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DRAINAGE DENSITY MAPPING USING ARCGIS IN THE LIWIEC WATERSHED

BY

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Abstract. In recent years, GIS methods have been successfully applied to determine watershed characteristics and shape. Drainage density, the total length of streams per unit area, impacts surface hydrology and reflects climatic effects on terrain. It is associated with hydrologic processes like infiltration, soil saturation, and runoff. This paper aims to enhance processing time and accuracy in determining drainage density using GIS. By applying various GIS functions, a grid network from a digital elevation model is converted to a vector file, revealing the drainage density of the Liwec watershed. Higher drainage density correlates with lower infiltration rates and higher surface flow velocity, often indicating more sediment transport, higher flood peaks, steep slopes, and low agricultural potential. The study's findings support future management planning in the area.

Keywords: digital elevation model, watershed, GIS, drainage density, hydrology.

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1. Introduction

One of the most significant criteria for every hydrological inquiry is drainage basin analysis. It gives useful information on the drainage system's quantitative description, which is an essential part of a basin's description.

Drainage density is the drainage basin parameter calculated in this study. The total length of channels per unit represents drainage density, and it defines the drainage spacing and dispersion in a watershed. The ratio that describes density may also be stated to indicate the number of rivers in the watershed that are required to drain the basin.

Drainage density has been studied in connection to a variety of factors in previous decades, including soil erosion and erodibility, along with sediment output. It is often collected as one of the areal factors in morphometric analysis in several research. Drainage morphometry has been proven to be particularly useful in determining the physical qualities of soil in the catchment, as well as the landforms and erosion processes that occur there. Infiltration, sheet erosion, soil saturation, overland flow, and their interconnections, which influence the development of runoff and sediment, are all directly connected to drainage density. The drainage density of a watershed is at the core of the climate, geomorphology, and hydrological balance.

The drainage density has a major influence on flood peaks, which may be classified into direct and indirect impacts (Merz and Blöschl, 2008). The control related with the length of the river system and hillslope routes is one of the most substantial direct impacts. Because the stream network has a larger flow velocity, drainage density has a considerable impact on the concentration time and hence the peak flow size. The interrelationship of landscape development, soil formation, erosion, and floods may provide an indirect control (caused by climate and regulated by geology).

Different methodological techniques have been used to determine drainage density throughout the previous fifty years. Even though field mapping is widely recognized as the most reliable method of determining stream networks, it is sometimes difficult, particularly for vast and isolated basins in the high-altitude mountainous areas. GIS and remote sensing technologies, together with data from multiple sources, have enabled increasingly advanced image analysis and spatial data processing in past few decades. Remote sensing of satellite data, according to many studies, is a highly useful approach for morphometric analysis at the catchment scale that is both timesaving and reasonably accurate.

With the introduction of GIS tools and techniques, as well as digital elevation models (DEMs), processes to map or extract stream network from DEMs have evolved. As a result of these advancements, most of the information obtained from topographic maps may now be collected digitally using GIS. DEMs that determine flow networks have been a helpful data source for the delineation stream networks and sub-watersheds because they provide a good

substitute for stream or drainage networks. GIS-based approaches are increasingly being utilized to delineate streams and basins, as well as derive geomorphometric characteristics to be used in hydrologic models.

The goal of this research is to perform an evaluation of drainage density using specific GIS tools in a location where digital data are already accessible.

2. Study Area

This paper's analysis is based on research and data collected from the Liwiec catchment, located in Poland (Fig. 1). Liwiec River flows in the plains of Southern Podlaskie Voivodeship and central Masovian Voivodeship and it is tributary of the Bug River. The total length of the river is 142 km, and its total basin has 2763 km². The study was conducted on about 50 km sector of Liwiec River.



Fig. 1 – Study area

3. Materials and Methods

Digital elevation data is now accessible from a variety of sources, including Google Earth Images, The Shuttle Radar Topographic Mission (SRTM), the United States Geological Survey (USGS), and the Advanced Spaceborne Thermal Emission and Reflect Radiometer (ASTER). The topography parameters as well as the drainage network extraction were both done using the USGS Digital Elevation Model at a resolution of about 30 m (Fig. 2). The DEM used was reprojected to the coordinate system ETRS/Poland CS92 (EPSG:2180) and clipped to the size of the research area.

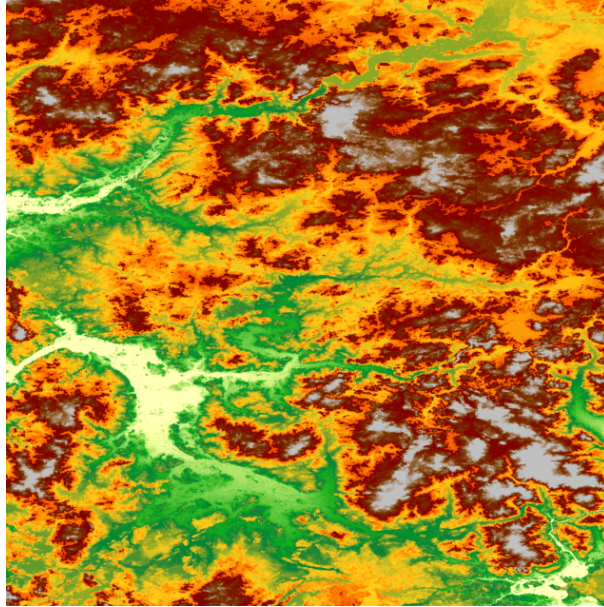


Fig. 2 – DEM used

3.1. Fill sinks

A DEM's area must be hydrologically constrained in order to successfully perform analyses with it. In other words, until the water drains from the network's edge, each DEM cell should flow towards the next downstream cell. Sinks (pits) can easily disrupt the DEM's connection. In the DEM, the pits depict low-altitude locations surrounded by higher land that disrupts the flow pattern. The goal of filling sinks is to provide a DEM that is hydrologically bound for watershed evaluations. The simplest approach for eliminating sinks is to raise their heights, and the "fill sinks" feature is perhaps the most well-known (Fig. 3).

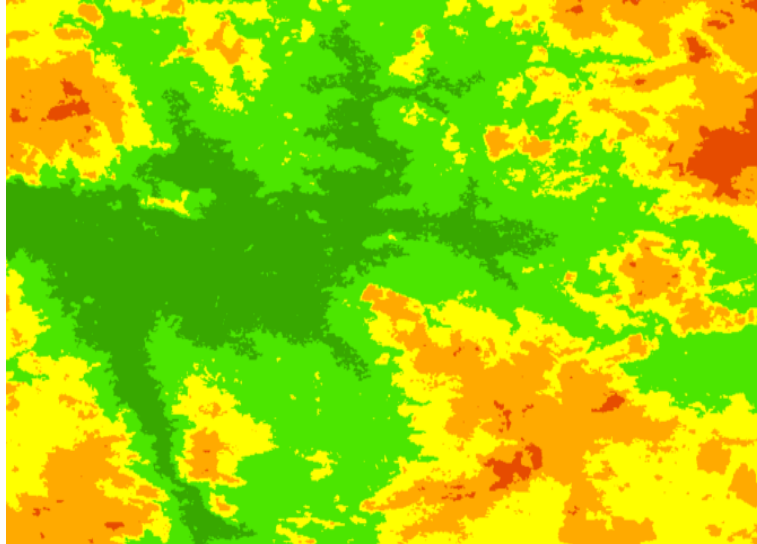


Fig. 3 – Filled sinks

3.2. River network

The drainage networks are extracted from DEM using gravity, which assumes that water would flow from higher to lower elevation through the sharpest descent and that there will be no interception.

After filling the sinks in the digital elevation model, several geoprocessing tools in ArcGIS were used to derive the drainage network of the Lewiec basin, such as flow direction, flow accumulation, stream links and stream order.

The direction of the water flowing from each cell is shown by a raster with the flow direction. The direction code for each value indicates the path outside each cell. The well-known D8 method was used to determine the flow direction from every cell towards its lower neighbor or neighbors over the topographic surface. Using the eight flow angle values, this technique can monitor and report the flow from one pixel to the next. The simplest technique to designate flow direction is to compute the flow direction from one cell to the next until the sharpest slope is reached (Fig. 4).

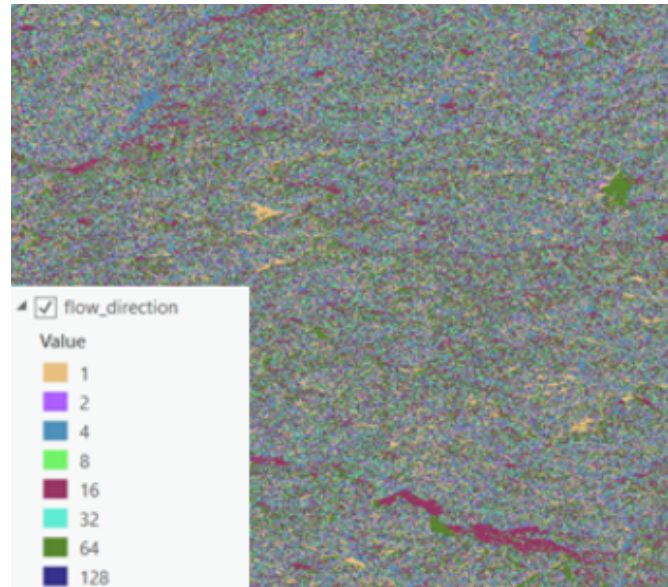


Fig. 4 – Flow direction

After calculating the flow direction for each cell, the flow accumulation for the region of interest may be derived. Using the flow direction grid to check the number of uphill cells that flow to any other cell makes the task way easier. To create a flow accumulation grid, summing all cells within a network is possible, with the value of each cell indicating the number of upwards cells flowing to it (Fig. 5).

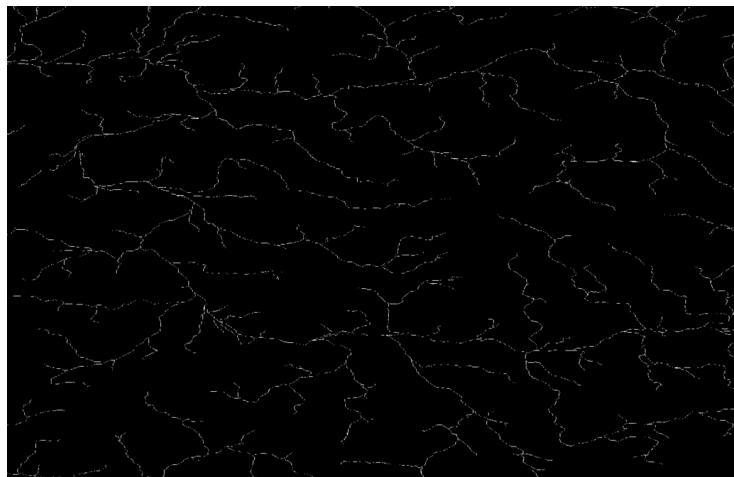


Fig. 5 – Flow accumulation

Based on (Strahler, 1964), the output of this approach may be used to create a stream/drainage network grid with stream order. Strahler's categorization scheme classifies a section with no tributaries as a first-order river. A second-order stream segment is formed when two first-order stream segments meet, and so on (Fig.6).



Fig. 6 – Stream order

3.3. Watershed delineation

The land surface that flows water to the discharge point is known as a watershed. The watershed's border is defined by a line drawn above the outlines that joins the watershed's highest heights. Watershed delineation is the process of determining the drainage area of a single point or a group of points based on the total area of flowing accumulation to a specific exit.

The delineation of the catchment can be performed manually using paper maps or digitally using GIS. DEM plays a significant role in delineation watersheds in ArcGIS. The flow direction grid must be tracked backwards to determine all the cells that are flowing via a certain output. They may then be picked and turned into a polygon representing the watershed (Fig. 7).



Fig. 7 – Watershed delineation

3.4. Drainage density

The length of a river channel per unit area of a drainage basin is referred to as a drainage density. The drainage density (Dd) measurement yields a numerical representation of landscape segmentation and runoff potential. Both permanent and intermittent rivers/tributaries must be included when calculating drainage density for a catchment region.

After specifying the threshold, a grid network was generated from the original DEM using the GIS functions “flow direction” and “flow accumulation”. With the help of a basic raster-to-vector GIS tool, the grid network was eventually turned into a vector file. Finally, the unit drainage density (defined as the total network length per unit area) was calculated.

4. Results

Drainage density is a helpful numerical measure of landscape fragmentation, runoff potential, the area’s infiltration capacity, plant cover, and climatic condition (Chorley, 1969).

It is feasible to quantitatively examine the link between drainage density and any other geographical variable using the approach of measuring drainage density within a fixed unit cell size. The drainage density in this study was calculated using a digital river network that was generated from a digital elevation model.

The Dd map reveals a general pattern of greater values along the river network’s major branches and lower values on top of hills and along ridges separating successive channels (Fig. 8).

Lewiec watershed studied covers an area of 1145 km², and the total length of the channels is 482,58 km. The research shows that GIS improves the evaluation and calculation of drainage density. Liwiec watershed has low drainage density of 0,42 km/km², describing a coarse drainage system.

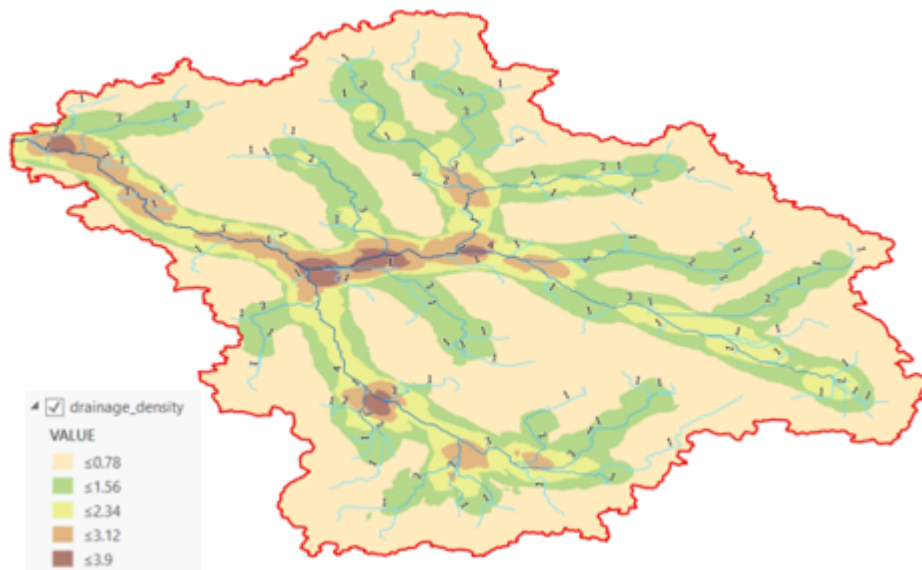


Fig. 8 – Drainage density

5. Conclusions

Drainage density is a well-known characteristic of watershed morphology that influences river flow development. As a consequence, it has the potential to alter the frequency pattern of surface flows.

The low value of drainage density in the Liwiec watershed indicates low basin relief with dense vegetation cover and permeable surface materials, resulting in lower runoff potential.

The assessment of drainage density gives a valuable numerical estimate of landscape subdivision and runoff capacity to hydrologists. Drainage density is perceived as an essential index since it is a measure of network structure and reveals the ratio between the erosive strength of surface runoff and the resistance of subsurface rocks and soils.

Calculating the drainage density is important in overland flow processes because it has an effect on the severity of floods, it is therefore very useful in theoretical flood prediction.

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ANALIZA DENSITĂȚII DE DRENAJ FOLOSIND ARCGIS ÎN BAZINUL
HIDROGRAFIC LIWIEC

În ultimii ani, metodele GIS au fost utilizate cu succes pentru a determina caracteristicile și forma bazinelor hidrografice. Densitatea de drenaj, adică lungimea totală a pâraielor pe unitatea de suprafață, influențează hidrologia de suprafață și reflectă efectele climatice asupra terenului. Aceasta este legată de procese hidrologice precum infiltrarea, saturația solului și scurgerea apei. Această lucrare își propune să îmbunătățească timpul de procesare și acuratețea în determinarea densității de drenaj folosind GIS-ul. Prin aplicarea mai multor funcții GIS, o rețea de grilă dintr-un model digital al elevației este transformată într-un fișier vectorial, indicând densitatea de drenaj din bazinul hidrografic Liwiec. O densitate mai mare a drenajului este asociată cu rate mai scăzute de infiltrare și o viteză mai mare a scurgerii de suprafață, indicând adesea un transport mai mare de sedimente, vârfuri de inundații mai ridicate, pante abrupte și un potențial agricol scăzut. Concluziile acestui studiu susțin planificarea viitoare a managementului în această zonă.