An Assessment of Digital Elevation Models (DEMS) From Different Spatial Data Sources

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Abstract

Digital Elevation Model (DEM) represents a very important geospatial data type in the analysis and modelling of different hydrological and ecological phenomena which are required in preserving our immediate environment. DEMs are typically used to represent terrain relief and are particularly relevant for many applications such as soil erosion volume calculations, flood estimate, quantification of earth materials to be moved for channels, roads, dams, embankment, etc. In this study, three different sources of spatial data in the generation of DEMs (Shuttle Radar Topography Mission, SRTM 30, Digitized Topographical map and Google Earth Pro.) were compared with field measured data from Total Station Instrument. The field data were used to generate Digital Elevation Models (DEMs) from 495 radial points over the test site. The accuracy of generated DEMs was assessed statistically by comparing: (i) estimates of some topographic attributes (slope and aspect), (ii) overall spot height estimation performance and (iii) independence of spot estimation errors and the magnitude of field measured height. From the results obtained, it was concluded that the DEMs from the satellite imagery (SRTM 30) did not perform well in collecting data for topographic works. The digitized topographic map gives a good result but the variation from the reference in this study may be as a result of human activities and erosion that have occurred from when the topographic map was produced and also the quality of the topographic map. The Google Earth pro was also seen to perform far better than the SRTM 30 data. Finally, it was recommended that Real Time Kinematic GPS combine with total station can be tested for speed and accuracy and also SRTM data. Also, other global terrain data sources, i.e. GTOPO, Microsoft Visual Earth and NASA World Wind can also be examined for suitability of their application over larger assessment area.

Keywords: *Digital Elevation Model (DEM), Google Earth image, SRTM, spot height*

1.0 Introduction and Background

Digital Elevation Model is the continuous representation of elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. Digital Elevation Models (DEMs) are useful in many geoscience applications, such as topographic mapping, earth's deformation, hydrological and biological studies.

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It is of immense significance to distinguish between DEMs and other forms of terrain representation. The two most closely used terms, and sometimes confused with DEM, are Digital Terrain Model (DTM) and Digital Surface Model (DSM). DTM is considered as a continuous, usually smooth, surface which, in addition to height values (as DEMs), also contains other elements that describe a topographic surface: slope, aspect, curvature, gradient, and others. Like Digital Terrain Models, Digital Surface Models contain the spatial elevation data of the terrain in digital format which is usually presented as a grid with natural and artificial features such as vegetation, buildings, etc. A filtered DSM will result in DTM and a DEM is considered the most important component of DTM [Maune et al, 2001; Li et al, 2005; and Jobin, 2010].

A wide range of application is now drilling the requirement for increased details in DEMs. Details in this instance are defined by the horizontal sample spacing and vertical accuracy of the measurement. DEM is also an important utility of Geographic Information System (GIS). Using DEM/3D modelling, landscape can be better visualized leading to a better understanding of certain relations in the landscape. Many relevant calculations, such as lakes and water volumes, Soil Erosion Volumes, quantities of earth to be moved for channels, dams, roads, embankments, etc., require information from DEM/3D modelling [ESRI, 2009].

The derivation of topographic attributes relies on digital elevation data sets that may be acquired from satellite imagery, digitizing the contour lines on topographic maps, or conducting ground surveys [Wilson and Grallant, 200]. Digital elevation data are typically compiled and stored in one of three data structures: (i) point elevation data on a regular grid, (ii) point elevation data in triangulated irregular networks, and (iii) digitized contour lines.

The popularity of square grid DEMs is owed to their visual simplicity and ease of computer implementation [Wilson and Grallant, 2000; Moore et al, 1991]. These square grids are arranged in rows and columns and each grid point represents the elevation at that location. Square grids have been criticized because they contain superfluous data in flat areas and they are unable to handle abrupt changes in elevation easily [Wilson and Grallant, 2000]. The choice of a smaller grid size would increase the first and reduce the second problem. Another undesirable result of using square grids is that the computed upslope flow paths will frequently zigzag across the landscape in unrealistic ways [Wilson and Grallant, 2000].

The second structure used to store digital elevation data is triangulated irregular networks (TINs). These networks are based on triangular elements or facets with vertices at the sample points [Wilson and Grallant, 2000; Moore et al, 1991]. Three adjacent points on a plane are connected to form triangular elements. TINs can easily model sharp features such as peaks and ridges, and they can also incorporate discontinuities [Wilson and Grallant, 2000]. TINs are more efficient from the point of view that the number of sample points and triangles can be varied to match the surface roughness. Computer storage space is less using TINs compared to regular grids. Calculating topographic attributes is sometimes more difficult than with square grids due to the irregularity of the TIN structure. For example, it may be more difficult to trace the upslope connections of a facet and therefore more difficult to estimate the upslope contributing area at different points in the landscape [Moore et al, 1993].

The final structure is the contour-based network consisting of small, irregularly shaped polygons bounded by adjacent contour lines and streamlines (lines drawn orthogonal to the contour lines). This type of structure is difficult to implement but is nevertheless popular in hydrological applications because it can reduce complex three-dimensional flow equations into a series of coupled one-dimensional equations in areas of complex terrain [Moore and Foster, 1990].

The provision of gridded elevation data sets by many national mapping agencies (e.g. United States Geological Survey (USGS) at http://www.usgs.gov) coupled with the development and wide distribution of methods for converting contour elevation data to square grids (see Hutchinson, 1989, for one such method) have contributed to the popularity of gridded elevation data sets and grid-based topographic attributes . Table (1) presents a list of grid-based topographic attributes and their connotations.

Most of the proposed algorithms for calculating topographic attributes have been implemented inside a GIS and are well documented in different literatures [Dunn and Hickey, 1998; Hornsky, 1998; Qiming and Xuejun, 2004; Shi et al, 2007; Zhou and Liu, 2004]. This state of affairs introduces two new challenges in particular: (i) the need to learn more about the performance of these different algorithms in different settings to maximize the likelihood that the algorithm is best suited to the application and landscape at hand; and (ii) the need to ascertain the performances or reliability of the different data sources for generation of grid – based DEMs in view of increasing number of global data set and the demand for such products. The former challenge is left for other studies while this paper focuses discussion on the latter.

The paper presents the result of an experiment to test the accuracy of DEMs that are generated from two global data set sources [Shuttle Radar Topography Mission(SRTM 30), and Google Earth Pro], digitized topographic map and the reference DEM generated by ground surveys for the study area. Useful results for the evaluated techniques and the achieved accuracies are presented herewith.

Table 1: Primary topographic attributes calculated from DEM data (after Moore et al (1991).

Attributes	**Definition**	**Significance**
Altitude	Elevation	Climate, vegetation, potential energy
Aspect	Slope azimuth	Solar insolation, evapotranspiration, flora and fauna distribution and abundance
Catchment area	Area draining to catchment outlet	Run-off volume
Catchment length	Distance from highest point to outlet	Overland flow attenuation
Catchment slope	Average slope over the Catchment	Time of concentration
Dispersal length	Distance from a point in the catchment to the outlet	Impedance of soil drainage

Attributes	Definition	Significance
Dispersal slope	Mean slope of dispersal area	Rate of soil drainage
Elevation percentile	Proportion of cells in a user-defined circle lower than the centre cell	Relative landscape position, flora and fauna distribution and abundance
Flow path length	Maximum distance of water flow to a point in the Catchment	Erosion rates, sediment yield, time of concentration
Plan curvature	Contour curvature	Converging/diverging flow, soil water content, soil characteristics
Profile curvature	Slope profile curvature	Flow acceleration, erosion/deposition rate, geomorphology
Slope	Gradient	Overland and subsurface flow velocity and runoff rate, precipitation, vegetation, geomorphology, soil water content, land capability class
Specific catchment area	Upslope area per unit width of contour	Runoff volume, steady-state runoff rate, soil characteristics, soil water content, geomorphology
Tangential curvature	Plan curvature multiplied by slope	Provides alternative measure of local flow convergence and divergence
Upslope area	Catchment area above a short length of contour	Run-off volume, steady-state runoff rate
Upslope height	Mean height of upslope area	Potential energy
Upslope length	Mean length of flow paths to a point in the catchment	Flow acceleration, erosion rates
Upslope slope	Mean slope of upslope area	Run-off velocity

2.0 Materials and Methods

2.1 *Elevation from Ground Survey*

Total station instrument was utilized in the ground survey exercise. The total station gives directly the reduced 3-D coordinates, provided the orientation coordinates, height of the instrument, height of the target of back sight station were inputted before work begen. After the orientation of the instrument has been made, sufficient number of scattered points (495 points) were observed at the site to define the topography of the site. Fig. (1) depicts the 495 scattered points in the