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Watershed Delineation from DEM by Model Builder in ArcGIS

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Abstract

The water level fluctuates continuously at local, continental, and global levels. Consequently, remote sensing offers extensive data for assessing the location, extent, and variability of change, including the causes and changes that occur and the reactions and repercussions of change. Considering the significance of the water level, this research focuses on describing the methodology and process to determine the water level in the Al-Zab River. This study offers a straightforward and cost-effective approach and procedure for precisely delineating flood danger regions in the Al-Zab River basin utilizing a geographic information system and the existing database. The proposed strategy for regionally dispersing flood risks combines the size of prior flood events and the geographical distribution of their causes. This approach allows for the calculation of a weighted score for each participant's causative component. The regional distribution of the flood hazard intensity level is obtained by categorizing the spatial patterns of the flood hazard index. The 30-m digital elevation model with a high resolution was utilized to evaluate the water level in this river. Furthermore, this work is considered the first step towards enhancing information management in the studied area. This study mainly aims to explain how to outline and define watersheds using ArcGIS for flood mapping.

Keywords: Watershed; Al-Zab River; DEM; Flood Danger; RS and GIS; SRTM.

1. Introduction

Water is a key component in maintaining a pristine natural environment and a major driver of economic and social development. Among all the renewable resources available, water is the most crucial. The assessment, conservation, development, and management of water are of great importance to all those who manage, facilitate, and utilize it, considering its importance to all life-sustaining activities. A connection exists between the expansion and management of water resources and other human-induced. All of humanity has a vested interest in preserving the natural ecosystems on which humans depend, and they range from issues of basic human well-being (food, security, and health) to issues of economic growth (industry and energy). Water supplies in rivers, lakes, and groundwater storage are decreasing as a result of a combination of low precipitation and high evaporation in many regions. Meanwhile, the increase in pollution is negatively affecting ecosystems and the health, lives, and livelihoods of those who lack access to adequate, safe drinking water and basic sanitation. The rise in the frequency of catastrophic events is likely evidence of underlying shifts that are affecting water supplies globally, particularly in India. Thus, this precious resource should be conserved and used optimally, which is crucial for sustainable development. Therefore, global food production must increase by approximately 3% every year to fulfill current and future food needs.

The Food and Agriculture Organization estimated that the amount of potentially usable farmland worldwide is approximately 3,200 million hectares, compared with the current overall harvested area of approximately 1,600 million

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hectares. In the future, water management is anticipated to have a major effect on the quality of life and the very existence of human civilization. As a significant natural calamity, flooding affects many regions of the globe, even wealthy nations. Thousands of lives are lost, and billions of dollars are damaged or destroyed annually as a result of this natural disaster. These risks and losses may be averted and mitigated by offering people accurate information about the flood risk using flood maps [1]. Maps of flood disasters are essential for ecological studies, emergency responses, and insurance premium calculations [2]. In general, flood disaster management comprises four phases: anticipation, planning, avoidance, mitigation, and damage assessment [3]. Studies showed that remote sensing (RS) and geographic information system (GIS) approaches are beneficial to each of these phases. The capacity to deliver timely and accurate flood information is/will be vital in reducing flood-related damages, considering that climate change and unpredictability are expected to exacerbate the flood issue in the future [4]. Milly et al. [5] examined the different ways in which RS and GIS methods have been effectively used for flood control. The last research should help scientists in developing countries truly appreciate the potential use of these tools in flood management, where RS and GIS approaches have traditionally been used primarily for flood control.

Karim et al. [6] conducted a simulation of the dam breach failure and the flood wave propagation, which is necessary for assessing flood hazards to provide precautions. In the present study, a two-dimensional HEC-RAS model was used to simulate the flood wave resulting from the hypothetical failure of the Al-Udhaim Dam on the Al-Udhaim River, Iraq, including the propagation of the resulting dam-break wave along 100 km downstream of the dam site for the overtopping scenario. Alwan et al. [7] used the digital elevation model (DEM) or three-dimensional surface to model and analyze the water flow in the Tigris River. Then, Khayyun et al. [8] simulated the catchment area's runoff of Hemren dam reservoir within the middle River Diyala reach beyond Derbendi Khan dam in the northeast of Iraq using the Soil Water Assessment Tool (ArcSWAT2012) model integrated with RS and GIS.

Geospatial Information Systems (GIS) are used effectively to depict the area of flooding and to evaluate flood maps to develop flood risk assessment maps and damage [9–11]. GIS should be applied in conjunction with a hydraulic approach to predict the flood profile for a certain return time. DEM is the most essential input for hydrologic models to produce flood danger maps. Watershed computation accuracy is directly proportional to the size and accuracy of topographic maps. In this investigation, DEM data from the Shuttle Radar Topography Mission was used [12].

1.1. Advantages of Flood Maps

The advantages of Flood maps are as follows [13]:

- Offer a foundation for land use development and land use limits;
- Inform stakeholders and the public in general about flood danger and flood risk;
- Better educate disaster management techniques;
- Facilitate community preparation and mitigation methods;
- Empower individuals and property owners with the knowledge to make informed choices about flood risks;
- Promote adaptation to climate change.

1.2. Types of Flood Maps

Although flood mapping procedures are very flexible, the Federal Flood Mapping Specifications Series defines four primary kinds of mapping that encompass a broad range of mapping operations. They include the following [14, 15]:

- ***Inundation Maps:*** These maps depict the extent of actual floodwaters or the projected reach of floodwaters during floods of different intensities. They are meant to help in the administration of disaster preparation strategies for communities in floodplains and flood-risk zones.
- ***Flood Hazard Maps:*** Engineering maps show the findings of hydrological and hydraulic research, such as the size of a regulated design flood. These maps serve regulatory purposes associated with land use planning and flood mitigation.
- ***Flood Risk Maps:*** Flood hazard or evacuation demarcation maps show other socioeconomic factors, including the possible loss or property vulnerability levels. These maps illustrate the social, economic, and environmental effects of a prospective flood disaster on towns.
- ***Flood Awareness Maps:*** The purpose of communication maps is to educate the community about the history of flooding in their areas, the likelihood of future floods, and the threats that any such flooding would bring to residential homes, businesses, infrastructure, and human existence. These maps involve a variety of extra content types, including pictures, text descriptions, and illustrations.

2. Study Area

Al-Zab is an Iraqi city belonging to the district of Hawija, 35 km north of Baiji. Al-Zab was considered a sub-district in 1960. This city includes 28 villages in addition to the center of the district. Al-Zab is administratively affiliated with the Hawija district, which is located at the confluence of the Tigris and Little Zab rivers. On the opposite side of the river is the city of Al-Zawiya (Figure 1).

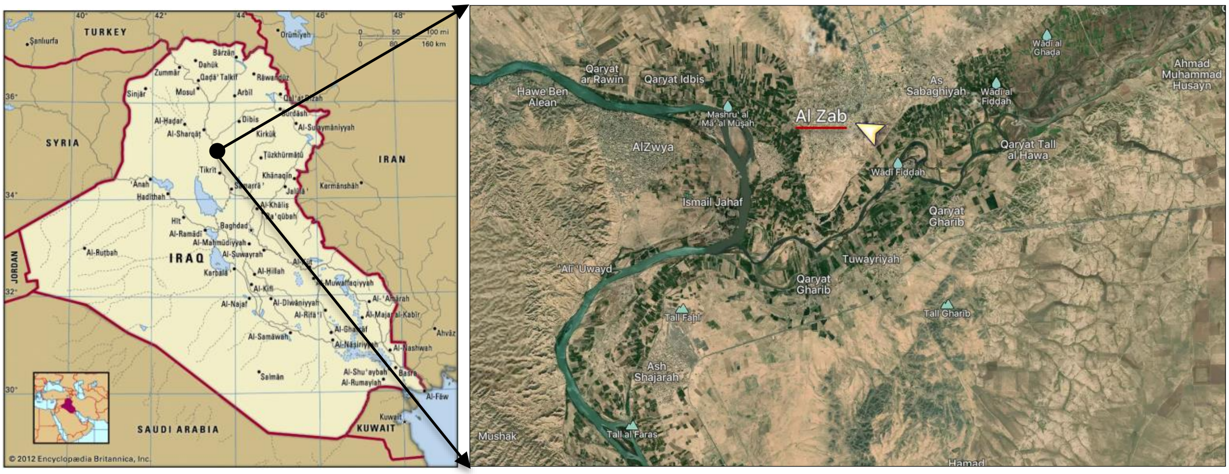


Figure 1. Location of the study area

3. Research Methodology

The initial stage in the approach is to outline a watershed polygon mesh utilizing DEM tiles and many techniques first from the Spatial Analyst toolbox's hydrology module. The search option allows for the location of all of the tools and functions used during the method. The first step in the watershed delineation process is to identify the locations of flow accretion within the research area, as shown in Figure 2.

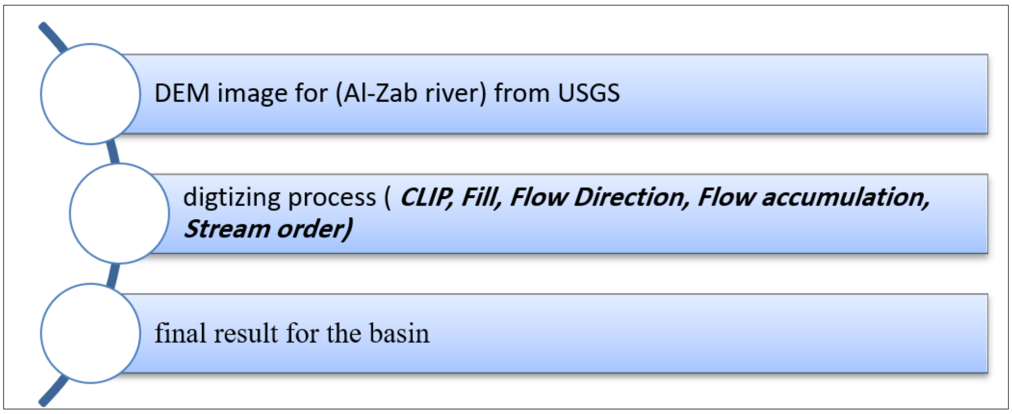


Figure 2. Locations of accretion of flow within the research area

3.1. Hydrology Tools

These technologies are used to simulate the flow of water over a surface. Quite a few sectors, including urban and regional development, farming, and tree-planting, may benefit from knowing the pattern of the Earth's surface. These subjects need a comprehension of how water moves over a region and how alterations to that region might impact that flow. Identifying the source and destination of the fluid may accurately represent water flow. How to extract hydrologic information from a DEM, definitions of key terms associated with drainage systems and surface processes, examples of implementations of hydrologic analysis, and how to use hydrologic analysis functions to simulate the flow of water along a surface are all covered below [16].

3.2. Delineation

A watershed is a gradual-incline region that contributes to the flow of water through intensive drainage. The Hydrology toolset in the Spatial Analyst toolbox, together with a DEM, may be used to draw a boundary around this area.

4. Results and Discussion

4.1. Fill

All sinks from the DEM layer can be removed using the fill feature of the Hydrology toolbox (Spatial Analyst). The DEM layer should be used as the input to the function. The file directory where the final layer will be saved should be specified. When the direction of flow between two vector cells is unknown, the system has a sink or fault (ArcGIS Resources, 2013) (Figure 3).

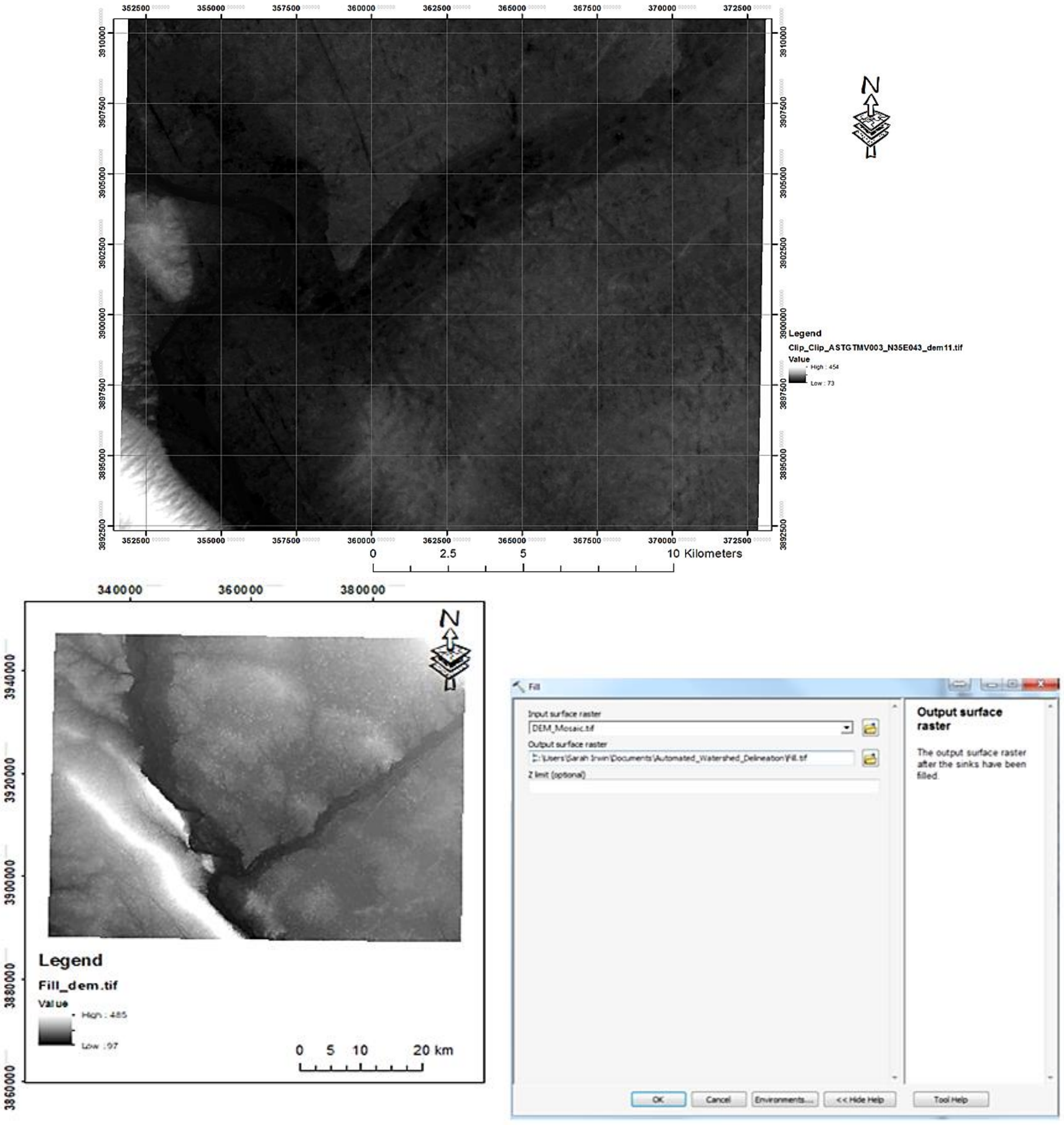


Figure 3. The result for the DEM after the filling process

4.2. Flow Direction

Every cell in a flow direction grid is assigned a value that corresponds to the direction in which water is expected to flow based on the underlying topography. This is a key step in hydrological modeling, as the flow direction determines the eventual destiny of water flowing across the surface of the ground. Flow direction grids may be made using the Flow Direction tool. A value is assigned to each raster cell based on the direction of flow leaving that cell using the Flow Direction function in the Hydrology toolbox (ArcGIS Resources, 2013). Figure 4 shows the end result of applying the flow direction procedure to the DEM.

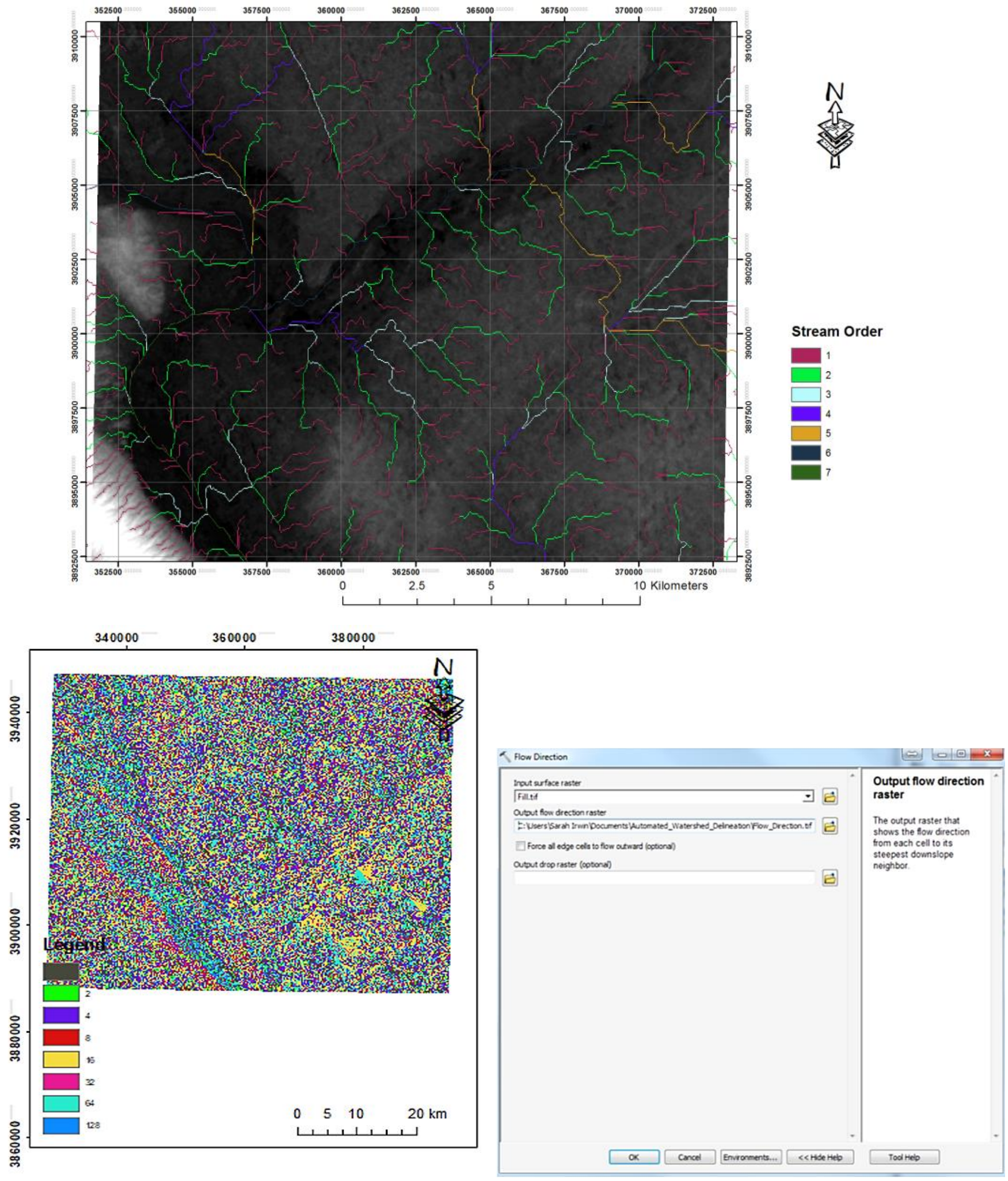


Figure 4. Outcome of the DEM flow direction procedure

The Flow Accumulation tool calculates the flow into every other cell by calculating which upstream cells pass through every downslope cell. As shown in Figure 5, the number of upstream cells flowing into a given cell determines its flow accumulation value. Figure 6 depicts the outcome of this procedure.

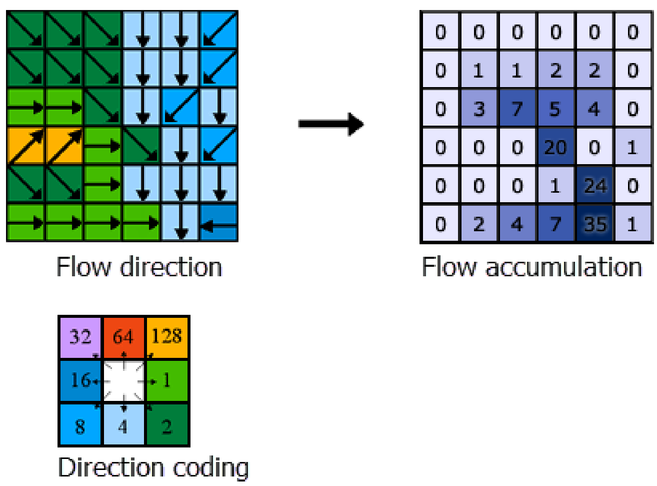


Figure 5. Determining the accumulation of flow

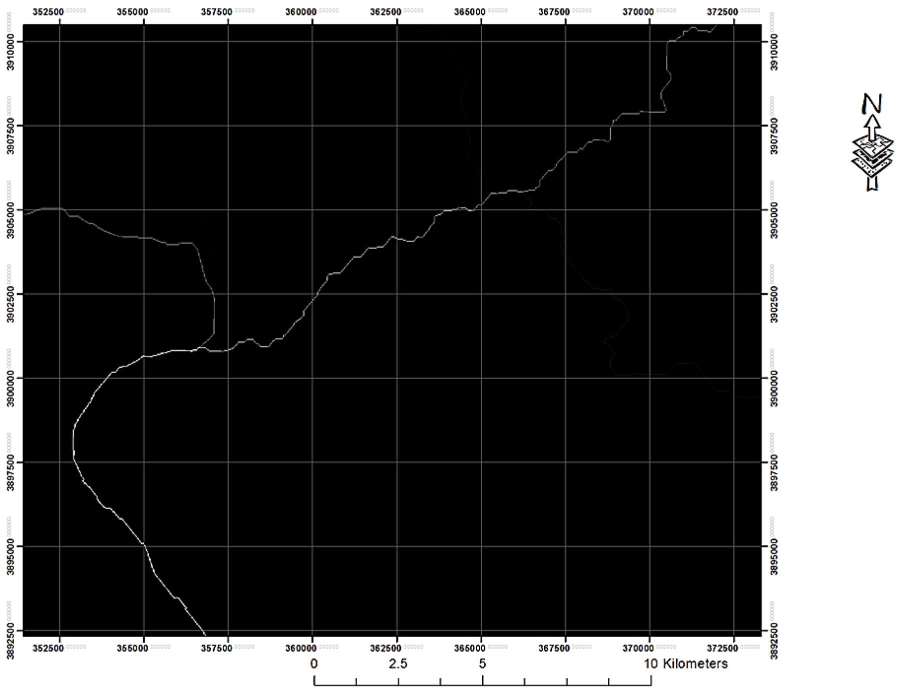


Figure 6. Resulting build-up of flow following the procedure

4.3. Stream Link

Links are the segments of a stream channel that link two consecutive junctions, a junction and the outflow, or a junction and the drainage division (Figure 7). The input stream raster may be generated by thresholding the Flow Accumulation tool's output. The stream raster linear network should be shown with values equal to or greater than one on a No Data backdrop.

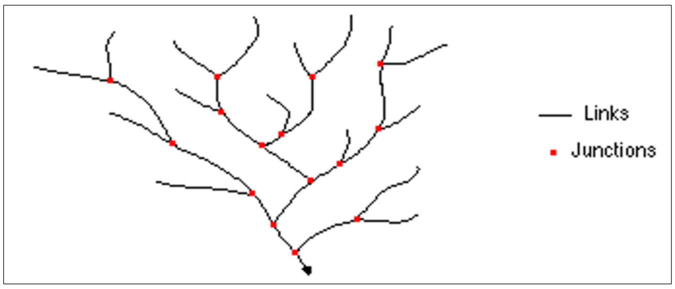


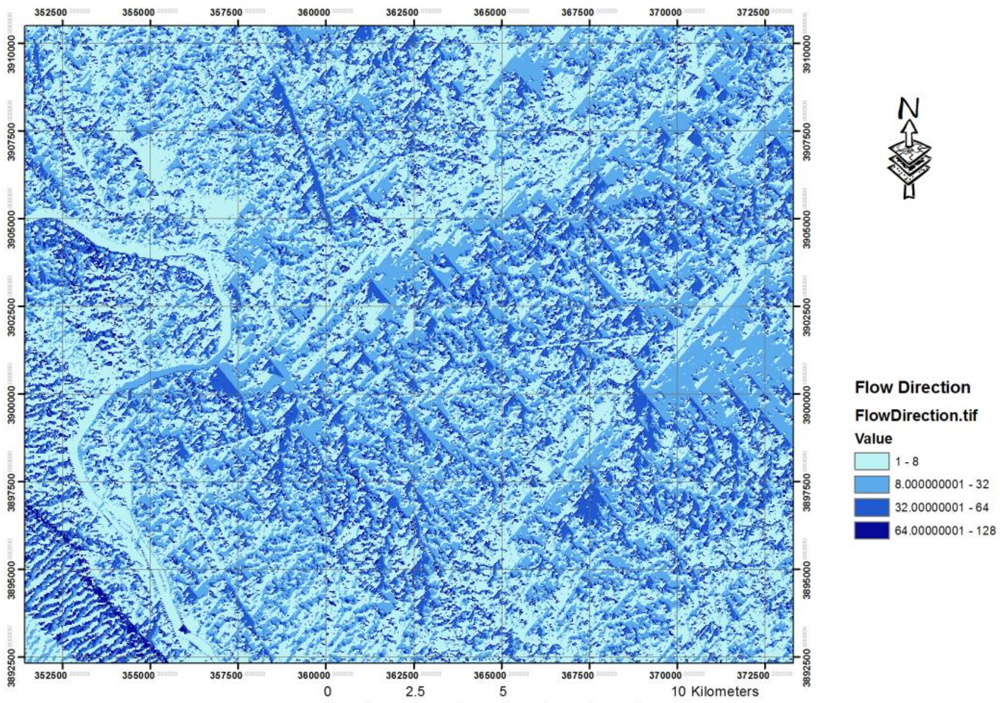
Figure 7. Links in a stream channel

4.4. Stream Order

Stream order produces superior results if the input stream picture and the input flow direction image come from the exact same surface. If the stream image is derived from a vectorized stream dataset, then the output may not be useful as the direction will not correspond with the location of stream cells on a cell-by-cell basis. The output of the Flow Accumulation tool may be used to generate a raster stream network using a threshold value to choose cells with a high accumulated flow. For instance, cells with more than 100 incoming cells are used to define the stream network. The Con or Set Null tool is used to generate a raster of a stream network in which flow accumulation values of 100.0 or more are set to one and the rest are set to the backdrop (NoData). Stream Link and Stream to Features may use the resultant stream network.

4.5. Stream to Feature

The input stream image linear networks must have values greater than or equal to one on a No Data backdrop. The Flow Accumulation tool's output can be used to generate an image stream network by adding a threshold to choose cells with a rise in accumulated flow. For instance, cells with more than 100 incoming cells are used to define the stream network. The Con or Set Null tool is used to generate an image of a stream network in which flow accumulation values of 100.0 or more are set to one and the rest are set to the backdrop (No Data). As shown in Figure 8, the resultant stream network may be used in Stream Link and Stream to Feature 8.



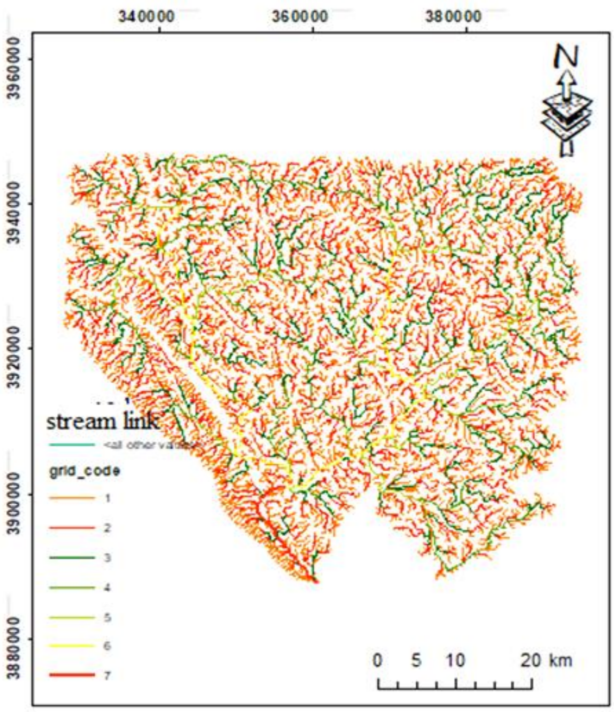


Figure 8. Stream to feature

Adjacent features with the same value should exist, such as the outcomes of the Stream Order or Stream Link tools. Stream to Feature should not be applied to a raster that has a few neighboring cells with the same value.

The output characteristics will be oriented in such a way that they point downstream.

4.6. Basin

Within the scope of the study, the drainage basins are separated from one another by locating ridge lines in the intervening space. A thorough examination of the input flow direction raster is carried out to identify any related cell sets that are part of the very same drainage basin. The drainage basins are produced by first finding the shed points at the margins of the analysis windows (places at which water would shed out of the raster), followed by locating the sinks, and then determining the contributing area located above each shed point. Consequently, a raster of the drainage basin is produced. Figure 9 shows a raster that outlines all of the drainage basins.

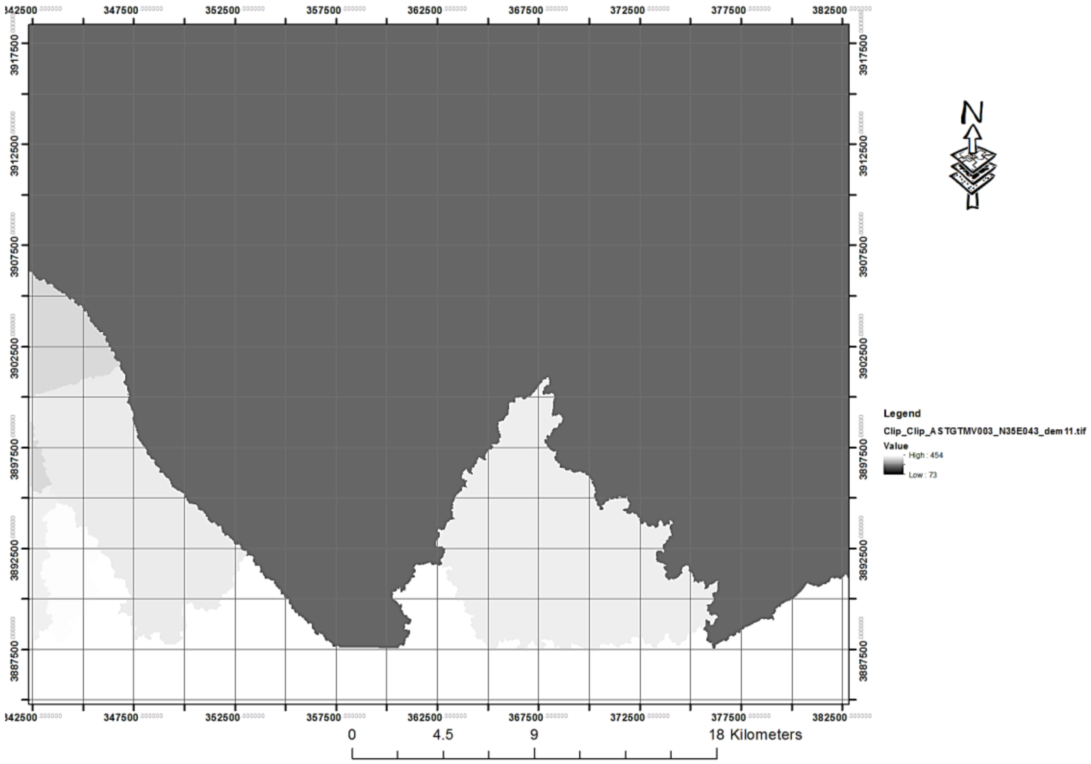


Figure 9. Developing a raster of all drainage basins

4.7. Watershed

A region of land that drains or 'sheds' water into a particular body of water is referred to as a watershed. Some watersheds drain into every body of water. Precipitation and snowmelt are carried by watersheds to streams and rivers for further processing. These compact bodies of water eventually join together to form bigger ones, such as lakes, bays, or seas. The route that water travels through the terrain is influenced to some extent by gravity. The area of contributing out of a set of cells in a raster is calculated, as shown in Figure 10.

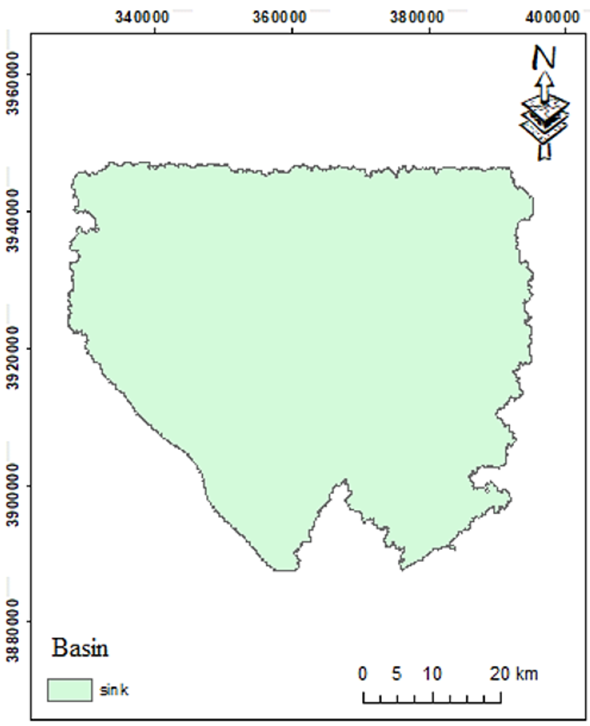


Figure 10. Determination of the contributing area of the basin

5. Conclusions

- Possible future floods in flood-risk areas of cities should be identified with the help of meteorological, hydrological, and topographical factors, including rainfall intensities in different periods of the region.
- This study explains how to identify and classify watersheds using ArcGIS software to analyze regional flood frequency.
- This technique offers decision-makers a speedy and effective analytical tool for flood hazard mapping to formulate defense, mitigation, and management strategies aimed at reducing damage resulting from urbanization and climate variability.
- This study demonstrated that RS and GIS methods are beneficial for detecting flood-vulnerable zones and creating maps of flood vulnerability.
- The research area was divided into sections with varying degrees of flood risk, ranging from very low to high.

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

6.2. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

6.3. Conflicts of Interest

The author declares no conflict of interest.

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