Geomorphological applications of digital elevation models: a historical review and future perspectives

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ABSTRACT

Digital elevation models (DEMs) are highly important spatial data because they support not only geomorphological studies but also various other research activities including hydrological and ecological analyses and landscape visualization. For such necessities, governmental agencies and private sectors have been producing and compiling DEMs. Today both medium-resolution global DEMs such as the SRTM and ASTER-G and high-resolution DEMs for smaller areas obtained from laser scanning or photogrammetry are available. DEMs are often handled with Geographic Information Systems (GIS). This paper summarizes the history and major types of geomorphological applications of DEMs and GIS, and presents some future perspectives.

I. GEOMORPHOLOGY AS MULTIDISCIPLINARY SCIENCE

Geomorphology is a research discipline studying characteristics and origin of landforms. In countries like Japan and the UK, geomorphology has been regarded as a part of Geography, and mainly taught in geographical departments. In contrast, in countries like the USA and Italy, Geomorphology is taught mainly in geological departments. There are also numerous geomorphological studies conducted by geo-physicists. Therefore, Geomorphology is highly multi-disciplinary, and such a chaacter is becoming more distinct with the progress of planetary sciences. Planets other than the Earth are not easily accessible and thus planetary sciences heavily depend on information obtained by space probes. Because landforms on the surface of a planet are the most typical information acquired by space probes, many scientists in planetary sciences conduct geomorphological studies.

II. DEMS COMBINED WITH GIS

GIS (Geographical Information Systems) have been developing since the 1960s to efficiently deal with spatial data and maps using computers. Their linkage with Geomorphology has been strengthened since the 1990s with the increased availability of digital elevation models (DEMs). Although DEMs have various formats and structure, the raster or grid type has been most commonly used with GIS. GIS enable integration of DEMs with other data such as remote sensing imagery. Today, GIS are regarded as an important tool for geomorphological studies.

III. ANALYSIS OF LANDFORMS USING DEMS AND GIS

Recently I wrote three articles concerning geomorphological applications of DEMs and GIS as chapters of books in English [1–3]. Based on their contents, seven major geomorphological applications of DEMs and GIS can be identified: 1) visualization of landforms; 2) basic morphometric measurements; 3) analysis of stream nets and watersheds; 4) automated landform classification; 5) soil erosion modeling; 6) landslide susceptibility modeling; and 7) quantitative measure-ments of topographic change. First, the first four items, related to interpretation and structure of landforms, are described below.

Visualization of landforms using DEMs and GIS is popular not only in Geomorphology but also in other fields. Recent geoscientific and geographical articles often include contour maps, shaded-relief images, and bird's eye views produced from DEMs. Such visualization is, in a sense, already too common to be a novel science. However, some recent geomorphological publications show examples of visual interpretation of shaded-relief images from DEMs to obtain new insights into glacial, hillslope, and tectonic landforms. Therefore, basic procedures of making maps from DEMs and their interpretation are still important in Geomorphology.

Basic morphometric measurements include derivation, compilation and mapping of parameters such as slope, aspect, and curvature. These parameters are used for analyzing not only landform characteristics but also hydrological processes and relations of landforms with other environmental elements like vegetation. These basic parameters have been used since long time ago but are still commonly used in recent studies. For example, characteristic slope angles that occur more frequently than other angles have been investigated in relation to the development and steady state of mountain slopes. In addition, fine DEMs with resolutions of a few meters or tens of centimeters are obtained from airborne and terrestrial laser scanning as well as latest photogrammetric techniques such as structure from motion (SFM), leading to quantitative research of micro-topography.

Various methods have been proposed to automatically delineate stream nets and watersheds. Their principles are usually simple, but methods tend to be more complex including the removal of spurious pits due to the discrete structure of grid DEMs and appropriate allocation of streams in flat areas. These methods facilitate quantitative geomorphological analyses of watersheds including the reexamination of the classic law by Horton. Although Horton's law was originally proposed in the mid-20th century, it is still important today in relation to newer concepts such as fractal. Classic studies on the law depended on manual delineation and measurement of stream nets and watershed divides. However, DEMs combined with GIS permit much faster data processing and statistical analyses based on abundant data. Furthermore, the capability of deriving an upstream area and associated streams for any place along a river is effective for complex spatial analysis of hydro-geomorphological processes.

Automated landform classification has been receiving attention because it is an objective method that differs from subjective methods such as visual interpretation of airphotos. However, it is still not easy to correctly delineate landform units such as alluvial fans and river terraces based solely on automated techniques. A realistic solution is to combine automated and non-automated procedures. At the same time automated methodology is further developing using more complex morphometric parameters along with artificial intelligence originally developed for automated recognition of objects in an image.

IV. Analysis of Topographic Changes Using DEMs and GIS

The 5th to 7th items noted in the previous section are related to temporal changes in landforms. Soil erosion modeling using DEMs and GIS often employs the Universal Soil Loss Equation (USLE) or its revised models. USLE is an empirical equation considering topography, rainfall, soil, land cover and land protection measure. Originally it was not intended to use with DEMs and GIS, but its structure corresponds well to the overlay function of GIS. Other more advanced soil erosion models including those with distributed hydrological models are also combined with DEMs and GIS.

Landslide susceptibility has been analyzed using data for 1) land conditions including slope, geology and vegetation, and 2) distribution of past landslides. To analyze such data, multivariate statistical techniques such as discriminant function analysis, logistic regression and artificial neural network have been employed. The main outcome is a map showing landslide susceptibility for areas including those without information about past landsliding.

Quantification of topographic change usually utilize topographic data for more than one periods. High-resolution DEMs for two different periods permit the mapping of elevation change or the amount of erosion and deposition, for areas of rapid topographic change such as floodplain with active channels. Changes in morphometric parameters other than elevation as well as areal statistical measures including spatial autocorrelation have been investigated.

V. Problems and Future Perspectives

The credibility or reliability of the above-noted analyses of landforms and topographic changes depend on the quality of the original DEM used. In many geomorphological studies only insufficient attention is paid to the error of source data. All DEMs include certain errors; nevertheless it is important to do geomorphologically meaningful analyses and interpretations using currently available DEMs, with attention to the limitation of data quality. For example, if detected geomorphological differences significantly exceed the level of data error, the detection is still meaningful.

Choice of spatial scale for data analysis is also important. Geographical analyses of land use and other spatial phenomena point to the modifiable areal unit problem – the same spatial data may yield statistically different results if the unit size used is different. Such analyses have been introduced also to Geomorphology, and more investigation on this issue is needed.

Another important issue is how to combine quantitative analyses using DEMs and GIS with classic, more qualitative geomorphological approaches based on field work and analogue mapping. Like the case of automated landform classification, complete automation and quantification are sometimes unrealistic. In addition, introducing classic methodology into modern methodology facilitates the utilization of knowledge accumulated before the DEM/GIS era. Appropriate balance of classic and modern approaches needs to be considered in each case study.

References

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