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Terrain Analysis

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Terrain analysis uses elevation data, especially digital elevation models (DEMs), to characterize the bare terrain surface and, in most cases, link terrain properties to the natural or built environment. Closely associated with spatial analysis, terrain analysis is a fundamental component of geographic information science and provides solid support for a wide variety of GIS modeling and analysis activities. Terrain analysis is built upon terrain surface characterization, as well as the easy accessibility and high quality of terrain data.

Digital Terrain Data

Terrain data most commonly take the raster format (i.e., DEMs), which records elevation on a cell-by-cell basis for each cell, but irregular sampling points, contour lines, and triangulated irregular networks (TIN) are also common elevation data formats. DEMs may be produced from one or multiple data sources, such as conventional topographic maps, sample points, and remotely sensed imagery, and the production process often requires substantial preprocessing and interpolation of source data. The user should pay special attention to understanding the effect of data lineage when dealing with various elevation data sets. The raster DEM format has the advantage of simplicity, and it matches the format of remotely sensed imagery, making DEMs easier to update and improve using imagery compared with other data formats. DEM resolutions vary from very fine (e.g., < 5 m) to very coarse (e.g., 1 km or coarser) based on data source and/or application purpose. However, each specific data set has a uniform cell size for the entire represented area, making it impossible to present more details for steep places than flat ones.

The spatial resolution of DEMs as indicated by the cell size is critical in terrain analysis because most terrain analysis conclusions depend on and may vary with the DEM resolution. For example, slope gradient calculated at a very fine spatial resolution (i.e., with small cells such as 1 m) may help identify a small hollow (or depression) of 3 m to 10 m in the middle of a hillslope; the same calculation at 30 m would not be able to identify the hollow but may better describe the overall steepness of the hillslope. Scientists have also found that surface and subsurface water flow across the entire terrain surface could be traced—thereby connected—on a cell-by-cell basis, but the outputs of this modeling activity are notably less accurate when DEM cells are larger than 10 m, and especially 30 m. The cell size also determines the size (and possibly cost) of DEM data sets and may influence the spatial extent of the analysis that is conceived or conducted.

The spatial extent as another component of spatial scale is important in terrain analysis for several reasons. First, the terrain analysis results for one area may not be applicable to another area. Second, the topography-based modeling of biophysical processes involving a particular point, such as being shadowed by remote hills or receiving runoff from a remote ridgeline, requires the complete consideration of all relevant areas that may impact this point. Third, the study area should be sufficiently large in comparison with the cell size, so that the analytical results for the edge cells, whose characterization is not supported by a complete neighboring area, would not severely bias the conclusion for the entire area.

Primary Terrain Attributes

The primary task of terrain analysis is usually to characterize the terrain surface based on the data. This involves either the computation of terrain attributes or the extraction of landform units, or both. Attributes that are directly calculated from the elevation data are called *primary* *terrain attributes*. Elevation is a special primary attribute because it can be directly read from some topographic data sets. Care should nonetheless be taken, since the regularly aligned DEM grid points rarely coincide with the points of interest. In this case, spatial interpolation may be used to estimate the elevation of an unknown point based on the elevations of its neighboring grid points. Whether using interpolation or not, the user should be aware that (minor) errors are inevitable because the terrain surface is continuous and it is impossible to report an elevation value for each point.

Other primary attributes such as slope, aspect, plan, and profile curvatures may be computed to characterize the shape of the terrain surface in a small area. Some attributes characterize the topographic position of a point in a user-defined local neighborhood. Examples include the distance of this point to the nearest ridgeline or streamline, its location in the runoff-contributing system (using attributes such as upslope contributing area), and its relative highness (using elevation percentile or relief). When a large neighborhood area is considered, primary terrain attributes can also characterize the topographic context of a point, describing its relationship (e.g., similarity or belongingness) with contextual landforms, such as peaks, hillslopes, valleys, and so on.

Secondary Terrain Attributes

Secondary terrain attributes are calculated from (multiple) primary terrain attributes to identify particular biophysical phenomena. Sets of secondary attributes are commonly combined to simulate the topographic controls of water flow, mass movement, and solar radiation. For example, the topographic wetness index integrates the two primary attributes of slope angle and upslope-contributing area to indicate the spatial variability of topographically controlled moisture conditions. As a result, flat places with large upslope contributing areas have a high topographic wetness index, as they tend to be wetter. Combining these two primary terrain attributes in another way produces the sediment transport capacity index, such that steep places with a large upslope-contributing area will have a high index, as they are more capable of transporting materials across the land surface.

Topographic shading is another secondary attribute that can be calculated for each point, based on its aspect, slope, and topographic position, to indicate how incoming solar radiation, and hence temperature and moisture, may vary across complex topographic surfaces. This calculation is often included in meteorological models to determine the amount of incoming solar radiation received in different parts of the landscape.

Landform Classification and Object Extraction

Even though the terrain surface is continuous across space, it is often examined to extract discrete land-form objects with distinct biophysical meanings (option 1) or is subdivided into various landform components based on human-defined criteria (option 2). Thresholds of attribute values, either derived empirically or specified by an expert, are often required in both cases. In the first case, water flow paths and watersheds (and their boundaries) can be extracted following a flow-routing algorithm. The size of the upslope-contributing area along the water flow path may then be evaluated to decide where there may be sufficient contribution of runoff to initiate a stream channel so that it can be mapped. A typical example for the second case is to divide a hillslope into upperslope, midslope, and lower-slope components, each corresponding to a range of (multiple) terrain attribute values. These components may then be further divided so that a lower slope includes footslope, toeslope, and so on. These divisions often reflect the need of identifying discrete landform objects with relatively uniform terrain properties, such as steepness, convexity, concavity, and so on.

When landform objects are treated as internally homogeneous geographic features, they may be described with a single value of a particular primary terrain attribute. As a result, not only does each DEM cell but also each landform object comprising multiple cells have its own primary terrain attributes. For example, a hillslope and its upper slope component may each have a slope gradient to indicate their overall erosion potentials, but each cell constituting these landform objects will have its own slope gradient (and hence erosion potential) as well. On the other hand, a mountain range comprising many hillslopes may also have its own (average) slope gradient to help differentiate it from nearby basins. In this way, a nested, or multiscale, landform object system has been suggested, which allows each point (cell) to be evaluated in multiple topographic contexts (e.g., as the central point of a small local area, as a component of a hillslope, or as a part of a mountain range to which the hillslope belongs). As a result, two remote points with similar local properties may be compared in terms of their different topographic contexts.

Landform classification aims primarily to delineate biophysical landscape units based on topographic characterization. In comparison with landform object extraction, landform classification focuses on differentiating the entire terrain surface into a few kinds of landscapes with sets of boundaries, but the outputs do not necessarily include discrete landform objects. These classes can be predefined (e.g., steep terrain, high elevation) according to the application needs; they may also be identified based on data, using procedures such as statistical clustering. If a fuzzy land-form classification is adopted, the output could be membership layers with each layer presenting the distribution of the precise similarity (or membership) to one landform prototype or class center. Because fuzzy landform classification allows gradual transitions from one landform class to another, as often happens in the real world, it may provide more realistic classification results.

Terrain Analysis in Practice

Terrain analysis has been incorporated into major commercial (such as ESRI ArcGIS, Intergraph Geomedia, MapInfo) and free public domain (PCRaster, TAPES, GRASS, LandSurf) GIS software. Terrain data are widely available (e.g., through the Internet) compared with other biophysical data sets. As a result, terrain analysis is frequently used in the GIS environment to model and analyze many biophysical components, including climate, hydrology, soil, soil erosion, landslides, and vegetation. In addition, the topographic surface often has direct importance in various applications, such as road construction, transportation planning, urban planning, cellular cell tower placement, and so on. In these cases, it is the terrain surface per se that needs to be addressed. Special-purpose analytical tools such as cut-and-fill analysis for road construction and viewshed analysis, which identifies all visible points from an observer's point, for cellular phone tower placement are often used.

A special application of terrain analysis is floodplain inundation mapping, because a minor rise of flood level in flat floodplains means rapid expansion of inundation area, making small relief changes of the terrain surface highly important. This process may also be influenced by factors such as soil (e.g., texture and moisture), land cover, and human structures (e.g., levees). Flood inundation is vital for wetland management, urban planning, and disaster prevention, and it is a challenge for both digital elevation data and the terrain analysis tools because the accuracy of terrain data may not be sufficient to support this form of analysis, and the terrain analysis tools are often developed in steep mountainous regions.

- terrain analysis
- elevation
- interpolation
- solar radiation
- raster
- spatial resolution
- floodplain

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See also

- Digital Elevation Model (DEM)
- Elevation
- Fuzzy Logic
- Interpolation
- Spatial Analysis
- Spatial Statistics

Further Readings

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