Watershed delineation using Geographic Information Systems

Dr. Hussain Zaydan Ali
Ministry of Science and Technology-Baghdad-Iraq

Abstract

Water resources have become significant element of national concern, notably in arid and semi-arid regions where they constitute serious geo-environmental issues. A watershed is a geographic area where all rainwater and any other type of precipitation drain into lakes, rivers, or other bodies of water. A watershed or running water infiltration area is the most important unit for management of wetlands and water resources. When creating watersheds, GIS assumes that water will simply flow downhill. Watersheds are physically delineated by the area upstream from an outlet point and are usually separated by ridgelines. Before watersheds can be managed, it is necessary to delineate their boundaries and this was done in ArcGIS using the hydrologic analysis tools.

Keywords: Watershed, GIS, Water resources.

تحديد المستجمعات المائية باستخدام نظم المعلومات الجغرافية

الخبير الدكتور حسين زيدان علي
وزارة العلوم والتكنولوجيا – بغداد – العراق

ملخص

لقد أصبحت الموارد المائية عنصر مهم وذو اهتمام دولي خصوصا في المناطق الجافة وشبه الجافة حيث إنها تكون مفاهيم بيئية خطيرة. يعتبر المستجمع المائي منطقة جغرافية حيث كل التساقط المطري أو أي نوع من التساقط ينساب نحو البحيرات, الأنهار أو الأجسام المائية الأخرى .يعتبر المستجمع المائي أو الماء الجاري في منطقة الارتشاح أهم وحدة إدارية للأراضي الرطبة والموارد المائية. عند تكوين المستجمعات المائية فان نظم المعلومات الجغرافية تفترض بان الماء سوف ينساب ببساطة أسفل المنخفض. يتم تحديد المستجمعات المائية فيزيائيا بمساحة أعلى المنحدر عند نقطة منخفضه والتي تكون عادة مفصولة بواسطة مناطق مرتفعة. قبل أن يتم إدارة المستجمعات المائية فانه من الضروري تحديد حدودها وقد تم باستخدام برنامج نظم المعلومات الجغرافية وأدوات التحليل الهيدرولوجية.

كلمات مفتاحيه: مستجمع مائي, نظم المعلومات الجغرافية, المواد المائية.

Introduction

A watershed is a land area that drains off to a natural body of water or surface water. Any rain that falls on or snow that melts in this land area runs off or drains into that body of water (and some deep percolates into the groundwater). A healthy watershed both stores and filters water before it reaches streams, rivers or lakes. As water percolates into the soil, the soil acts as a filter and removes impurities. Watersheds are the most suitable units to conserve water resources and ecosystems and to plan the sustainable usage of them. Precipitations fall onto the ground discharges on some waterways differ to slope of the land. In all conditions, there is an area, in which running waters infiltrated [٥], [٦].

Watershed is a natural laboratory of hydrology. It can be defined as the area that drains the entire precipitation into a particular stream outlet. In other word it is the catchments' area from which all precipitation i.e. rainfall as well as snow melt water drained into a single stream. It forms naturally to dispose the runoff as efficiently as possible. It is a natural convergent mechanism which consists of a network / branch of streamlets converging into a major stream. Studies of morphometry and hydrologic analysis on different watersheds have been carried out in many parts of the world. Relief
and climate is the key determinants of running water ecosystems functioning at the basin scale [٤].

Watersheds are physically delineated by the area upstream from an outlet point and are usually separated by ridgelines. Before watersheds can be managed, it is necessary to delineate their boundaries and this is done in ArcMap using the hydrologic analysis tools. These tools are available in ArcGIS after one has enabled the Spatial Analyst extension. The Hydrology toolbox can be found in ArcToolbox under Spatial Analysis [١], [٣].

MATERIALS AND METHODS

ArcHydro is a model developed as an Add-on to ArcGIS software. It is used to extract topologic variables from a digital elevation model raster (DEM) for building geometric networks for hydrologic analysis. Most watershed managers use this facility more than other advanced hydrologic analysis for their watershed management requirement [٧].

Study area

One of the most recent near global elevation data sets is the one recorded during the ١١ day Shuttle Radar Topographic Mission based on a C-band interferometric radar configuration (See figure ١). This information, representing the radar reflective surface (which may be vegetation, man-made features or bare earth), was collected in ٢٠٠٠ and is now available at a horizontal spatial resolution of ٩٠ meters [٢].

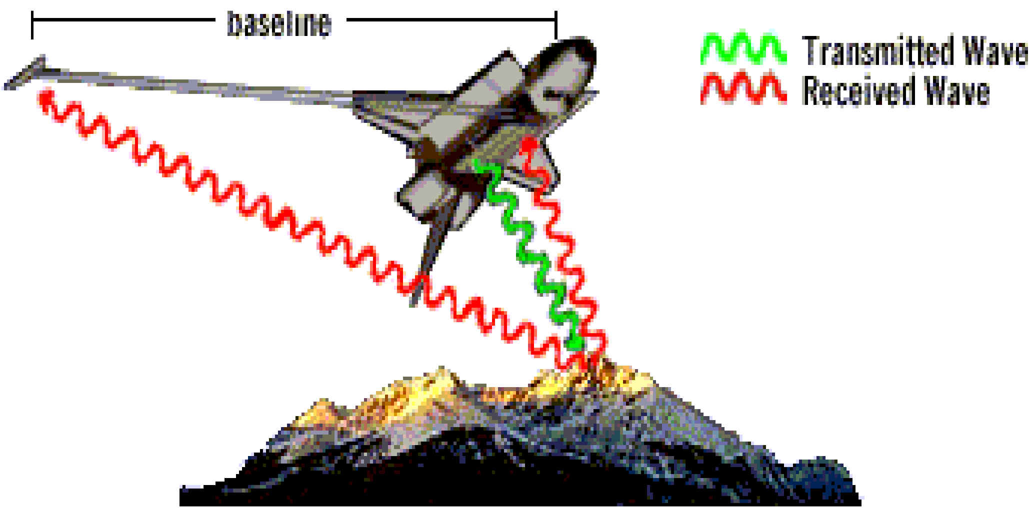

Figure (١) SRTM single-pass InSAR configuration.

Figure (٢) represent the digital elevation model of the study area extracted from

SRTM data.

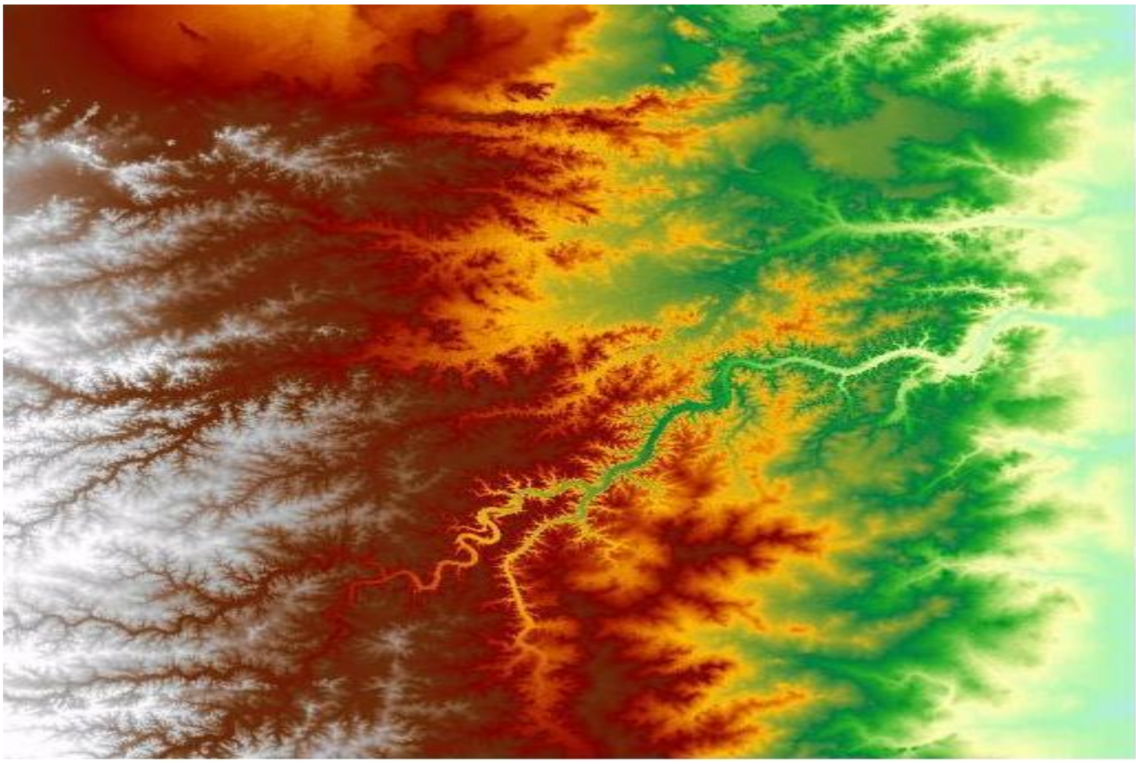

Figure (٢) Color Coded DEM of the study area.

The major data used for the study was the ٩٠m DEM, Arc Hydro Add on/ Extension, ArcGIS ٩,٢. The procedure used for watershed delineation in ArcHydro involves a sequence of steps accessed through the toolbar menus. Sinks are artifact features from DEM creation which are cells in which there is no adjacent downstream cell. Once sinks were filled, flow direction was calculated using the adjusted DEM values and steepest flow path algorithm and eight-direction pour path model. The next step was the calculation of flow accumulation; based on this flow direction raster, a flow accumulation tool was applied that calculates how many cells contribute flow to any given cell. The D٨ algorithm is being used here in this study. It is scripted into ArcGIS ٩,٣, ESRI. The D٨ algorithm [٥] has been the most commonly used method of approximating flow direction on a topographic surface. This model has been incorporated into ArcGIS by ESRI. D٨ method (eight flow directions, Figure ٣), was introduced by O'Callaghan and Mark [٧] and has been widely used by Tarboton [٨], and Jenson [٦]. It is a very simple method for specifying flow directions is to assign flow from each pixel to one of its eight neighbors, either adjacent or diagonal, in the direction with steepest downward slope.

Results and Discussion

Creating a flow direction grid

In order to calculate a drainage network, a grid must be created that contains a code for the direction in which each cell in a surface drains. Flow direction is essential in hydrologic modeling because the flow characteristics of each individual cell can be analyzed together to provide us with information about drainage characteristics at the landscape level. Flow direction grids are creating using the Flow Direction tool. For every ٣x٣ cell neighborhood, the grid processor finds the lowest neighboring cell from the center. Each number in the matrix below corresponds to a flow direction, that is, if the center cell flows due north, its value will be ٦٤; if it flows NE, its value will be ١٢٨; and so on (figure ٣).

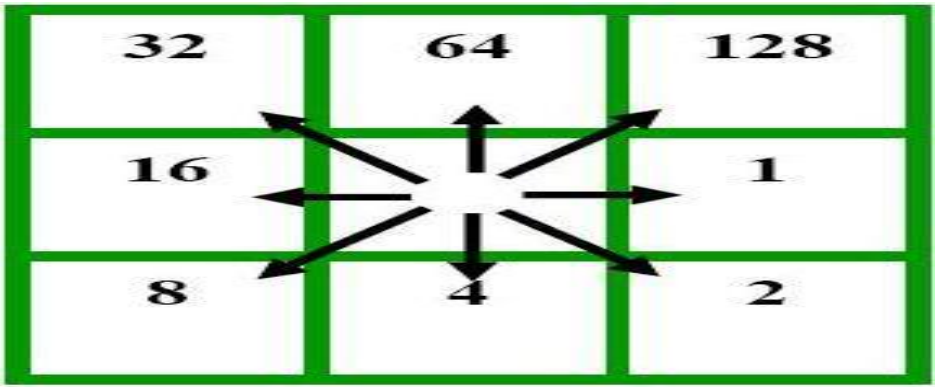

Figure (٣) ESRI Flow direction encoding.

These numbers have no numeric meaning, but are simply a coded directional value that indicates the steepest descent based on elevation values from the DEM. The result is shown in figure (٤).

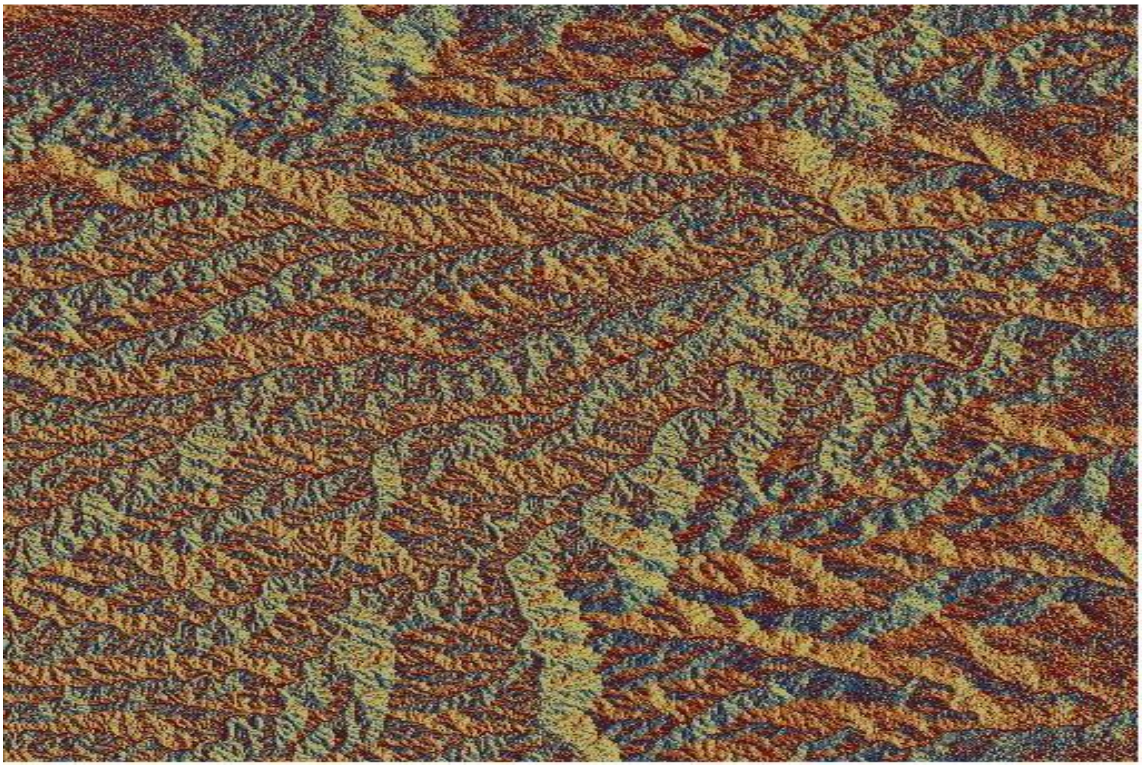
Figure (٤) Calculated Flow Direction Map of the Studied Area.

Create a flow accumulation grid

Watersheds are defined spatially by the geomorphologic property of drainage. In order to generate a drainage network, it is necessary to determine the ultimate flow path of every cell on the landscape grid. Flow accumulation is used to generate a drainage network, based on the direction of flow of each cell. By selecting cells with the greatest accumulated flow, we are able to create a network of high-flow cells. These high-flow cells should lie on stream channels and at valley bottoms. The result is shown in figure (٥).

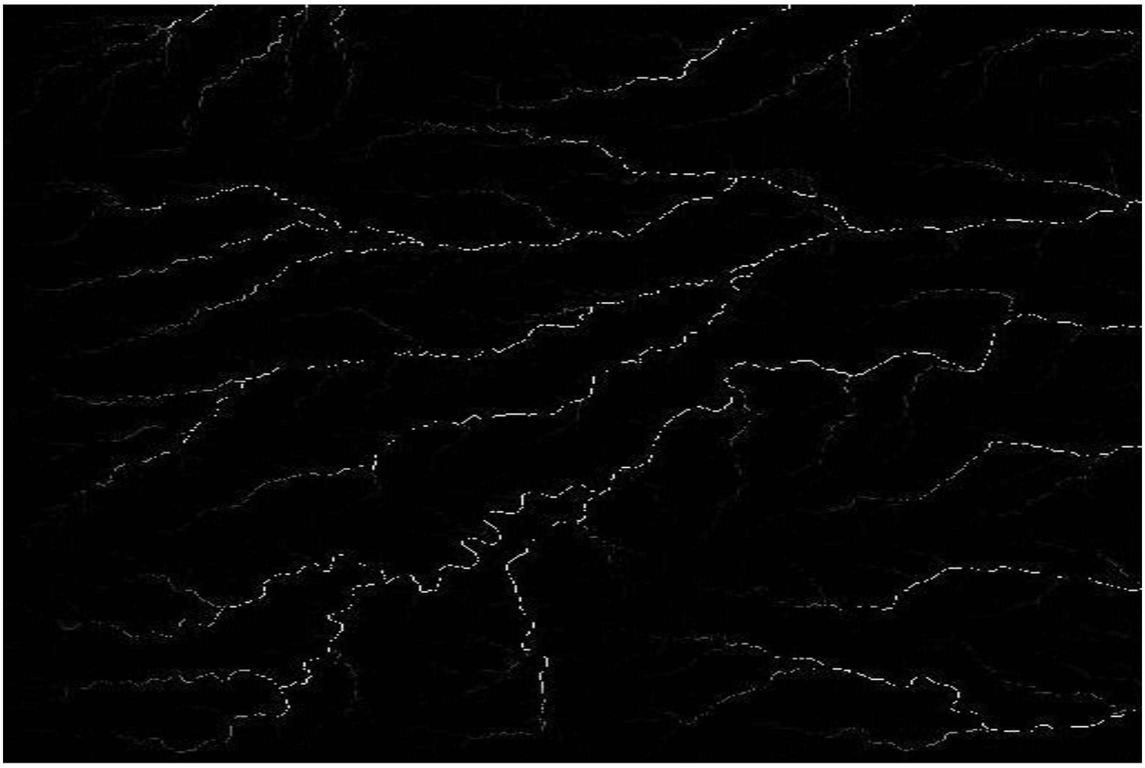

Figure (٥) Calculated Flow Accumulation Map of the Studied Area.

Create outlet (pour) points

In many cases you will already have a shapefile that indicates the locations of hydrometric gauging stations or watershed outlet points. I add this point file to ArcMap. This file is created using ArcCatalog.

Delineating watershed

Pour points should be added as close to the centre of cells as possible. Everything upstream from each point will define a single watershed. The result is shown in figure (٦).

Figure (٦) Watershed Area Layer.

Conclusions

Watersheds, also known as basins or catchments, are physically delineated by the area upstream from a specified outlet point. Watersheds can be delineated both manually on paper maps and digitally in a GIS environment. The process outlined above includes steps for delineating watersheds in ESRI's ArcGIS ٩,٣ software. The watershed is a basic spatial reference unit in hydrology. Topography determines the extent of a watershed. All water generated inside the watershed divide flows toward the stream outlet.

References

[١] ArcHydro Tools for ArcGIS ٩,٢- Tutorial published by ESRI Press, Redlands CA May ٢٠٠٧.

[٢] Bamler Richard, (١٩٩٩). “The SRTM Mission: A World-Wide ٣٠m Resolution DEM from SAR Interferometry in ١١ Days”, Photogrammetric Week ١٩٩٩, Wichmann Verlag, Heidelberg, pp. ١٤٥-١٥٤.

[٣] Maidment, D., ٢٠٠٢. ArcHydro GIS for Water Resources. ESRI Press, Redlands, CA.

[٤] Frissell, C. A., W. J. Liss, C. E. Warren, and Hurley, M. D. (١٩٨٦). A hierarchical framework for stream habitat classification: viewing streams in a watershed context, Environmental Management, ١٠, ١٩٩-٢١٤.

[٥] Jenson, S. K., and J. O. Domingue, ١٩٨٨. Extracting topographic structure from digital elevation data for geographic information system analysis, Photogramm. Eng. Remote Sens., ٥٤(١١), ١٥٩٣–١٦٠٠.

[٦] Jenson, S. K., ١٩٩١. Applications of hydrologic information automatically extracted from digital elevation models, Hydrol. Process., ٥(١), ٣١– ٤٤.

[٧] O’Callaghan, J., and D.Mark (١٩٨٤). The extraction of drainage networks from digital elevation data. Computer Vision, Graphics & Image Processing , ٢٨, ٣٢٣–٣٤٤.

[٨] Tarboton, D.G., ١٩٩٧. A new method for the determination of flow directions and upslope areas in grid digital elevation models. Water Resour. Res., ٣٣, ٣٠.