DIGITAL TERRAIN MODELLING WITH GIS: NATURE AND PRACTICAL APPLICATIONS IN EARTH SCIENCES

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ABSTRACT

Geographical Information System provides a wide range of functions for spatial analysis and modeling including Digital Terrain Modeling (DTM). Understanding the Nature of DTM or Digital Elevation Model (DEM) can confer understanding of the nature of the processes in the Earth Surface and applying it in spatial analysis of Earth Science data.

The paper begins by reviewing the nature of DTM with data input, methods of DEM interpolations, DEM quality and applications of DEM to different fields of studies. Further, the paper focus on the cases of study using DEM and demonstrates the GIS ways of analyzing the spatial and attribute data in relation to the geo-structural, geo-chemical fields of studies. The first example was given in this paper explains of how to use DEM for interpolating linear features such as fault/ lineament density map (as a part of geological structural study) in Hoabinh study area. Next, the paper examines the steps of using the DEM method for interpolating the distributions of Geo-chemical elements from the field sampling survey points for establishing a map showing the anomalies of chemical elements as mineral resources. The problem of calculating the thickness and volume of a stratum using the DEM method is discussed and illustrated.

1. INTRODUCTION

Digital Terrain Modeling with GIS is a process of interpolating and graphical simulation of the spatial terrain data (geographical elevation data) and its practical applications. The primary result of DTM is a raster digital image simulating the terrain surface expressed by matrix of pixels with coordinates x_i, y_j and z_{ij} elevation values. The DTM generation methods are different depending on the types of data inputs for interpolations. DTM (or DEM) can be generated from elevation points, digitizing contour lines, aerial stereo photos, Spot stereo images or by interpolation of the Radar interferometry imageries (Kenyi and Raggam, 1996). DEM and its derived products are used for watershed analysis (David, Willam, and Kathleen, 1998), soil erosion studies, agro-climatic modeling. The other applications using DEM data are traficability study, route designing, non-points source pollution and inter visibility studies (Wetch, Roy, 1990) and hydrologic modeling (Moore, 1996). The terrain interpolation and analysis functions are not restricted to the terrain (elevation) surface, however it can be applied to any series of geographical data, such as population densities, ground water pressure values, chemical concentrations, depths of a strata gathered by bore holes. In the Earth sciences DEM interpolation methods can be used in wide range including geological structural, geochemical, and morphological studies. The DTM interpolation was used for creating fault density map as a spatial GIS layer for geological structural study in Hoabinh area of Vietnam. The DEM interpolation method was applied for constructing the map showing chemical concentrations of elements based on surveying samples points in Thamquan area, North Vietnam. DEM can be used for calculating the thickness and volume of strata based on bore-holes or other data.

2. NATURE OF DTM

The nature of DTM is expressed not only by process of interpolation and simulation of terrain surface but also its applications to any spatial and none-spatial geographical data, to social and natural sciences with wide range of users. The DEM quality is depending on data input to DEM, scale of DEM, method of interpolation and GIS software used. The direct product of DEM is raster based image file with coordinates *x, y* showing geographical location and elevation *z* value. The derived products of DEM are contour map, slope and aspect maps, 3D viewing.

2.1. Data input to DEM

The inputting elevation data for DEM creation are point, line data, and raster based remotely sensed stereo imageries and interferometry SAR data. The *terrain point data* expressed as series of points including the extreme high and low points of the terrain, saddle points and points on stream and ridges with *x, y, z* values, regularly or irregularly spaced and makes up the skelet of terrain (Clarke, 1990). These data obtained by standard ground surveying technique or by GPS and by manually assisted photogrammetric stereo models (Markorovic, 1984) or obtained from grid DEMs to construct TIN models (Heller, 1990; Lee 1991). None elevation point data can be used for DEM interpolation are sampling data of geochemical or pollutant concentrations with the z values represented the concentration values and depths obtained by borehole data. The *lines data* are contour data digitized from topographical map, or generated automatically from photogrametric stereo model (Lemmen, 1998). Contour data imply a degree of smoothness of the terrain. Other line features such as road network, stream network and lineament/ tectonic faults can be inputted to DEM creation of road network density, stream density or fault/lineament density maps. The *remotely–sensed elevation* data was obtained by stereoscopic interpretation of stereo aerial photos. DEM can be generated using Spot stereo images (SPOT DEM) and using interferometry of SAR data (INSAR DEM). Space-borne lasers can also provide elevation data in narrow swathes (Harding *et al,* 1994).

2.2. Spatial DEM Interpolation

DEM interpolation methods can be different depending on data inputs for spatial interpretation. The Triangulated Irregular Network (TIN) and GRID methods are used for DEM generation. *TIN* is the set of adjacent, non-overlapping triangles computed from irregularly spaced points with *x, y* coordinates and *z* values. The TIN model expresses the topological relationship between triangles and their adjacent neighbors; i.e., which points define each triangle and which triangles are adjacent to each other. The surface value is calculated based solely on the *z* values of the triangle nodes within which the point lies. The *GRID* method builds the data in the grid cell by overlaying the point, line data to a grid, examples, the contour lines are overlaid on the regular grid cell and the elevations are read at each grid intersection point. The interpolated points are calculated using different mathematical interpolations. Spatial interpolations are grouped into local interpolations (inverse distance weighting, natural neighbor interpolation, TIN, rectangle-based), geo-statistical (kriging), and the variational approach (Mitasova & Mitas, 1993).

2.3. DEM quality

The quality of DEM depends on the quality of data input sources, interpolation technique and the map scale. The more elevations points data inputted, the more accurate DEM produced. The larger map scale will give higher quality of DEM. Computing shaded relief allows a rapid visual inspection of the DEM for local anomalies that show up as bright or dark spots and it can indicate random and systematic errors. Contour line presentation of DEM can be used for checking elevation errors in source data. The DEM of resolution from 5 to 50 meters is used for hydrologic modeling and soil erosion analysis (Biley and Beven, 1992), correction of SAR imagery. The small DEM resolution of 50 to 200 meters is used for microclimatic variation model (evaporation and vegetation pattern).

2.4 Products derived from DEM and DEM presentation

The direct products derived from DEM are slope maps, aspect maps, contour maps, shaded relief maps and 3D perspective view. DEM can be presented in the forms of original digital raster file, contour line map, shaded relief (**Fig**. **2(b).**), and 3D perspective viewing (**Fig. 1**). The slope is expressed as the change in elevation over a certain distance and is a raster file color coded according to the steepness of the terrain. Aspect map is expressed in degrees from 1 to 360 and color coded according to the prevailing direction of the slope at each pixel. Contour maps portray changes in terrain with series of lines that connected points of equal z values. Shaded relief map provides an illustration of variation in elevation based on user–specified viewing position and the areas that would be in sunlight are highlighted, and the area that would be in shadow are shaded. The 3D perspective view is a visual simulation of terrain based on position from which the view is calculated to make a good view on the terrain.

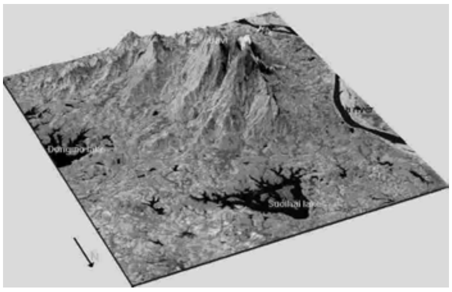
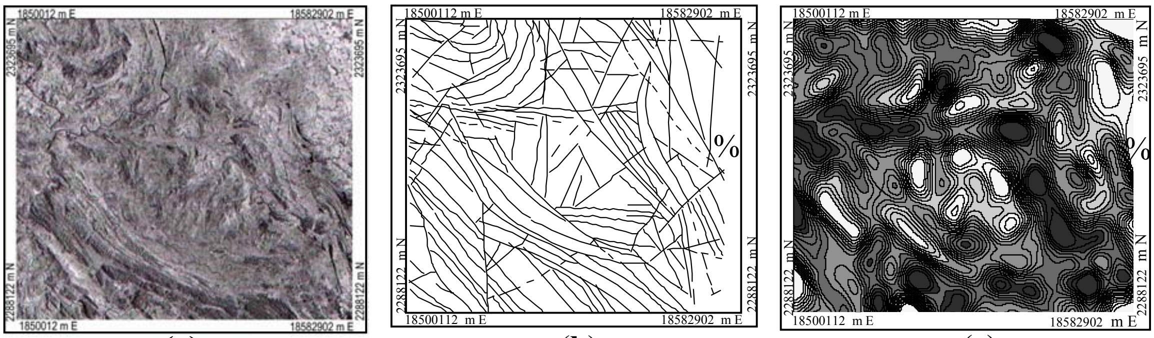


Figure 1. The DEM draped over Spot image with 3D viewing, Bavi, Vietnam

3. APPLICATIONS OF DTM TO THE ERTHS SCIENCES

3.1. Geology: Build up fault density map of Hoabinh area using DEM

GIS in integration with remote sensing technology is an approach for a geological structural study. The lineament /faults features were derived from Landsat MS imagery (**Fig. 2 (a**) and (**b**)) of the study area by digital image processing verified by field checking and



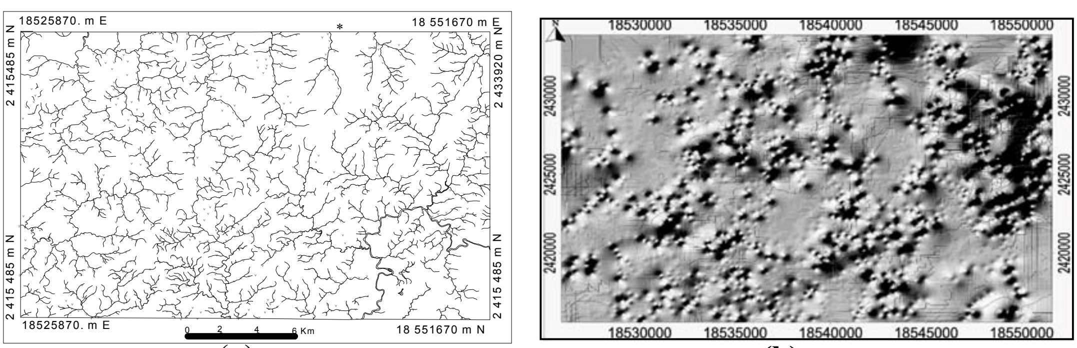
(a) (b) (c)

Figure 2. Fault density Map using DEM interpolation, HoaBinh, Vietnam. (a)-Landsat MS principal component1, (b) - Fault interpreted from Landsat Image, (c)- Fault density created by DEM: dark color area - high fault density; white area - low fault density.

comparing with existing geological map. To build up the fault/lineament features density map (**Fig. 2 (c**)) these features are overlaid with the grid cells by INTERSECT command in ARC/INFO environment. The frequency command (ARC/INFO) was used to calculate the values of total length of the lineament/faults (or calculating number of lineament/ faults) intersected to a grid cell. The values are used as point features to build DEM file showing fault density map. This fault/lineament density map layer can be used for other spatial analysis by overlaying with other layers (geological, geo-morphological) to find out the prospective mineral resources area.

3.2. Application to the Geochemistry: Interpretation of concentration of chemical elements using DEM interpolation, Thamquan area, Vietnam

The study area is located in the Northern Vietnam. The samples of bottom mud were taken for chemical analysis of concentration of elements by field survey. The results of this



(a) (b)

Figure 3. The schemes of surveying mud samples (a) and DEM interpolating chemical concentration of elements presented as "shaded relief" surface (b)

analysis are stored in a dBase lookup table having fields: samples_ID, concentration of Pb, concentration of Zn, concentration of Co and others fields. The spatial distribution of samples points (**Fig. 3 (a))** were digitized, topologically created and stored in GIS ARC/INFO environment as point covered having point attribute tables. Joining two these tables to create the spatial and attribute data base used to generate the DEM showing the concentration of chemical elements in the study area. **Figure 3 (b**) is the "shaded relief" of DEM interpolating concentrations of chemical elements based on samples taken by field surveying. The digital values of chemical concentrations of elements in DEM files were digitally reclassified in two new classes for each element. The Fig. 4. Illustrated the map of Pb concentrations divided in three classes: 1) Pb ranging from to $3x10^{-3\%}$; 2) Pb from 3 - $10x10^{-3\%}$ and 3) Pb > $10x^{10-3\%.}$

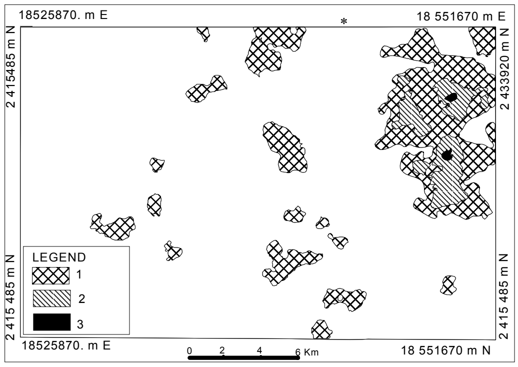


Figure 4. The concentration of Pb in Thamquan: 1) From 1-3x10^{-3}%; 2) from 3 - 10 x10^{-3}%

3.3 DEM and Calculating thickness and volume of a stratum in GIS

The thickness and volume of a stratum are calculated based on DEM values of its lower (base) and upper (roof) surfaces. Supposing the base surface of a stratum is A and its roof surface is B. These surfaces are digitally interpolated using DEM method based on borehole depth data. The A or B surface is the matrix of *n* columns multiplied by *m* rows pixels with the coordinates x_i, y_j (where i = 1, 2, 3,..*n* and j =1, 2... *m*.) and depth values of $z_{i,j}$.

The thickness (T) of stratum at any pixel coordinate x_i,y_j is calculated as below:

$$Tx_i, y_j = (dAx_i,y_j - dBx_i, y_j)$$

Where dAx_i,y_j *and* dBx_i,y_j are digital numbers (the depth values) at pixel i, j.

- *The volume of a stratum (V)* in an area of *n* column and *m* rows with spatial resolution of a pixel is r^2 can be approximately calculated by following equation:

$$Vt = \sum_{i=1, j=1}^{n,m} r^2 (dAx_i, y_j - dBx_i, y_j)$$

- *Applications:* The steps for calculating thickness and volume of stratum can be given as below:

1) Creating point coverage by inputting depth values of bore-holes at surface A and B,
2) DEM generation for A and B surfaces (DEM files in raster format);
3) The thickness (T) of a stratum at any given pixel of coordinate x_i, y_j is calculate using overlaying operation:

$$T = DEM (A) – DEM (B)$$

4) Use volume option in a GIS software environment to calculate the volume of a stratum

4. CONCLUSION

Digital Terrain Modeling with GIS provides a wide range for spatial analysis of geographical data and terrain simulation. The use of DEM is not only in real terrain analysis, but it can be applied in wide range of applications to Earth Sciences. The quality of DEM depends on map scale, data input and software used for interpolation. DEM and products of DEM are used for spatial analysis and modeling in natural and social sciences related to the use of geographical data. GIS with DEM used in Geology for mapping and spatial analysis as well as for interpolating prospective area of mineral resources and calculating the volume and thickness of a stratum.

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