Geodesy

WATERSHED DELINEATION USING DIGITAL ELEVATION MODEL IN ARCGIS

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ABSTRACT: *The watersheds can be useful in defining the boundaries of the basin or to divide that basin into subbasins. This case study aims to create a boundary that represents the contributing area for a certain pour point. The watershed is delineated from the DEM (Digital Elevation Model) by calculating flow direction and flow accumulation and using them further into the analysis. To achieve this, ArcGIS will be used to perform the analysis leading to watershed delineation.*
Keywords: *watershed delineation; GIS; DEM, flow direction; flow accumulation.*

1. Introduction

The watershed is a portion of land that acts as a catchment for water. In other words, it represents the portion collecting water from rainfall and snowmelt and discharges it into common water bodies. Basically, it is the area that drains surface water between high elevation and low elevation. Because the water moves by gravity, it can be found underground or on the surface. There are multiple ways that water can enter a stream, but a substantial part of it will enter as run-off from the land (land that represents the stream's watershed). There are situations where the water flows to a central depression such as a swamp or a lake where there is no surface water exit.

GIS is a powerful tool in data input, data management and storage, data manipulation and analysis and data output. It is also known as capable of doing an integrated analysis of spatial data for achieving the information required for certain application. Thanks to this feature, GIS has been widely used to enhance the efficiency of watershed management because of the various factors and components in watersheds.

This paper aims to perform a watershed delineation by using Digital Elevation Model in ArcGIS. ArcGIS provides a hydrologic analysis system that can be used with watershed, water resource and land use. The GIS setting is ideally convenient for watershed-based analysis or both obtaining model input and presenting the results of the model. The techniques that are used to determine the watershed delimitation by surface drainage are at long last dependent on topographical information collected in a local neighbourhood on the DEM.

The process of delineation and the analysis of the watersheds can be done in various forms suitable to the necessities of the user and the resources available.

In the past, watershed delineation was mainly performed by using hand delineation. So, the area of the water catchments is set taking account on the topographical landscape of the area. The boundaries of the watershed will pursue major ridgelines around the streams and meet at the point where the water drains out of the watershed, also known as the mouth of the stream.

The first step in the delineation process in GIS is the grid representation of topography, also known as a digital elevation

model. After this, a various additional grids are made, representing multiple hydrologic characteristics of the landscape. A GIS can delineate watersheds from the "hydrologic grids" by detecting all locations within a DEM that are uphill of a discharge. DEM (Digital Elevation Model) is known to be a digital cartographic dataset in XYZ coordinates, that can be represented as a vector or as a raster. The DEM can be derived from various methods, such as photogrammetric methods or contour lines.

The objective of this case study is to define the drainage area of a particular pour point. The process of watershed delineation will be done using GIS tools. In other words, this study aims to show the applicability of GIS as a tool in performing watershed delineation.

2. Methodology and materials

The case study was conducted on a 15 km section of the Pradnik River (total length is 33.4 km). Pradnik River, a left tributary of Vistula, is running through the Krakow-Czestochowa Upland in Lesser Poland Voivodeship (fig. 1).

Using DEM among GIS has proven to be a strong tool since it enables methods for analysing topographic characteristics with quality and operational advantages.

There are multiple methods of collecting DEM data such as aerial photogrammetry, laser scanning, field surveying, GPS and others.

A fast and inexpensive way to analyse hydrological systems is provided by using Shuttle Radar Topography Mission (SRTM) data in GIS-based watershed assessment. The DEM dataset used in this case study is downloaded from USGS that uses SRTM and the resolution of the raster dataset is about 30 m (fig. 2).

To create the final map for the watershed delineation, the following steps were used:
1. The first step in delineating the
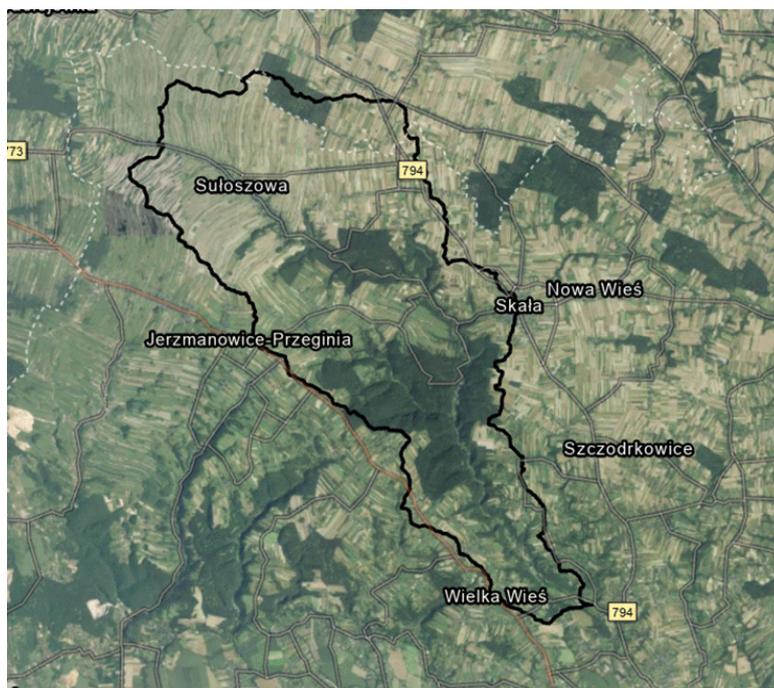
Fig. 1. Study area
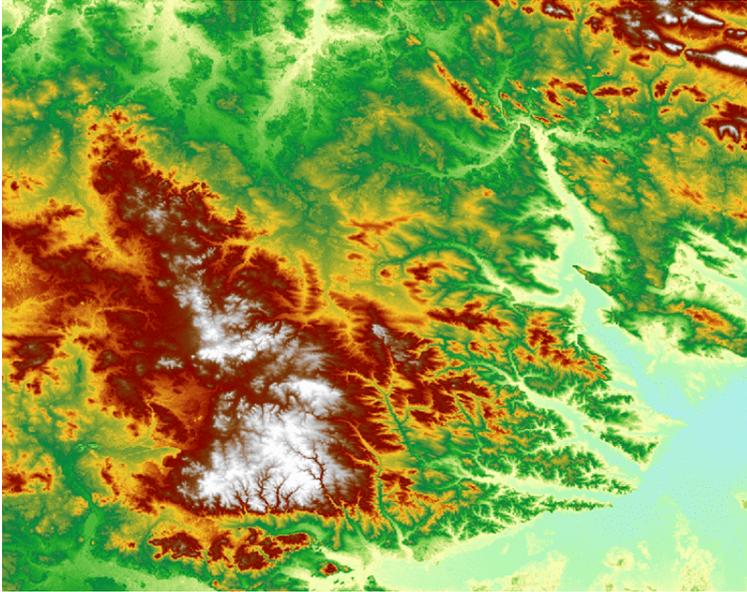
Fig. 2. DEM used

watershed is to prepare the Digital Elevation Model (DEM) of the terrain.

2. Using the Fill operation in the Hydrology menu in the Spatial Analyst Tools to get rid of the small imperfections of the raster.

3. Using the Flow Direction sub menu in the Hydrology menu to calculate the flow direction of the layer.

4. Using the sub menu Flow Accumulation in the Hydrology menu to define the flow accumulation of the layer.

5. Creating the Pour Point that represents the point where the water discharges to the reservoir. In this step, a new shapefile was created, point type, and the pour point was drawn by using the Drawing Tools.

6. Using the sub menu Watershed in the menu Hydrology to create the watershed. The inputs needed are a raster of flow direction and the pour point layer.

7. Converting the Watershed layer from raster format to shp (shapefile) format.

8. Create the final map, displaying the contour of the watershed and the river

layer within the watershed.

2.1. Fill sinks

In order to perform analyses with a DEM, its area must be hydrologically bounded. In other words, each DEM cell must flow into the subsequent downstream cell till the water drains from the edge of the network. The sinks (also known as closed depressions or pits) can easily break this connectivity within the DEM. The pits represent low altitude areas in the DEM, which are surrounded by higher ground that breaks the flow path. The purpose of filling sinks is to build a hydrologically bounded DEM for watershed reviews (fig. 3.a). The easiest method for removing sinks is to increase their altitudes and most likely the best-known method is to use the "Fill sinks" function (fig. 3.b).

2.2. Flow direction

A raster with the flow direction shows the direction of the water coming out of each cell of a filled altitude raster. There are eight different values in the flow direction raster,
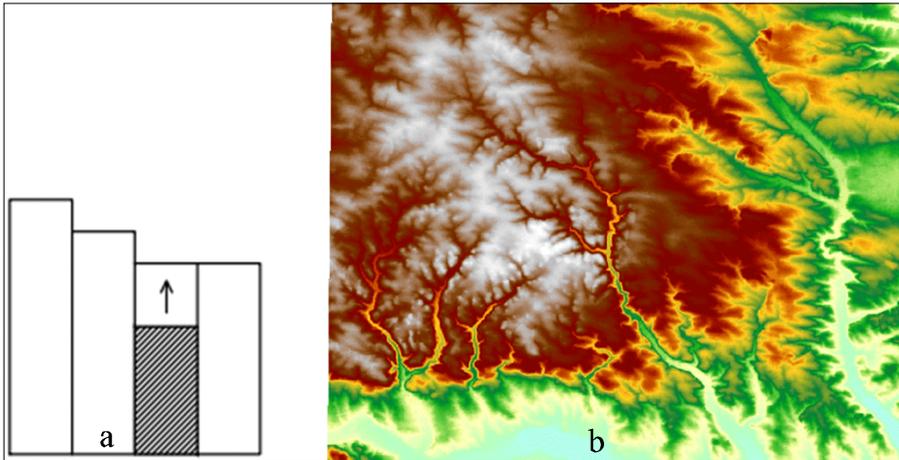
Fig. 3. How filling Figure (a) Filled area sinks work (b)

as shown in fig. 4. Every value shows the direction code indicating the course of the flow outside each cell. The acquainted D8 algorithm was used in the process of setting the direction of flow from each cell to its lower neighbour or neighbours across the topographic surface. This procedure can track and present the flow from every pixel to next pixels using the eight values of the flow angle.

The easiest way to assign flow directions is

to calculate the flow direction from a certain cell to that of the neighbours, till it reaches the steepest slope. The flow direction from each network cell to its downstream neighbour is determined from the filled sinks DEM. The flow direction is determined by reviewing the eight neighbours of a cell and setting the neighbour with the steepest descent slope. After this, the direction resulted is codified like a value in a fresh grid representing the "flow direction" (fig. 5).

The main characteristic of this kind of
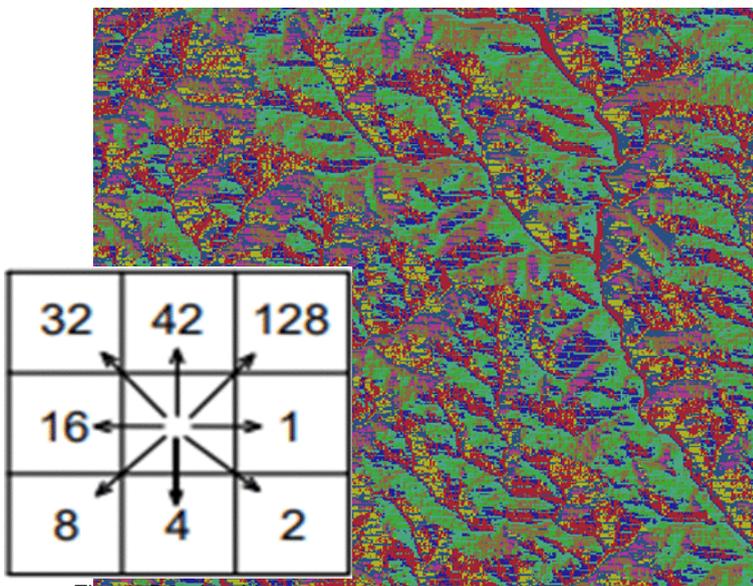
Fig. 4. D8 algorithm

Fig. 5. Flow direction

process is that the flow will always gather in a single point, it can't go in multiple directions. This can be taken as an advantage or a disadvantage, mainly depending on the purpose of the studies. The feature that is most unwelcomed is that the flow is targeted in one of the eight potential directions, that means that the result relies on the grid orientation of the DEM.

2.3. Flow accumulation

After flow direction is calculated for every cell, the flow accumulation can be calculated for the area of interest. When using the grid of flow direction, it is easy to collect the number of upwards cells that drain to any other cell. To build a "flow accumulation" grid, the summarizing can be made for all cells inside a network, where the value from each cell signifies the number of uphill cells draining to it.

In ArcGIS, the function Flow Accumulation uses the accumulated weight of all cells draining into every cell down the output raster to compute the accumulated flow. When there is no weight raster available, a certain weight of one of the cells

is applied to the others, and the equivalent of the cells in the raster output will be represented by the number of cells that drain into each cell (fig. 6).

2.4. Pour point

The pour point (outlet) is the point where the water drains out of a certain area. It's known to be the lowest point throughout the limit of the basin. This point can represent a dam or a gauge station. In this case study, the outlet is a point located in the lowest part of the area where the intersection with another river takes place (fig. 7).

When aiming to proceed watershed delineation, the outlet must have a well-known position. The outlet can be represented as a single cell or a group of cells.

In the end, the catchment is mainly represented by all the cells that are draining via flow directions to the outlet.

2.5. Watershed delineation

Watersheds, known also as basins or catchments, represent the land surface that drains water to the pour point.
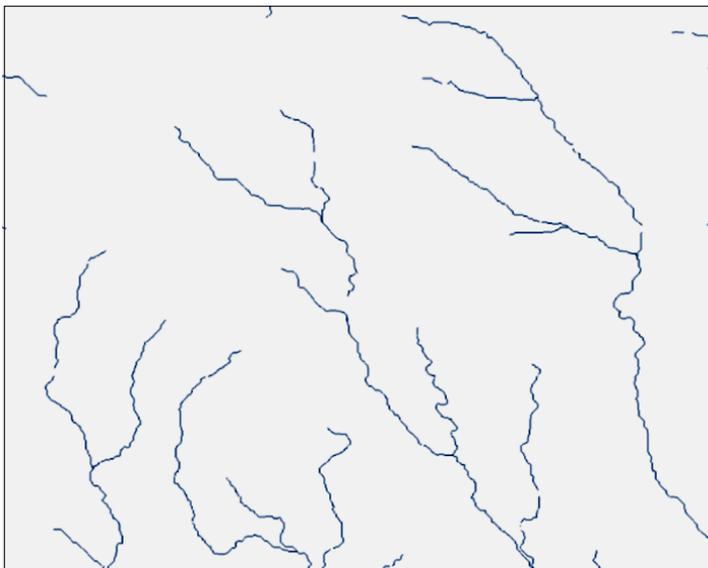
Fig. 6. Flow accumulation
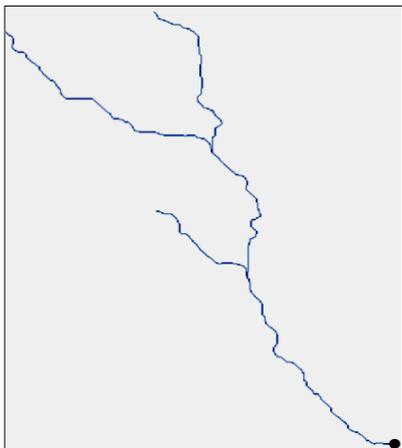
Fig. 7. Pour point

the total surface of flowing accumulation to a certain outlet.

The delineation of the watershed can be done manually with the help of paper maps, or in a digital environment such as GIS. DEM plays an important role in delineating the watersheds in ArcGIS, because it helps recognize the drainage model and demarcate basins (fig. 8).

To establish all the cells that are flowing through a certain output, the flow direction grid must be followed backwards.

After that they can be selected and transformed into a polygon that represents the watershed.

Fig. 8. Watershed delineation

The boundary of the watershed is made from the line drawn above the contours merging the highest altitudes enclosing the watershed. Watershed delineation consists in detecting the drainage area of a point or a batch of points and can be determined from

3. Results

In order to delineate a watershed for this study case it was necessary to follow the next steps: to fill sinks in the DEM, to create the flow direction, to determine flow

accumulation, to define the outlet and the final step, to perform the watershed delineation. The scope in this exercise was to use GIS tools to perform a less labour-intensive delineation. An illustration of the final result can be seen in fig. 9.

The process in GIS starts with a digital elevation model, known to be a grid or a raster of square cells representing the topography.

The first step consists in applying the Fill Sinks function to the DEM to adjust any

Fig. 9. Delineated watershed

4. Conclusions

There are a lot of methods to perform the delineation and the analysis of the watersheds based on the necessities of the user and the resources available. Even if the watershed area is easier to be delineated on a paper map, using GIS for delineations makes the process effortless and more reproducible.

Through this case study the utility of GIS in performing a watershed delineation has been underlined.

depressions that occur in the field. The next step is to create the flow direction aiming the steepest path of the flow using the Flow Direction function. After that, the flow accumulation is determined. This grid archives the number of the cells that are discharged into a particular cell in the grid, resulting in the runoff direction across the watershed. The defined pour point and the raster data of the flow direction are mandatory to perform the watershed delineation.

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