AN APPROACH TO SLOPE LENGTH AND FEATURES CALCULATING USING DEM AND GIS.

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Abstract

Earth surface presents characteristics of declivity ondulations, slopes, features and lengths. This peculiarities are given from both external and internal processes and agents which models the relief. Analyzing quantitatively this topographical phenomena with computer techniques and digital format information contribute to make these processes easier and faster. A good representation of this topographic topics by mean of DEM, make suitable layers into a GIS in order to further cartographic analysis and results.

I.- Introduction and objectives.

1.- Introduction.

A *Digital Elevation Model (DEM) is an machine representation of a phenomenon, in this case, of Earth* surface topography. Its validity depends on initial data quality and quantity for to generate it. To study data distribution over the study area contributes to homogeneity and representativity of a given phenomenon. High data distribution density and appropriated interpolation methods are important for obtaining good degree of reliability of models. DEM derived models would have better representativity and would be a suitable tool for verify topographical variables, such as: slopes, aspects, roughness, declivity length, features, et cetera.

2.- Objectives.

A. To show feasibility for variable calculating such as declivity length and feature, from DEM.
B. To calculate declivity length and feature employing both different scale DEM and raster GIS.

II Methodology.

1.- DEM generation.

Digital elevation models have been obtained through two ways:

In the first way and specially for 1:50,000 scale, contour lines, some elevation points and critical features of relief have been digitized. Equidistance between each contour lines were 10 meters.
According to topographic peculiarities of the study area, a 30 meters grid was settled. A linear interpolation method was used, with a moving window of 3 x 3 pixels.

In the second way, a DEM had been provided by INEGI (Instituto de Geografía, Estadística e Informática). This DEM was obtained from aerial photo altimetry restitution in 1:250,000 scale, including 50 meters spacing ancillary curves. It has a grid spacing of 87.68 meters, for 20 degree northern latitude. Such a model is similar to US Army DEM.

Once the data have been integrated to the geographical data source of GIS, and geocoded correctly, some studies were performed in order to validate its accuracy.

Some known verification points were randomly selected, and model and ground truth values were contrasted for each position. For both models an RMS smaller than the pixel size was obtained. 90 percent of these points had given an error lesser than pixel size stated for this scale, and this fact confirms that these *models lie within the international parameters (Bosque, 1994).* Correlation coefficient had shown a fitness of 95 % between estimated values versus real ones.

Thus statistical data show that we could start upon an acceptable modeling of the topographical reality although we have to take in account the limitations of a raster structure (Bosque, 1992). Further derived digital models would have known initial errors.

2.- Calculating derived models.

Magnitudes derived from the model were declivity length and feature. It was possible to combine the length with the slope factor s of Universal Soil Loss Equation, and to conform the topographical factor, LS. This was also used for declivity features, to obtain the slope curvature, i.e., whether they are convex, straight line or concave. Two procedures were used:

2.1.- Lambda (λ) and L calculation.

Declivity length is a spatial unit which is related to run-off occurring site. This measuring is normally acquired on field by mean of topographical methods and sometimes is obtained indirectly through analogical cartographic techniques (CEOTMA, 1991). Declivity length and slope factor are commonly used such a (general) factor which relies expected soil loss by surface unit to the loss which would be in a standard condition of 9 % slope and of 22.13 meters length (FAO/UNESCO and PNUMA, 1980). Two steps were involved in this operation: 1.- Lambda (λ). 2.- Use of equation 1. 3.- Finally, using of S and product with L.

a. λ calculation.

DEM and GIS would be used to calculate lambda, from Equation 2. (Zaragoza, 1993).

$$\lambda = \frac{\Delta H}{Sen\,[Tg^{-1}\,\frac{\Delta H}{l_o}\,]} \quad (1)$$

where: λ = theoretical length.
l_o = distance between each point and grid.
ΔH = height difference between maximum and minimum pixel or point respect to its 8 neighbors (it was obtained applying $\Delta H = Tg\ A * l_o$).

Once A angle (digital model of slopes in degrees or DMSD) and l_o value are known, that is the distance between grid or pixel size, the height difference would be extracted. With this datum, equation 2 would be accomplished.

b. L calculation

$$L = \left(\frac{\lambda}{23,13}\right)^m \quad (2)$$

Equation (1) allows to calculate L. λ is length field value, which is compared with standard length unit of 22.13 meters and (m) is an exponent which is influenced by length and slope angle, soil properties and climate, et cetera. The U.S. Department of Agriculture recommends the following values: m= 0,6 for slopes > 10%; m= 0,3 for very long slopes and lesser than 1.5%; and m=0.5 for the rest of slopes.

2.2.- S factor calculating.

$$S = \left[\frac{0.43 + 0.30\,s + 0.043\,s^2}{6.613}\right] \quad (3)$$

S value is determined from equation 3, proposed by Runoff and Soil-loss Data Center Wischmeier and Smith, and employs an Digital Model of Slopes in percents (DMSP or factor s).

Furthermore, when L and S had been yet obtained, the product of both would be done, and thus topographic joined factor LS is ready to be used in USLE equation, which relates other variables such as rainfall, soil type, vegetation and agricultural practices.

In all cases the procedures were performed within a raster GIS, and specially by map algebraic operation modules and mathematical operations, maps overlapping, recoding, and so on. It is necessary to be careful in transforming degrees into radians and vice versa when trigonometrical operations are been performed.

b) Slope feature calculation.

Regarding to declivity feature, whole Earth surface is considered to have an inclination degree and curvature. The curvature is "a changing level of slope angle in respect to distance expressed in degrees for each 100 meters (Young, 1972 cited by Carter, 1990). Each terrain slope may be divided in certain categories or morphological classes, as they are concave, straight lined and/or convex. The first ones would present negative curvatures and the convex ones would be positive, as straight lines would present null degree curvature. The following equation would be used:

$$C = [\frac{\theta_1 - \theta_2}{0.5 \times l_1 + l_2}] \times 100 \quad (4)$$

where: C = curvature

θ_1 and θ_2 = they are upper and lower slopes angles respectively; those represents the distance between upper angle and lower angle, and thus successively along the slope

l_1 and l_2 = they are each slope segment's length

100 and 0.5 = constant values.

Young (1972) had stated the following curvature classes and from these any declivity features would be combined:

Table 1. Feature classes.

Class	Description
> 100	Strongly convex
10 to 100	Moderately convex
1 to 10	Slightly convex
1 to -1	Near to null or straight lined
-1 to -10	Slightly concave
-10 to -100	Moderately concave
> -100	Strongly concave

For applying that equation into raster GIS, DEM should be generated at first, and then DMSD should be calculated. Each pixel would contain a numerical value of the slope. A moving 3 x 3 matrix should be applied, in order to obtain the mean value of DMSD ($DMSD_{mean}$) in degrees. The resulting file should be subtracted to the original values of DMSD. Finally, the θ_1 and θ_2 values are obtained. As pixel size is known, we also would know l_1 and l_2. Thus curvature values of each pixel might me extracted. Next step consists in recoding the values according to previous class ranges of declivity.

It would be stated that this is another procedure among many ones, and literature should be consulted, such as Felicísimo (1994), who also employees a moving matrix.

This result allows to evaluate globally what happens along a hillside where exist any erosion processes: crawling, sliding and material moving, and other sediment processes due to length and feature characteristics of the relief.

All former steps would be executed for each DEMs.

3.- Results.

The test area is located in a tectonic and volcanic region, which belongs to new volcanic axe or so called trans-Mexican fringe at 20° degree northern latitude. Both tectonic and volcanic structures are predominant. The climate is a transitional one between arid Northern Mexico and the humid South.

Application results from using former equations over this territory show interesting data in order to employ such digital information sources appropriately, and to treat those for large national territory areas.

The DEM derived from 1:50,000 scale shows the better detail. Joint LS values might be integrated in USLE methodology. The greater detail of DEM, the better results of such factor would be obtained, while 1:250,000 DEM underestimates topographic factor. Nevertheless it is possible to use it for regional scale evaluation.

Regarding to declivity feature for both models, the higher the detail, the algorithm is capable to estimate some micro-topographical roughness, detecting or displaying concave or straight line trends, in harm of convex features. The lower the detail, straight lines and convex features are predominant, decreasing concave ones notably. This is due to relief generalizing.

4.- Conclusions.

Results have been compared between both models, and these in turn have been compared to a test sector of analogical map (topographical) at 1: 50,000 scale. Although it is necessary to validate them with field data from different climatic and topographic ambient since features have influences from external and internal relief-modeling agents, which could vary in every points of the Globe.

A 25,000 scale could offer mayor advantages whenever DEM had more than 90% of feasibility. Then it would be possible to detect some micro-topographic features, between 10 and 50 meters. Generalization is too big for 250,000 and 50,000 scales, that we could obtain only a regional slope value.

Although this procedure is theoretical, may be suitable for objectives which do not requires too much accuracy. It would save time and costs, in relation to topographical methods, when it was used for to calculate large areas. Digital management and integration into a GIS may improve results validation.

Using declivity features joined to other derived models such as roughness, slopes and aspects, would support to geometrical signatures characterization within a image classification scheme, such like to remote sensing techniques, and thus to explain morpho-structures. These models are denominated Multi-variable Digital Models (MDM) (Felicísimo, 1994).

We have taken into account the accuracy limitations in displaying such structures in raster data. This problem would be avoided by increasing the DEM spatial resolution. On the other hand, it seems appropriate to test with vector structures and to compare with raster one.

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