measurement developed to express the amount elevation difference between adjacent cells of a digital elevation grid (Riley *et al.*, 1999), proving data on the relative change in height of the hill slope (Esri, 2020). The index has been utilized in this study with the raster function generating the visual representation of the TRI for Nyanga District of Zimbabwe. This study seeks to add to the body of knowledge the application of GIS and remote sensing in determining topographic ruggedness, and its relationship with drainage density.

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2. Literature Review

2.1. Topographic Ruggedness Applications

Various researches have shown the significance of TRI in analyzing topographic characteristics. Riley *et al.* (1999) note that the measurement is commonly used in species distribution studies to account for the heterogeneity of topography or terrain, and if the value is larger it means the area is more rugged. The index has also been used to quantify landscape ruggedness for animal habitat analysis using Geographic Information Systems (GIS) (Sapping *et al*., 2010). On a similar note, TRI has also been used to determine the quantitative analysis of topographic ruggedness in reindeer winter grounds for two regions in Norway (Nellemann and Fry, 1995). Topographic ruggedness was found to be significantly higher in high use areas, while indices of topographic ruggedness reflecting fine scale features (10-20 m) matched well with the availability of potential feeding sites. Thus topographic structure should be considered a useful habitat attribute for planning on reindeer winter habitats, as the measurement provides a simple technique for quantifying differences in fine scale ruggedness between habitats.

In another study, Konkathi *et al.* (2019) developed a static fire risk index with topographic ruggedness as one of the parameters influencing forest fires. MODIS land cover type yearly L3 global 500m SIN grid (MCD 12 Q1) was used to compute fuel type based on historical fire data and STRM DEM was used to compute slope index, elevation index, aspect index, and TRI. The study exhibited 32.38% fire risk zone.

TRI has also been used as one of the macro-topographic factors in enhancing planning of timber harvesting in Zalesina, Croatia (Duka *et al.,* 2015). Unevenness of topographic was determined based on the TRI which showed moderately to very high rugged topographic on 60.1% of the study area, where vehicle mobility could be difficult.

3. Study Area, Materials and Methodology

Nyanga District is located in Manicaland Province of Zimbabwe, and lies along the international border with Mozambique. The latitude of Nyanga is -18.220079, and the longitude is 32.746369. The district has an average yearly temperature of 20.22 °C, and typically receives about 138.47 millimeters of precipitation, and has 122.71 rainy days annually.

3.1. Materials

The study utilized DEM for Nyanga District downloaded from the United States Geological Survey (USGS) Shuttle Radar Topography Mission (SRTM) at 1 Arc Second Global (30 m) resolution (Figure 2). Spatial Analyst tool in ArcMap10.8 was used to perform topographic analysis from DEM. Topographic algorithms and focal statistics were used to determine topographic ruggedness index (TRI) for the study area.

4. Results and Discussion

4.1. Calculating Topographic Ruggedness Index (TRI)

TRI for the study was generated to express the amount of elevation difference between adjacent cells of a DEM, and the following calculations were performed on DEM using focal statistics Focal Statistics in ArcMap for the original grid and for its square.

4.2. Focal Statistics Calculations in ArcGIS

The significance of Focal Statistics is a statistic function performed on DEM such as the mean, maximum, minimum or sum of all values in the neighborhood. This study considers rectangle neighborhood which is specified by providing a width and a height in either cells or map units, and only the cells with centers which fall within the defined object are processed as part of the rectangle neighborhood (Esri, 2023). The Focal Statistics calculations are as follows:

4.2.1. Focal Sum of DEM

Given a DEM, Focal statistics was used to;

Compute S = *Focal Sum (over the* 3 * 3 *square neighborhoods) of DEM* ... (1)

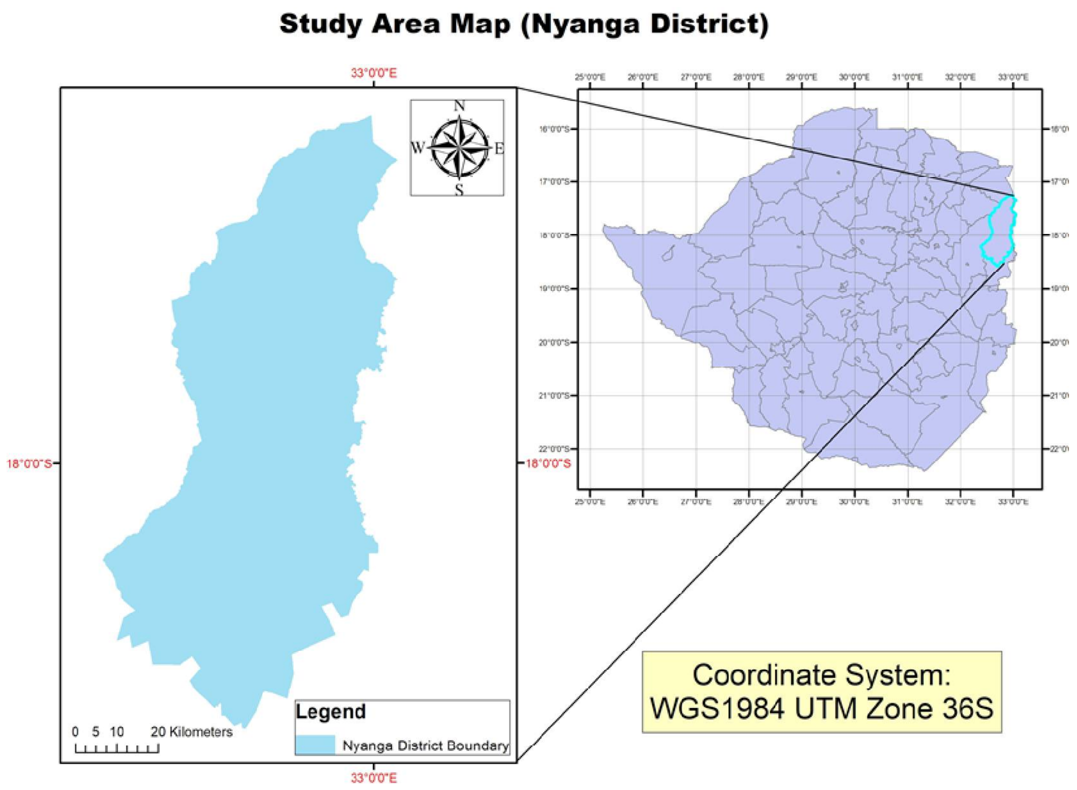

Figure 1: Location of Study Area

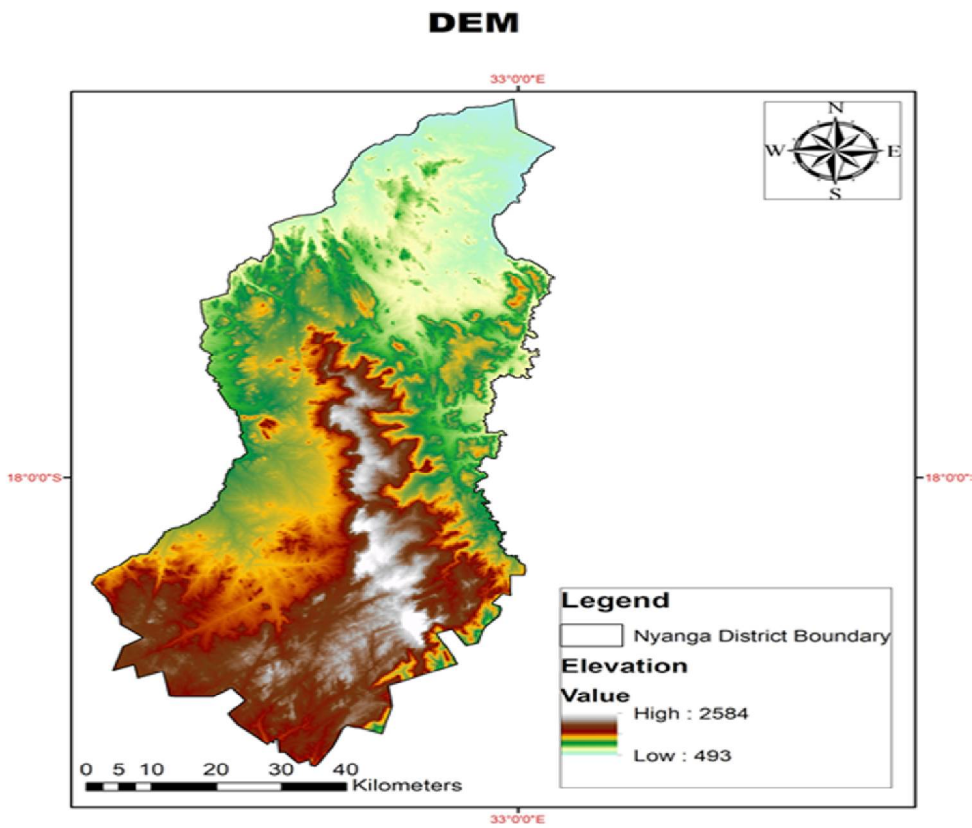

Figure 2: Elevation Map for the Study Area Downloaded from USGS

The resultant focal sum is illustrated in Figure 3 below.

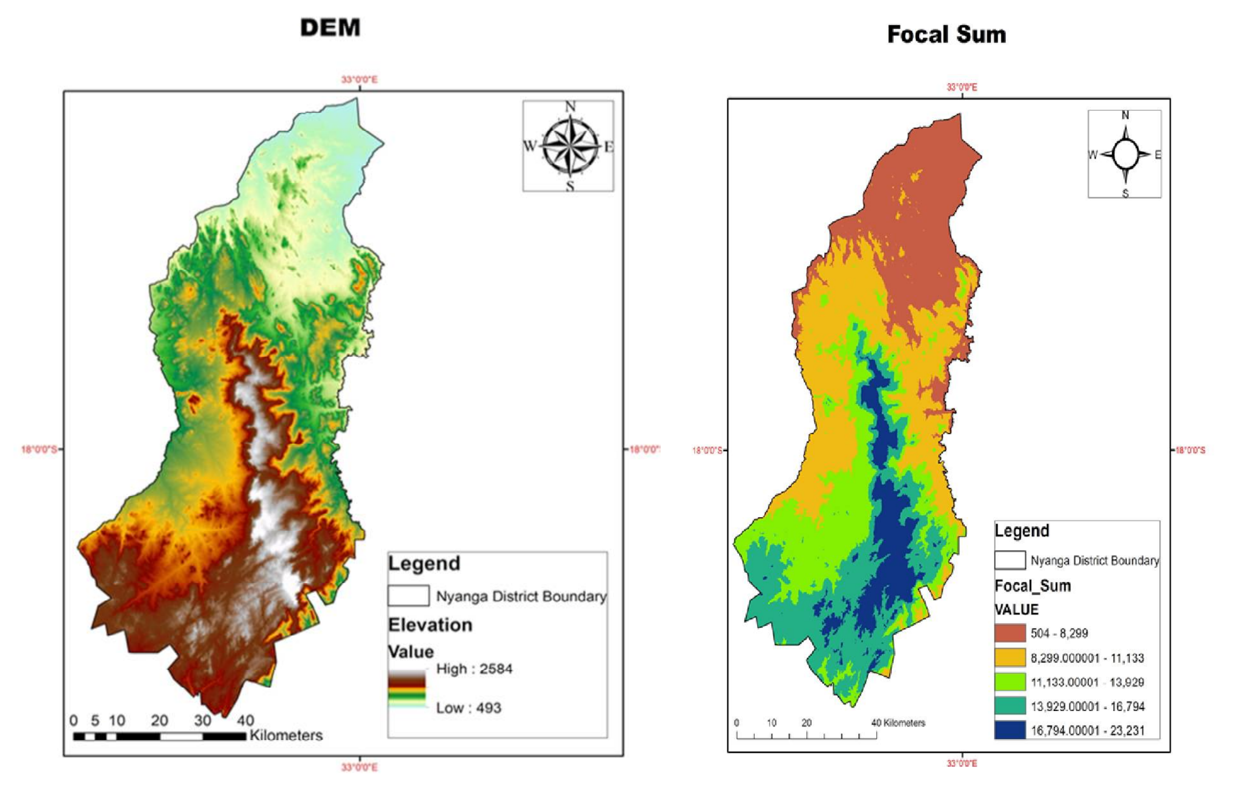

Figure 3: DEM and Focal Sum of DEM

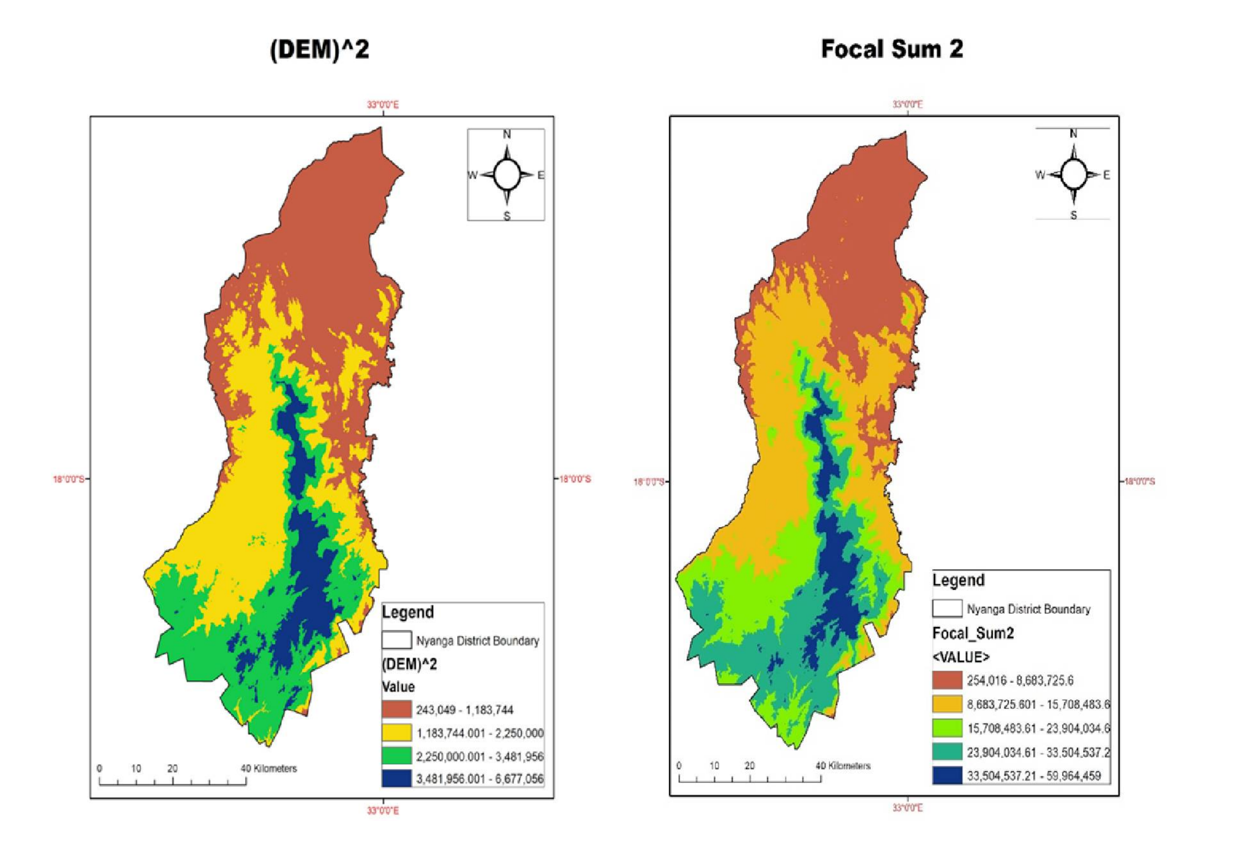

Figure 4: Representation of *DEM* ² and Focal Sum of *DEM* ²

4.2.2. Focal Sum of DEM ²

Given a DEM, Focal statistics was used to calculate $(DEM)^2$ using Math Algebra (Raster Calculator) in spatial analyst toolbox as:

$$(DEM)^2 = (DEM) * (DEM) \quad \text{... (2)}$$

Focal sum of $(DEM)^2$ (Figure 4) was computed as:

$$\textit{Focal Sum of } (DEM)^2 = \textit{Focal Sum (over 3 * 3 neighborhoods) of } (DEM)^2 \quad \text{...(3)}$$

4.3. TRI Calculations

Raster Calculator in Math Algebra was used to calculate the TRI (r) and a TRI map for the study area was generated. The representation of TRI is shown in Figure 5 below. TRI calculates the Root Mean Square Deviation (RMSD) for each cell grid in a DEM, calculating residuals or elevation differences between a grid cell and its eight neighbors.

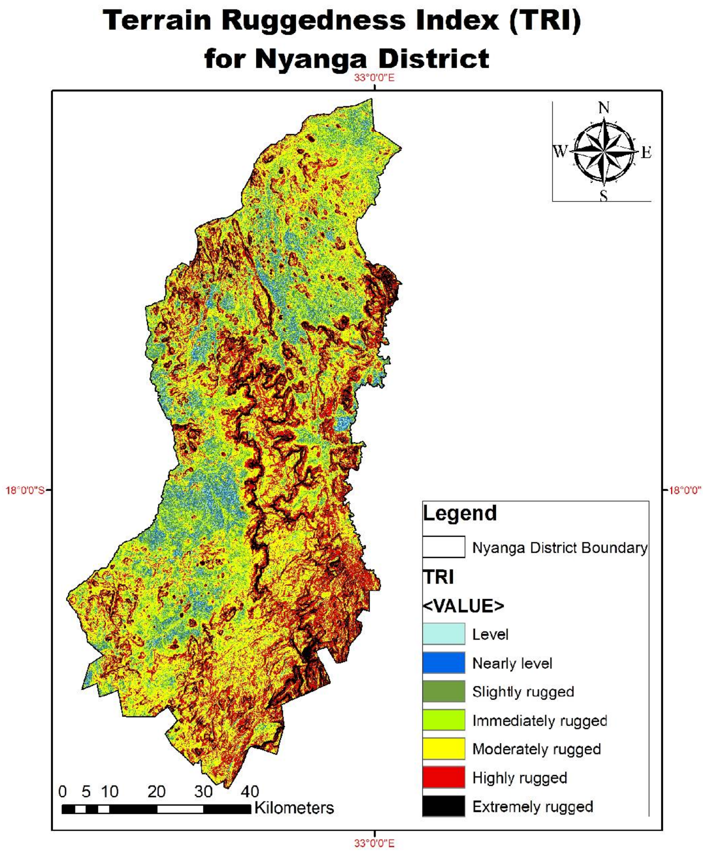

Figure 5: TRI for the Study Area

4.3.1. Method

Given that $\boldsymbol{x}$ be the value in the central square; xi, $i = 1, \ldots, 8$ index the values in the neighboring squares; and r be the topographic ruggedness index, such that r^2 equals the sum of $(xi - x)^2$. Two algebra are computed as follows:

i. The sum of the values in the neighborhood, equal to s = Sum $\{xi\} + x$; and

ii. The sum of squares of the values, equal to t = Sum $\{(xi)^2 + x^2$.

Expanding the squares:

$$r^2 = Sum\ \{(xi - x)^2\}$$

$$r^2 = Sum\ \{xi^2 + x^2 - 2 * x * xi\}$$

$r^2 = Sum\{xi^2\} + 8 * x^2 - 2 * x * Sum\{xi\}$

$r^2 = [Sum\{xi^2\} + x^2] + 7 * x^2 - 2 * x * [Sum\{xi\} + x - x]$

$r^2 = t + 7*x^2 - 2 * x * [\text{Sum}\{xi\} + x] + 2 * x^2$

$r^2 = t + 9 *x^2 - 2 * x * s$

This study employed Focal Statistics and Math Algebra in ArcMap to generate TRI for the study area as follows:

$(TRI)^2 = [t] + 9*[DEM^2] - 2*[DEM] * [S]$

$$TRI = \sqrt{([t] + 9*[DEM^2] - 2*[DEM] * [S])} \quad ...(4)$$

5. Conclusion

The ruggedness zones derived from TRI calculations are namely; level, nearly level, slightly rugged, immediately rugged, moderately rugged, highly rugged and extremely rugged zones. The higher the TRI, the higher the ruggedness, while areas with low TRI resemble flat areas. Though the TRI strongly depends on a local scale slope derived from an average adjacent neighbor slope algorithm, and selection of different lag distances in the computation of spatial variability, the model is suitable for calculating ruggedness index for habitat area analysis, where sources of error in DEMs will not entirely affect biological interpretations of data. The algorithm presented could also be used for smaller areas with high quality data and corrected DEMs. This study supports views by Dilts *et al*. (2023) that despite widespread adoption, ruggedness metrics require thorough testing using both artificial landscapes and real world applications. Therefore, further studies may focus on machine learning models to generate accurate TRI.

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Author Declaration

I acknowledge that this piece of work is my own and has not yet been published anywhere.

Conflicts of Interest

No potential competing interests to declare.

References

Amatulli, G., Domisch, S., Tuanmu, M.-N., Parmentier, B., Ranipeta, A., Malczyk, J. *et al.* (2018). A Suite of Global, Cross-scale Topographic Variables for Environmental and Biodiversity Modeling. *Scientific Data*, 5, Article number: 180040. DOI: doi:10.1038/sdata.2018.40.

Dilts, T.E., Blum, M.E., Shoemaker, K.T. *et al*. (2023). Improved Topographic Ruggedness Indices More Accurately Model Fine-scale Ecological Patterns. *Landscape Ecol.*, 38, 1395-1410. https://doi.org/10.1007/s10980-023-01646-6.

Duka, A., Porsinsky, T. and Vusic, D. (2015). DTM Models to Enhance the Planning of Timber Harvesting. DOI: 10.2298/GSF15S1035D.

Esri. (2020). Topographic Ruggedness Index (TRI). Living Atlas of the World. 2020. Available on: https://livingatlas_dcdev.opendata.arcgis.com/content/28360713391948af9303c0aeabb45afd/about. Accessed on July 03, 2023.

Esri. (2021). ArcMap 10.8 Help Archive: Curvature Function. Available on: https://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/curvature-function. Accessed on November 30, 2023.

Konkathi, P., Shetty, A., Kolluru, V., Yathish, P.H., and Pruthviraj, U. (2019). Static Fire Risk Index for the Forest Resources of Karnataka. *IEEE International Geoscience and Remote Sensing Symposium,* 6716-6719, Yokohama, Japan. DOI:10.1109/IGARSS.2019.8898522.

Nellemann, C. and Fry, G. (1995). Quantitative Analysis of Terrain Ruggedness in Reindeer Winter Grounds. *Arctic*, 48(2), 172-176. doi: 10.14430/arctic1239.

Riley S.J., De Gloria S.D. and Elliot R. (1999). A Topographic Ruggedness Index that Quantifies Topographic Heterogeneity. *Intermountain Journal of Sciences,* 5 (1-4), 23-27.

Sappington, J.M., Longshore, K.M. and Thompson, D.B. (2010). Quantifying Landscape Ruggedness for Animal Habitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert. *Journal of Wildlife Management*. DOI: https://doi.org/10.2193/2005-723.

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