Calculating Topographic Index Using ArcGIS

Hussain Zaydan Ali **Zainab Abdulsattar Abdulateef**
Ministry of Science and Technology / Directorate of Space and Communications
Baghdad-Iraq
E-mail: hussainzayali53@yahoo.com

Abstract

Elevation values are most often used in algorithms to calculate surface derivatives such as slope, aspect, flow direction and upstream contributing area. The topographic index is a function of the upstream contributing area and the slope of the landscape. These features were extracted from digital elevation maps (DEM) obtained from Shuttle Radar Topography Mission (SRTM). Topography is an important control on hydrological processes. This index has become widely used in hydrology, and was used to describe the spatial distribution of the soil moisture and related landscape processes. It controls flow accumulation, soil moisture, distribution of saturation zones, and depth of water table, organic matter, and plant cover distribution.

Key Words: Digital Elevation Model, Topographic Index and Hydrology.

حساب المعامل الطبوغرافي باستخدام ArcGIS

حسين زيدان علي **زينب عبد الستار عبد اللطيف**
وزارة العلوم والتكنولوجيا / دائرة الفضاء و الاتصالات
بغداد–العراق

الخلاصة

تستخدم قيم الارتفاع غالبا في خوارزميات حساب مشتقات السطح مثل الميل ، التوجه ، اتجاه الجريان ومساحة أعلى النهرالمساهمة . يعد المعامل الطبوغرافي دالة لمساحة أعلى النهر المساهمة ، وميل سطح الارض. يمكن استخلاص هذه الخصائص من خرائط الارتفاع الرقمي والذي يتم الحصول عليه من مهمة مكوك الفضاء الراداري الطبوغرافي .تعد الطبوغرافية عامل مسيطر و مهم للعمليات الهيدرولوجية. ان هذا المعامل قد اصبح مستخدما بشكل واسع بالهيدرولوجي ، ويمكن استخدامه لوصف التوزيع المكاني لرطوبة التربة والعمليات على سطح الارض المتعلقة بها. ان المعامل يسيطر على تجمع الجريان، رطوبة التربة، توزيع مناطق الاشباع ، عمق مستوي المياه الجوفية ، المادة العضوية ، وتوزيع الغطاء النباتي.

الكلمات المفتاحية: موديل الارتفاع الرقمي ، المعامل الطبوغرافي و الهيدرولوجي.

Introduction

A DEM offers the most common method for extracting topographic information and enables the modeling of surface processes. DEMs can be generated from contour lines, with radar interferometry data derived, for instance, from Space Shuttle Radar Topography Mapping mission (SRTM), or from stereo satellite data derived from electro-optical scanners such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). From DEM is possible to derive all those attribute like slope, aspect, terrain plan and profile curvature, flow-paths length along hill slopes, upslope contributing area(Tarboton, 1997; Manfreda, 2011). Usually they are the most discriminate input parameter in the model of some physically and spatially distributed phenomena. These are for example hydrological, and geomorphological processes like erosion phenomena, landslides and shallow landslides, river discharge, filtration and infiltration processes, wetness index, etc.(Jenson, and Domingue, 1988; Jenson, 1991; JPL, 1999; Qin 2011). The Shuttle Radar Topography Mission (SRTM) is a joint project between NASA and NGA (National Geospatial Intelligence Agency) to map the world in three dimensions. Flown aboard the NASA Space Shuttle Endeavour February 11-22, 2000, SRTM successfully collected data over 80% of the Earth's land surface. This set is available at 3 arc-seconds (90m) for regions between 60 deg. N and 56 deg. S latitude (Tarboton,1997). A topographic wetness index has been used extensively to describe the effects of topography on the location and size of saturated source areas of runoff generation as follow:

$TI = \ln(a/\tan\beta)$

where

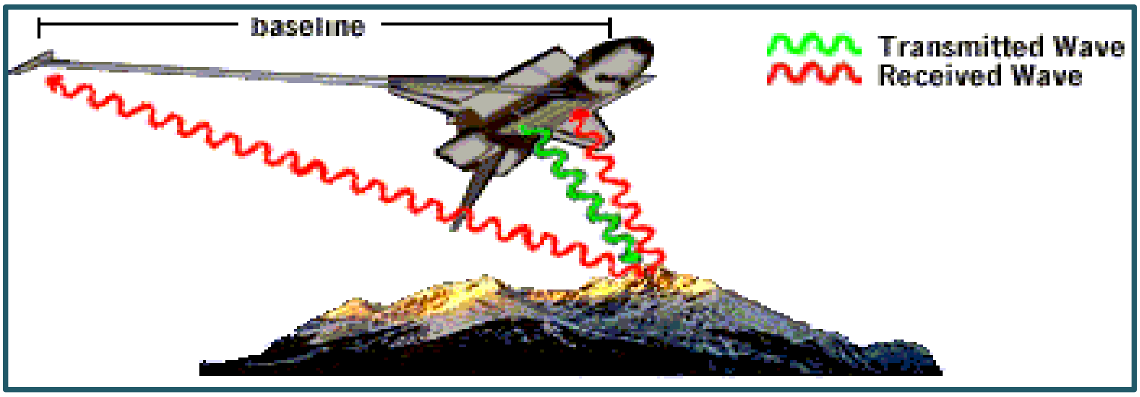
a = upslope contributing area per unit contour length (m);

and $\tan\beta$ = surface slope (rise/run) as a fraction.

This particular equation assumes steady-state conditions and uniform soil properties (i.e., transmissivity is constant throughout the catchment and equal to unity), and predicts zones of saturation where as is large (typically in converging segments of landscapes), β is small (at base of concave slopes where slope gradient is reduced), and transmissivity is small (on shallow soils). These conditions are usually encountered along drainage paths and in zones of water concentration in landscapes. Therefore ,the aim of this study is to calculate the topographic index , which is a function of upslope contributing area and surface slope from digital elevation model.

Materials and Methods

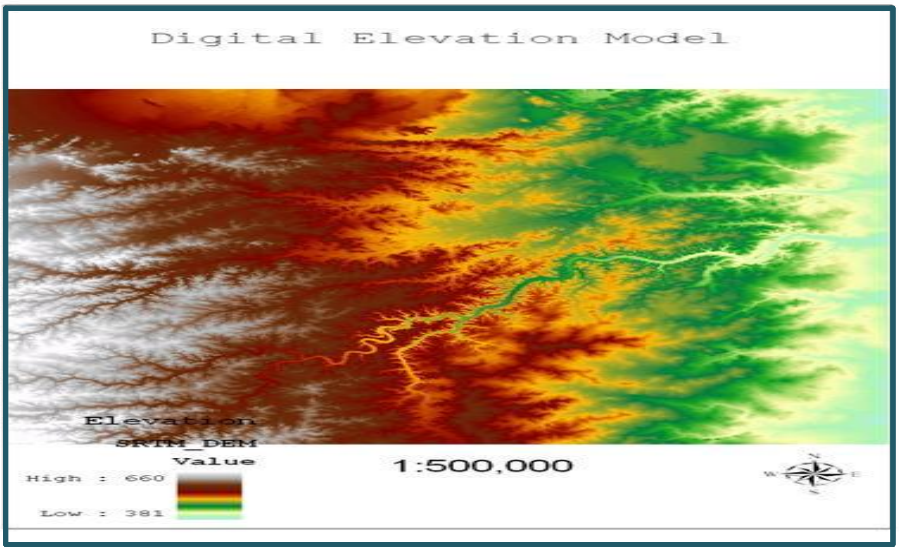
The major data used for the study was the 90m DEM obtained from SRTM, as shown in Fig. (2). Because the unit for spacing between cells in the original



Figure(1) SRTM Single-Pass InSAR Configuration (Bamler, 1999).

SRTM image is specified as Latitude/Longitude, a projected coordinate transformation needs to be applied to the image before computing the slope. Otherwise, the resulting image from ArcGIS would not be correct. While Fig. (3) indicates the range of elevation data in the study area. The DEM-derived slope is generally identified as the maximum rate of change in value from each cell to its neighbors. The output grid from this process should be measured as angle of slope or percent slope or dimensionless slope. Slope is defined as the rate of elevation change in a cell's 3 by 3 neighborhoods(Maidment, 2002). Here we are interested in the degree angle of the slope as defined as the angle defined by rise (vertical distance change) and run (horizontal distance change), see Fig. (4). For continuous case, it is obtained by computing the partial derivative components in x, y direction for each point. In practice, because DEM image is the discrete grid data, the derivative is computed using finite difference method in each cell's neighborhood.Upslope area, a, is defined as the total catchment area above a point or short length of contour(Moore, *et al.*, 1991). The specific catchment area, as, is

Figure(2) Original SRTM Data (JPL. (1999).



Figure(3) Color Coded DEM of the study area.

defined as the upslope area per unit width of contour and is a distributed quantity that has important hydrological, geomorphological, and geological significance (Costa, and Burges, 1994). The specific catchment area contributing to flow at any particular location is useful for determining relative saturation and generation of runoff from saturation excess in models such as TOPMODEL (Beven, *et al*., 1984). Different are methods or algorithms to compute the upslope area. These are based on different interpretation to describe flow directions: D8, Multiple Flow, and D∞ methods. Aspect identifies the down-slope direction of the maximum rate of change in value from each cell to its neighbors. The values of the output grid will be the compass direction of the aspect (expressed in positive degrees from 0 to 360, measured clockwise from the north). The direction of flow is determined by finding the direction of steepest descent from each Cell. Our flow direction model uses the same definition of ArcGIS flow direction. Flow accumulation is computed by accumulating the weight for all cells that flow into each down slope cell. For cells that have no incoming flows, the weights are 1. For those with incoming flows, the weight is 1 plus the sum of weight for each cell flowing into this cell. The Compound Topographic Index (CTI), commonly referred to as the Wetness Index (Moore, *et al*., 1991; Hjerdt, 2004), is a function of the upstream contributing area (flow accumulation) and the slope of the landscape. It is not directly supported in ArcGIS implementation

Results And Discussion

Topographic index can be used to describe the spatial distribution of the soil moisture and related landscape processes. As specific catchment area increases and slope steepness decreases, topographic index and soil moisture content increase. This can lead to higher correlations of soil moisture with topographic index than with specific catchment area and slope steepness. Topographic index controls flow accumulation, soil moisture, distribution of saturation zones, depth of water table, evapotranspiration,
thickness of soil horizons, organic matter, pH, silt and sand content, plant cover distribution. ArcHydro is a model

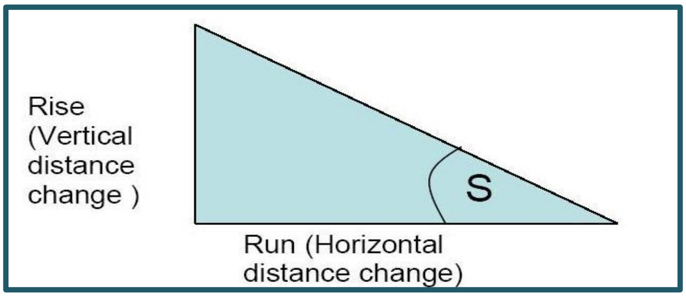


Figure (4) Definition of slope as the angle from horizontal.

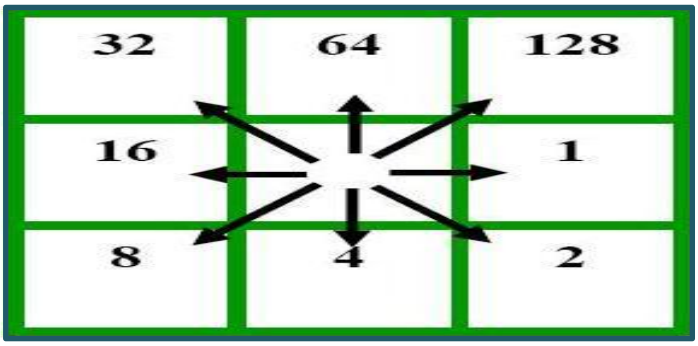
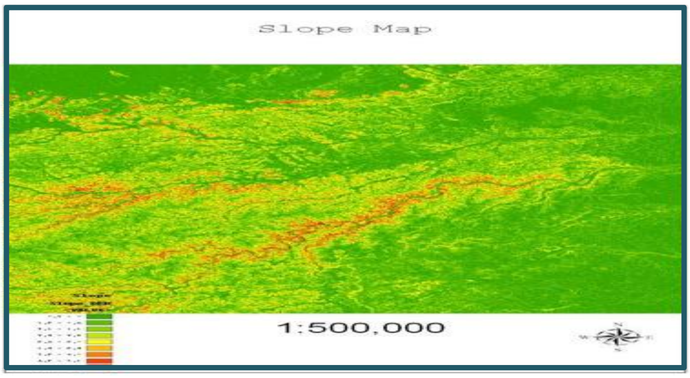
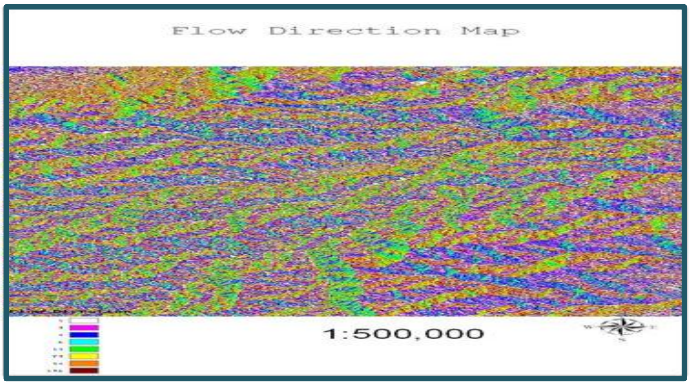


Figure (5) ESRI Flow direction encoding.

developed for building hydrologic information systems to synthesize geospatial and temporal water resources data that support hydrologic modeling and analysis. The model is developed as an Add-on to ArcGIS software. It is used to extract topographical variables from a digital elevation model raster (DEM) for building geometric networks for hydrologic analysis. Fig. (6) to (9) represent the surface derivatives derived from DEM.



Figure(6) Calculated Slope Map of the Studied Area.



Figure(7) Calculated FlowDirection Map of the Studied Area.

Figure(8) Calculated Flow Accumulation Map of the Studied Area.

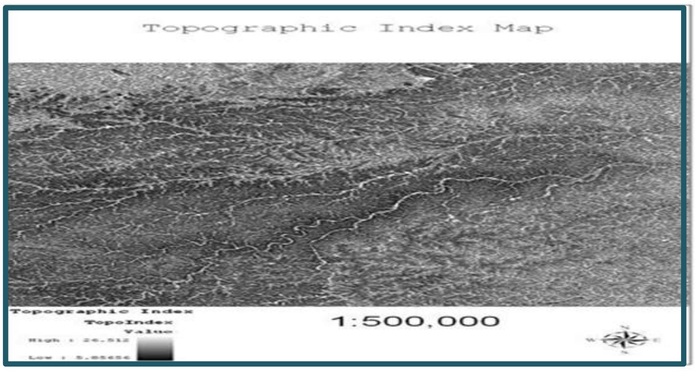


Figure (9) Topographic Index.

With the combination of two or more primary topographic attributes like local slope and drainage area is possible to derive secondary attributes like Wetness Index (WI), or topographic index. The Values of the Index were ranging from 5.85 to 26.5 in the studied area as indicated in Fig. (9).

Conclusions

TWI or wetness index is an important topographic index for modeling the topography-related geographical processes at hillslope or catchment scale. This is because TWI can quantify the control of local topography on hydrological processes and indicate the spatial distribution of soil moisture and surface saturation. The value of TWI is influenced by the algorithms to calculate a and the approximation of $\tan\beta$. Topographic indices are used to map hydrologically sensitive areas (HSA), and are particularly applicable to hydrologic systems driven by shallow subsurface flow. The Compound Topographic Index (CTI), commonly referred to as the Wetness Index, is a function of the upstream contributing area (flow accumulation) and the slope of the landscape. It is not directly supported in ArcGIS implementation.

References

Bamler, R. ,(1999) The SRTM Mission: A World-Wide 30m Resolution DEM from SAR Interferometry in 11 Days, Photogrammetric Week, Wichmann Verlag, Heidelberg. (99) 145-154.

Beven, K.; Kirkby, M. J.; Schofield, N. and Tagg, A. F. ,(1984) Testing a Physically Based Flood Forecasting Model (TOPMODEL) For Three UK Catchments, J. Hydrol. 69(1), 119–143.

Costa-Cabral, M.and Burges, S. J. ,(1994) Digital Elevation Model Networks (DEMON): A Model of Flow Over Hillslopes for Computation of Contributing and Dispersal Areas, Water Resour. Res. 30(6), 1681–1692.

Hjerdt, K. N. ; J. J. McDonnell ; J. Seibert and A. Rodhe, (2004) A new Topographic Index to Quantify Downslope Controls on Local Drainage, Water Resour. Res. 40(5),1-6.

Jenson, S. K., (1991) Applications of Hydrologic Information Automatically Extracted from Digital Elevation Models, Hydrol. Process. 5(1), 31– 44.

Jenson, S. K. and Domingue, J. O., (1988) Extracting Topographic Structure from Digital Elevation Data for Geographic Information Systems Analysis, Photogrametric Engineering and Remote Sensing. 54(11), 1593-1600.

JPL. ,(1999) SRTM Home Page. http://www-radar.jpl.nasa.gov/srtm/.

Maidment, D., (2002) ArcHydro GIS for Water Resources. ESRI Press, Redlands, CA. Rockware, 2008. http://www.rockware.com/.

Manfreda, S.; M. Di Leo and A. Sole, (2011) Detection of Flood Prone Areas Using Digital Elevation Models, Journal of Hydrologic Engineering. 16(10), 781-790.

Moore, I. D.; Grayson, R. B.and Landson, A. R. ,(1991) Digital Terrain Modelling: a Review of Hydrological, Geomorphological, and Biological Applications' , Hydrological Processes. 5(1), 3-30.

Qin, C.Z.; Zhu, A.X.; Pei, T.; Li B.L.; Scholten, T.; Behrens, T. and Zhou, C.H.,(2011) An Approach to Computing Topographic Wetness Index Based on Maximum Downslope Gradient. Precision Agric. 12(10),32–43.

SRTM (Shuttle Radar Topography Mission)FAQ,(2004). http://seamless.usgs.gov/website/seamless/faq/srtm_faq.asp.

Tarboton, D.G. ,(1997) A New Method For The Determination of Flow Directions and Upslope Areas in Grid Digital Elevation Models. Water Resour. Res. 33(2), 309–319.