

MODULE – 7 LECTURE NOTES – 1

INTRODUCTION

1. Introduction

Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. Terrain features like drainage basins and channel networks can also be identified from the DEMs. DEMs are widely used in hydrologic and geologic analyses, hazard monitoring, natural resources exploration, agricultural management etc. Hydrologic applications of the DEM include groundwater modeling, estimation of the volume of proposed reservoirs, determining landslide probability, flood prone area mapping etc.

DEM is generated from the elevation information from several points, which may be regular or irregular over the space. In the initial days, DEMs were used to be developed from the contours mapped in the topographic maps or stereoscopic areal images. With the advancement of technology, today high resolution DEMs for a large part of the globe is available from the radars onboard the space shuttle.

This lecture covers the definition of DEMs, different data structures used for DEMs and various sources of DEMs.

2. Definition of a DEM

A DEM is defined as "any digital representation of the continuous variation of *relief* over space," (Burrough, 1986), where *relief* refers to the height of earth's surface with respect to the datum considered. It can also be considered as regularly spaced grids of the elevation information, used for the continuous spatial representation of any terrain.

Digital Terrain Model (DTM) and Digital Surface Model (DSM) are often used as synonyms of the DEM. Technically a DEM contains only the elevation information of the surface, free of vegetation, buildings and other non ground objects with reference to a datum such as Mean Sea Level (MSL). The DSM differs from a DEM as it includes the tops of buildings, power lines, trees and all objects as seen in a synoptic view. On the other hand, in a DTM, in

addition to the elevation information, several other informations are included, viz., slope, aspect, curvature and skeleton. It thus gives a continuous representation of the smoothed surface.

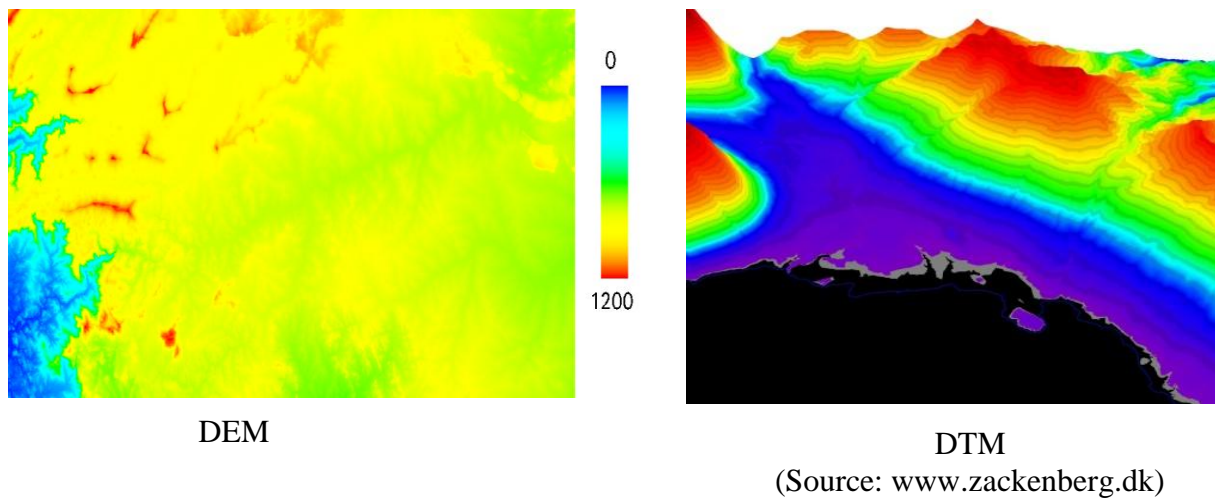


Figure 1. Example of a (a) DEM and (b) DTM

3. Types of DEMs

DEMs are generated by using the elevation information from several points spaced at regular or irregular intervals. The elevation information may be obtained from different sources like field survey, topographic contours etc. DEMs use different structures to acquire or store the elevation information from various sources. Three main type of structures used are the following.

- a) Regular square grids
- b) Triangulated irregular networks (TIN)
- c) Contours

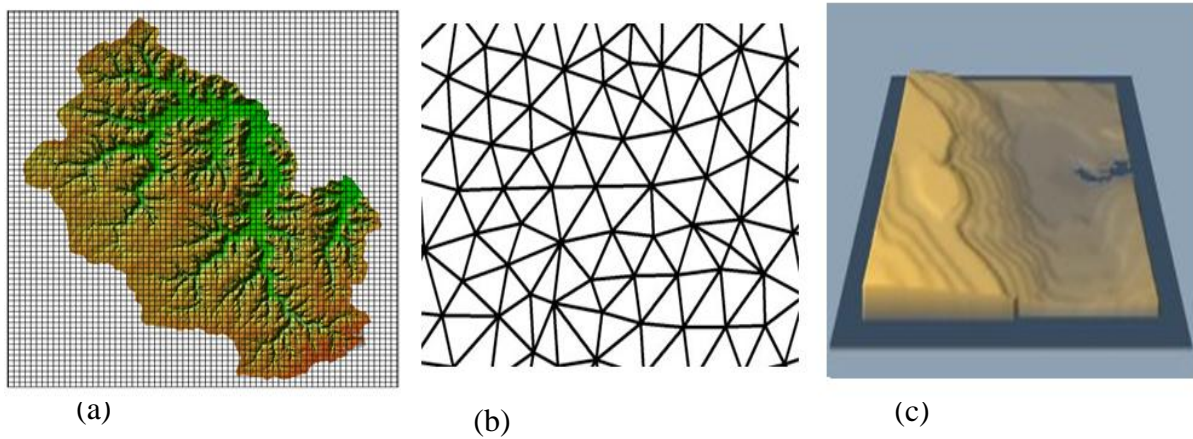


Figure 2. Different types of DEMs (a) Gridded DEM (b) TIN DEM (c) Contour-based DEM

a) Gridded structure

Gridded DEM (GDEM) consists of regularly placed, uniform grids with the elevation information of each grid. The GDEM thus gives a readily usable dataset that represents the elevation of surface as a function of geographic location at regularly spaced horizontal (square) grids. Since the GDEM data is stored in the form of a simple matrix, values can be accessed easily without having to resort to a graphical index and interpolation procedures.

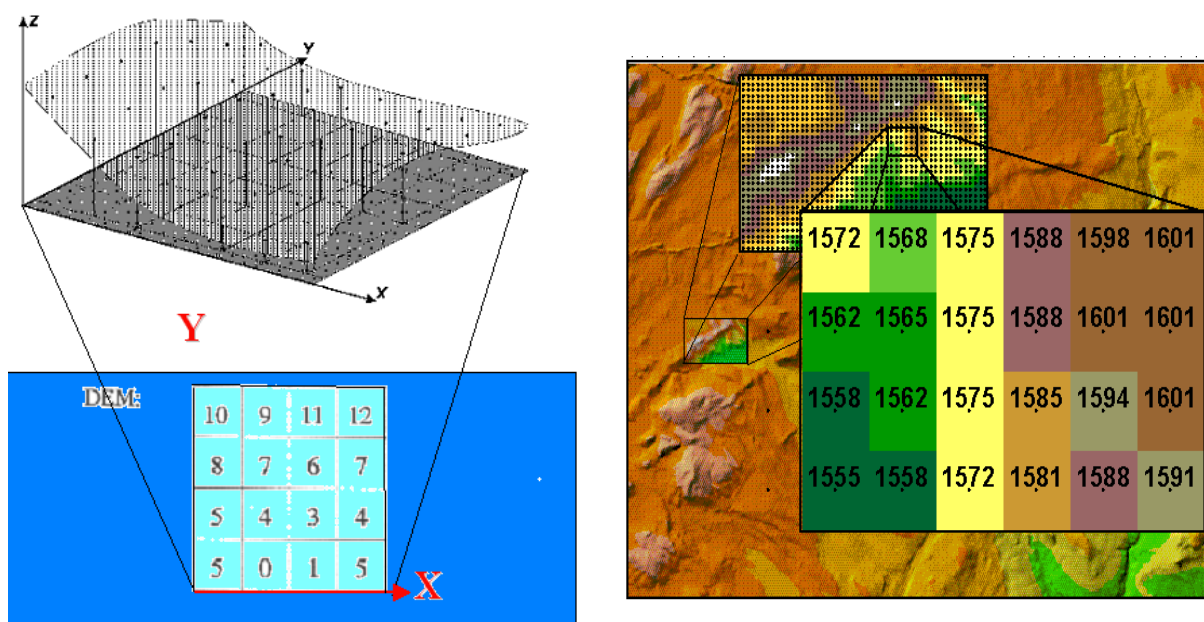


Figure 3. Gridded DEM

Accuracy of the GDEM and the size of the data depend on the grid size. Use of smaller grid size increases the accuracy. However it increases the data size, and hence results in computational difficulties when large area is to be analyzed. On the other hand, use of larger grid size may lead to the omission of many important abrupt changes at sub-grid scale.

Some of the applications of the GDEMs include automatic delineation of drainage networks and catchment areas, development of terrain characteristics, soil moisture estimation and automated extraction of parameters for hydrological or hydraulic modeling.

(b) TIN structure

TIN is a more robust way of storing the spatially varying information. It uses irregular sampling points connected through non-overlapping triangles. The vertices of the triangles match with the surface elevation of the sampling point and the triangles (facets) represent the planes connecting the points.

Location of the sampling points, and hence irregularity in the triangles are based on the irregularity of the terrain. TIN uses a dense network of triangles in a rough terrain to capture the abrupt changes, and a sparse network in a smooth terrain. The resulting TIN data size is generally much less than the gridded DEM.

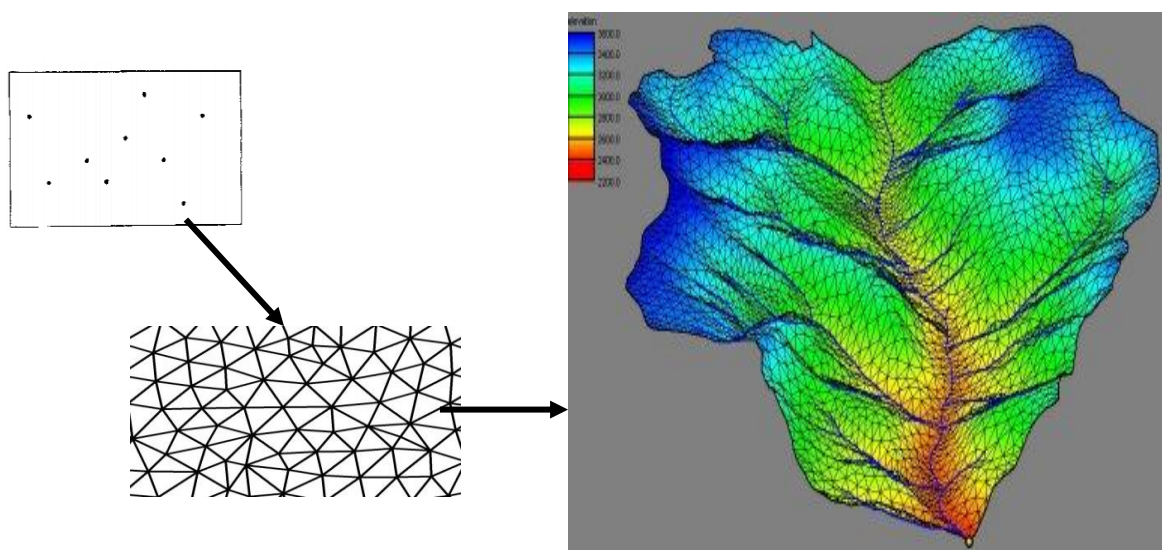


Figure 4. TIN DEM

TIN is created by running an algorithm over a raster to capture the nodes required for the triangles. Even though several methods exist, the Delaunay triangulation method is the most preferred one for generating TIN. TIN for Krishna basin in India created using USGS DEM data (<http://www.usgs.gov>) is shown in Fig.5. It can be observed from this figure that the topographical variations are depicted with the use of large triangles where change in slope is small. Small triangles of different shapes and sizes are used at locations where the fluctuations in slope are high.



Figure 5. TIN for Krishna basin created from USGS DEM data

Due to its capability to capture the topographic irregularity, without significant increase in the data size, for hydrologic modeling under certain circumstances, TIN DEM has been considered to be better than the GDEM by some researchers (Turcotte et al., 2001). For example, in gridded DEM-based watershed delineation, flow is considered to vary in directions with 45° increments. Using TIN, flow paths can be computed along the steepest lines of descent of the TIN facets (Jones et al., 1990).

(c) Contour-based structure

Contours represent points having equal heights/ elevations with respect to a particular datum such as Mean Sea Level (MSL). In the contour-based structure, the contour lines are traced from the topographic maps and are stored with their location (x, y) and elevation information.

These digital contours are used to generate polygons, and each polygon is tagged with the elevation information from the bounding contour.

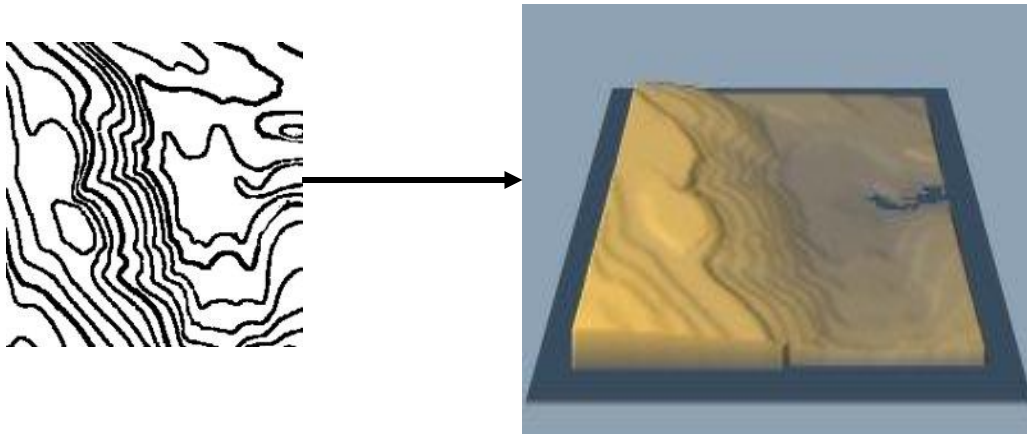


Figure 6. Contour-based DEM

Contour-based DEM is often advantageous over the gridded structure in hydrological and geomorphological analyses as it can easily show the water flow paths. Generally the orthogonals to the contours are the water flow paths.

Major drawback of contour based structure is that the digitized contours give vertices only along the contour. Infinite number of points are available along the contour lines, whereas not many sampling points are available between the contours. Therefore, accuracy of DEM depends on the contour interval. Smaller the contour interval, the better would be the resulting DEM. If the contour interval of the source map is large, the surface model created from it is generally poor, especially along drainages, ridge lines and in rocky topography.

4. Sources of digital elevation data

Elevation information for a DEM may be acquired through field surveys, from topographic contours, aerial photographs or satellite imageries using the photogrammetric techniques. Recently radar interferometric techniques and Laser altimetry have also been used to generate a DEM.

Field surveys give the point elevation information at various locations. The points can be selected based on the topographic variations. Contours are the lines joining points of equal

elevation. Therefore, contours give elevation at infinite numbers of points, however only along the lines.

A digital elevation model can be generated from the points or contours using various interpolation techniques like linear interpolation, kriging, TIN etc. Accuracy of the resulting DEM depends on the density of data points available depicting the contour interval, and precision of the input data.

On the other hand, photogrammetric techniques provides continuous elevation data using pairs of stereo photographs or imageries taken by instruments onboard an aircraft or space shuttle. Radar interferometry uses a pair of radar images for the same location, from two different points. The difference observed between the two images is used to interpret the height of the location. Lidar altimetry also uses a similar principle to generate the elevation information.

Today very fine resolution DEMs at near global scale are readily available from various sources. The following are some of the sources of global elevation data set.

- GTOPO30
- NOAA GLOBE project
- SRTM
- ASTER Global Digital Elevation Model
- Lidar DEM

GTOPO30 is the global elevation data set published by the United State Geological Survey (USGS). Spatial resolution of the data is 30 arc second (approximately 1 Kilometer). The data for the selected areas can be downloaded from the following website.

<http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html>

The Global Land One-km Base Elevation Project (GLOBE) generates a global DEM of 3 arc second (approximately 1 kilometer) spatial resolution. Data from several sources will be combined to generate the DEM. The GLOBE DEM can be obtained from the NOAA National Geophysical Data Centre.

Shuttle Radar Topographic Mission (SRTM) was a mission to generate the topographic data of most of the land surface (56°S to 60°N) of the Earth, which was jointly run by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). In this mission, stereo images were acquired using the Interferometric Synthetic Aperture Radar (IFSAR) instruments onboard the space shuttle Endeavour, and the DEM of the globe was generated using the radar interferometric techniques. The SRTM digital elevation data for the world is available at 3 arc seconds (approximately 90 m) spatial resolution from the website of the CGIAR Consortium for Spatial Information website: <http://srtm.csi.cgiar.org/>. For the United States and Australia, 30m resolution data is also available.

ASTER Global Digital Elevation Model (GDEM) was generated from the stereo pair images collected by the Advanced Space Borne Thermal Emission and Reflection Radiometer (ASTER) instrument onboard the sun-synchronous Terra satellite. The data was released jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). ASTER instruments consisted of three separate instruments to operate in the Visible and Near Infrared (VNIR), Shortwave Infrared (SWIR), and the Thermal Infrared (TIR) bands. ASTER GDEMs are generated using the stereo pair images collected using the ASTER instruments, covering 99% of the Earth's land mass (ranging between latitudes 83°N and 83°S). ASTER GDEM is available at 30m spatial resolution in the GeoTIFF format. The ASTER GDEM is being freely distributed by METI (Japan) and NASA (USA) through the Earth Remote Sensing Data Analysis Center (ERSDAC) and the NASA Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/lpdaac/products/aster_products_table).

Light Detection and Ranging (LIDAR) sensors operate on the same principle as that of laser equipment. Pulses are sent from a laser onboard an aircraft and the scattered pulses are recorded. The time lapse for the returning pulses is used to determine the two-way distance to the object. LIDAR uses a sharp beam with high energy and hence high resolution can be achieved. It also enables DEM generation of a large area within a short period of time with minimum human dependence. The disadvantage of procuring high resolution LIDAR data is the expense involved in data collection.

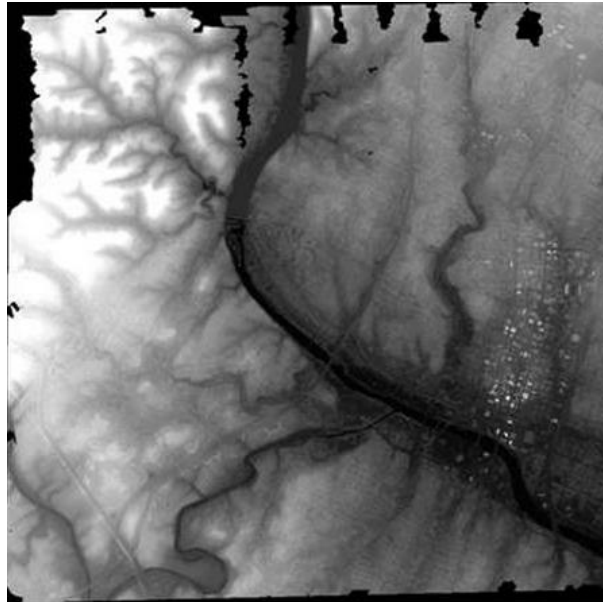


Figure. 7. Lidar DEM at 5m resolution for the downtown area of Austin

(Source: <http://www.crwr.utexas.edu>)