Article

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Extraction of Drainage Networks in the Masamba Watershed Using NASADEM

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Abstract: The drainage network consists of all river channels that flow toward a reference point. It is bounded by a topographically defined distribution of drainage. The network begins with first-order streams that have no tributaries. Within a drainage network, one or more drainage patterns may be present. This study aims to extract drainage networks and identify drainage patterns in the Masamba watershed. The data used is NASADEM, analyzed through software-based spatial analysis methods. The analysis procedure includes sink filling, flow direction, and flow accumulation, as well as the eight-direction (D8) approach and Strahler's stream ordering method. The results show that the Masamba watershed exhibits three drainage patterns: trellis, parallel, and dendritic. The trellis and parallel patterns occur mainly in the upstream part of the watershed, while the dendritic pattern dominates the middle and downstream areas. Based on these observations, the Masamba watershed can be classified as having a combined drainage pattern. In addition, stream orders were identified up to six levels, with the sixth-order stream representing the main river in the watershed. In 2020, a flash flood disaster struck the Masamba urban area, which is located in the downstream region. This indicates that drainage patterns have an influence on flooding. Information on drainage networks and patterns can serve as a guideline for governments, planners, and communities in addressing flood risks through sustainable watershed management approaches.

Keywords: Extraction drainage networks, drainage pattern, NASADEM, Masamba watershed

1.0 Introduction

Drainage networks, and the associated channel links and watershed, are fundamental concepts in earth science. Drainage channels are lines where fluvial processes work to drain water and mineral material out of the local area, allowing gravitational processes on the slopes to continue into the lower landscapes. The geometry and topology of drainage networks is an important study in geomorphology (O'Callaghan et al., 1984). A drainage network can be described as a regular pattern of tributary confluences with increasing stream order, characterized by average morphological properties (Billen et al., 1994). A proper understanding of the structure and functions of drainage networks is essential for water resource management, ecosystem studies, and environmental research (Wu et al., 2019). Drainage networks are typically defined where the upstream drainage area exceeds a specified threshold (Liu et al., 2016). Their quantitative measurement and analysis, often carried out through morphometric studies, provide key insights into surface hydrology (Mohammad et al., 2024). The development of drainage networks depends on geology, precipitation, and both exogenic and endogenic forces of the region (Sreedevi et al., 2013). A drainage system refers to the pattern formed by streams, rivers, and lakes within a watershed (Zhang et al., 2012). Detailed delineation of drainage networks is often the first step in many natural resource management studies (Liu et al., 2016). Automatic extraction of drainage networks and watersheds from digital elevation models (DEMs) has become an area of growing interest in various fields (Guo-dong et al., 2014). However, such analyses do not always reveal the actual drainage patterns that have developed.

A digital elevation model (DEM) is a raster-based digital representation of ground surface topography or terrain. DEMs are derived either from remote sensing methods or by digitizing and transforming contour maps into raster format through surface analysis. They have been widely used in geomorphology, hydrology, geology, terrain parameter extraction, engineering and infrastructure design, as well as many other applications. Currently, elevation data are available from several major sources, ranging from low to high spatial resolutions. Each raster cell (or pixel) contains a value representing its altitude above sea level (Hosseinzadeh, 2011; Abrams et al., 2020). Drainage network extraction plays an important role in geomorphological analysis, hydrologic modeling, and non-point source pollutant simulations, among others (Wu et al., 2019). The typical approach to extracting drainage networks from gridded DEMs can be categorized as single-flow direction algorithms, such as the D8 algorithm (Fairfield et al., 1991; Guo-dong et al., 2014). Since the 1980s, the development and application of D8-based algorithms for automatic drainage network extraction from DEMs have attracted significant research interest (Liu et al., 2016). High-resolution DEMs enable greater detail in delineating low-order stream (headwater) segments of drainage networks, which are particularly valuable for applications in physically-based hydrologic process modeling (Giertz et al., 2006).

The objectives of this study are to extract drainage networks from NASADEM and to analyze the drainage patterns in the Masamba watershed. The results can be used to calculate morphometric parameters of the watershed, including drainage density (Dd), stream frequency (Fs), bifurcation ratio (Rb), texture ratio (T), basin ratio (Bh), and basin relief. Flood-prone areas can be identified using a morphometric parameter approach. Determining the drainage networks of a watershed is the first step in analyzing its morphometric characteristics. These parameters are essential components in hydrological modeling and resource management planning.

2.0 Study Area and Material

This research was conducted in the Masamba watershed, located in North Luwu Regency, South Sulawesi Province, Indonesia. Geographically, the Masamba watershed lies between 120°19′ to 120°54′ E and 2°06′ to 2°64′ S. Indonesia is a vast archipelagic country consisting of tens of thousands of islands, with topography ranging from highlands to lowlands (Nganro et al., 2024). The Masamba watershed spans elevations from 16 m to 3,010 m above sea level. The Masamba watershed affected flash floods in the urban area of Masamba in 2020,

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the flash flood occurred in the Masamba River which caused damage to infrastructure and facilities, residences, and agricultural land. The flash flood disaster resulted in 39 deaths, 9 missing people, 106 people injured, 1,545 houses washed away and 20,447 peoples displaced (Ma'mur et al., 2024). Three main rivers flow through the urban area: the Baliase River, the Masamba River, and the Radda River. A river functions as a natural drainage system, channeling water from its upstream source to its estuary, bounded by riverbanks on both sides along its course (Nganro et al., 2025). This situation highlights the need for further research to investigate the morphometric characteristics of the watershed, beginning with the extraction of drainage networks.

The data used to extract the drainage networks is NASADEM, which can be freely downloaded from the web portal https://dwtkns.com/srtm30m/. NASADEM is considered the successor to the SRTM DEM dataset (Uuemaa et al., 2020). Released in February 2020, NASADEM was produced by reprocessing SRTM radar data, with improved accuracy achieved through the integration of auxiliary datasets such as ASTER, ICESat, and GLAS. The primary objective was to eliminate voids and other limitations present in the original SRTM dataset (Uuemaa et al., 2020; Tran et al., 2023; Nganro et al., 2025). The original SRTM mission was a joint project involving NASA, the National Geospatial-Intelligence Agency (NGA), the German Aerospace Centre (DLR), and the Italian Space Agency (ASI) (Okolie et al., 2024). Digital elevation models (DEMs) provide topographic information in digital form, offering an efficient means for terrain analysis and visualization (Bhardwaj, 2021). The study area and NASADEM data are shown in Figure 1.

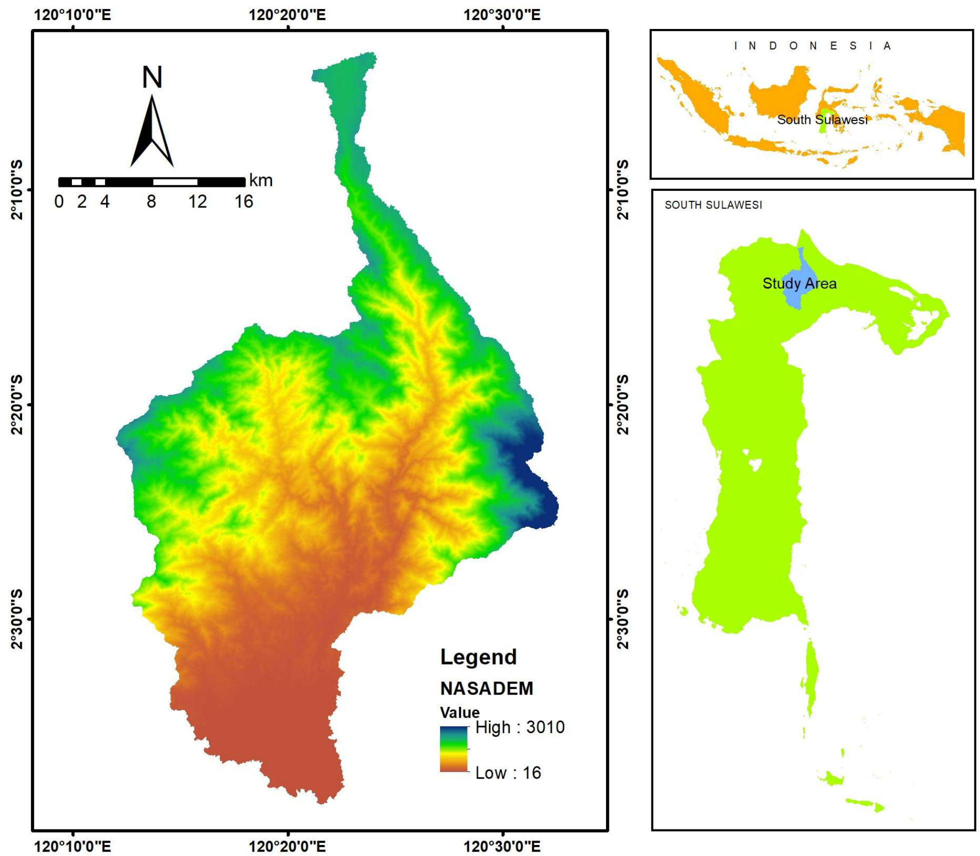

Figure 1: Study area and NASADEM

3.0 Theory/Literatur Reviews

3.1 Drainage networks

Drainage networks, also known as river networks, are composed of several interconnected river segments. The endpoints of these segments are referred to as nodes (Zhang et al., 2012). Drainage networks are one of the main inputs for estimating rainfall–runoff, predicting flood levels, and managing water resources. Their parameters include the number of streams and their lengths (Liu et al., 2016). Quantitative measurement and analysis of drainage networks are carried out through morphometric studies. According to Horton (1945), the rho coefficient represents the relationship between the bifurcation ratio and stream length, and it indicates the storage capacity of a drainage network (Mohammad et al., 2024). A drainage system refers to the pattern formed by streams, rivers, and lakes within a watershed. In such a system, rivers or streams are always interconnected, forming networks (Zhang et al., 2012). T In Figure 2, the numbers 1, 2, 3, and 4 represent river segments or streams that form part of a watershed drainage system. These numbers denote the stream order, classified according to the system introduced by Strahler (1957).

3.2 Strahler stream order

Stream order is used to describe the hierarchy of streams from the headwaters to the outlet of a watershed (NSW, 2022). This hierarchy resembles the structure of a tree and forms the drainage network. The structure is established by assigning an order number to each tributary (Zhang et al., 2012). A first-order stream has no tributaries flowing into it. When two first-order streams meet, they form a second-order stream. Similarly, when two second-order streams join, they create a third-order stream, and so on. This principle continues until the highest-order stream is reached at the outlet node. There are three types of nodes: junction nodes, which connect river segments; source nodes, which

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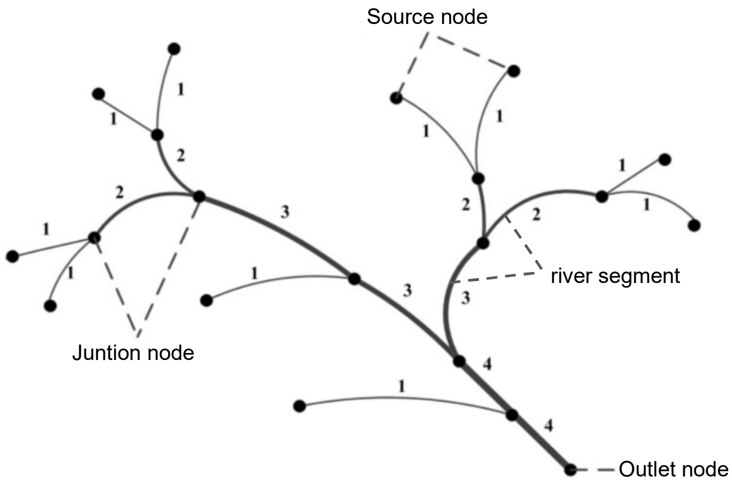
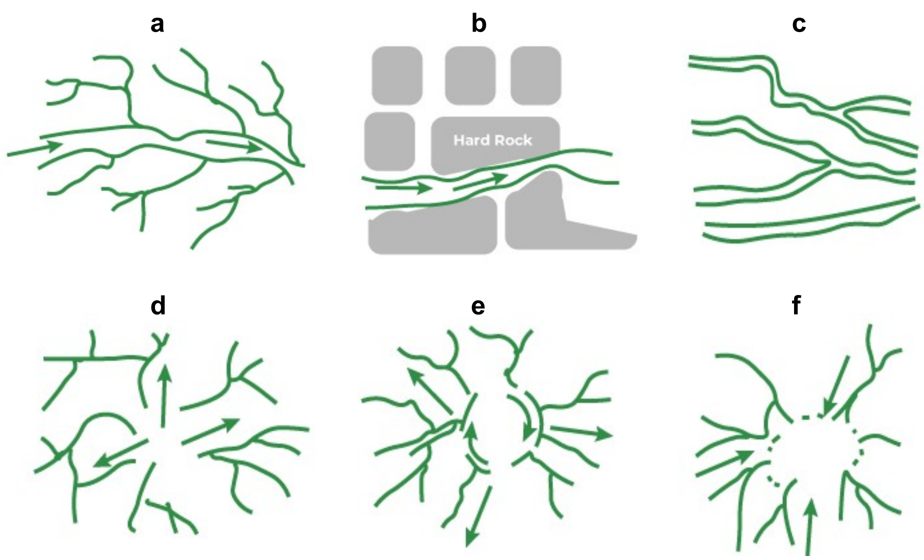
correspond to river springs; and outlet nodes, which indicate where the flow exits the watershed (Zhang et al., 2012). In Figure 2, the number 1 represents a first-order stream, the number 2 a second-order stream, while the numbers 3 and 4 indicate third- and fourth-order streams.



Source: (modified from Wan et al., 2022)
Figure 2: Type of nodes in a drainage network. Numbers 1, 2, 3, and 4 represent the Strahler stream orders.

3.3 Drainage patterns

River segments within a drainage network can be organized into different types of drainage patterns (Zhang et al., 2012). These patterns are influenced by regional geology and are controlled by factors such as structural features, regional slope, and the erosional characteristics of bedrock. The drainage pattern of a watershed can provide an initial indication of the type and structure of underlying rocks (Massinai et al., 2022). The most common drainage patterns include dendritic, trellis, parallel, radial, annular, and centripetal (Wan et al., 2022; GeeksforGeeks, 2025). These patterns are shown in Figure 3.



Source: (modified from GeeksforGeeks, 2025)

Figure 3: Drainage patterns: (a) dendritic; (b) trellis; (c) parallel; (d) radial; (e) annular; (f) centripetal

The dendritic pattern (Figure 3a) is the most common type of river system, where tributaries of a main river join in a branching form analogous to the twigs of a tree. In the trellis pattern (Figure 3b), the main river flows along a strike valley, while smaller tributaries enter from the steep mountain slopes at nearly right angles, giving the system a trellis-like appearance. In the parallel pattern (Figure 3c), tributary streams develop in a parallel arrangement, typically on surfaces with a pronounced slope. The radial pattern (Figure 3d) consists of streams that originate from a central point and radiate outward, resembling the spokes of a wheel. The annular pattern (Figure 3e) develops in areas of relatively flat terrain, where streams flow outward from a central upland in a circular arrangement. The centripetal pattern (Figure 3f) is characterized by streams that converge toward a central point, similar to the inward flow of a whirlpool(Zhang et al., 2012; GeeksforGeeks, 2025).

3.4 Eight direction "D8" approach

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The direction of river flow is analyzed for each pixel using DEM data. Water flows from a pixel to one of its eight surrounding pixels, with each cell allowed to drain into only one adjacent cell. Each cell is assigned a code ranging from 1 to 128. The D8 approach discretizes flow into one of eight possible directions, each separated by 45° (Moussa, 2009). Other approaches include the multiple-direction method (MD8) and the triangular single-direction method (M∞) (Seibert et al., 2007). Flow direction is determined based on the 3×3 cell environment: the grid processor evaluates the central cell and assigns flow toward the lowest neighboring cell. For example, if the flow direction is north, the cell is assigned a value of 64, while if the flow direction is south, the value is 4 (Ahmed et al., 2010). The direction coding scheme is illustrated in Figure 4.

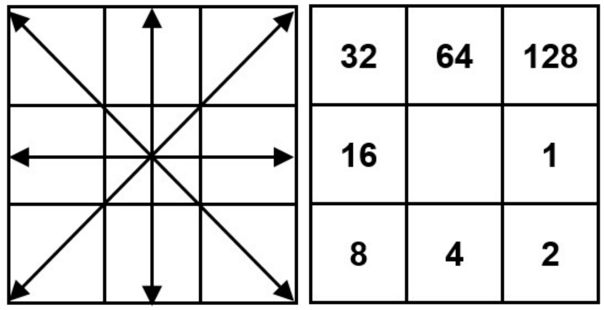

Figure 4: Direction coding

The DEM data used in this study has a resolution of 30 × 30 m. At this resolution, it is not possible to clearly illustrate the function of flow cells on a small-scale map. Therefore, the pixel size was enlarged to 900 × 900 m during the analysis process. This adjustment was made to enhance the visibility of the grid and to facilitate understanding of the flow direction codes and grid codes on the map. These features are illustrated in Figure 5.

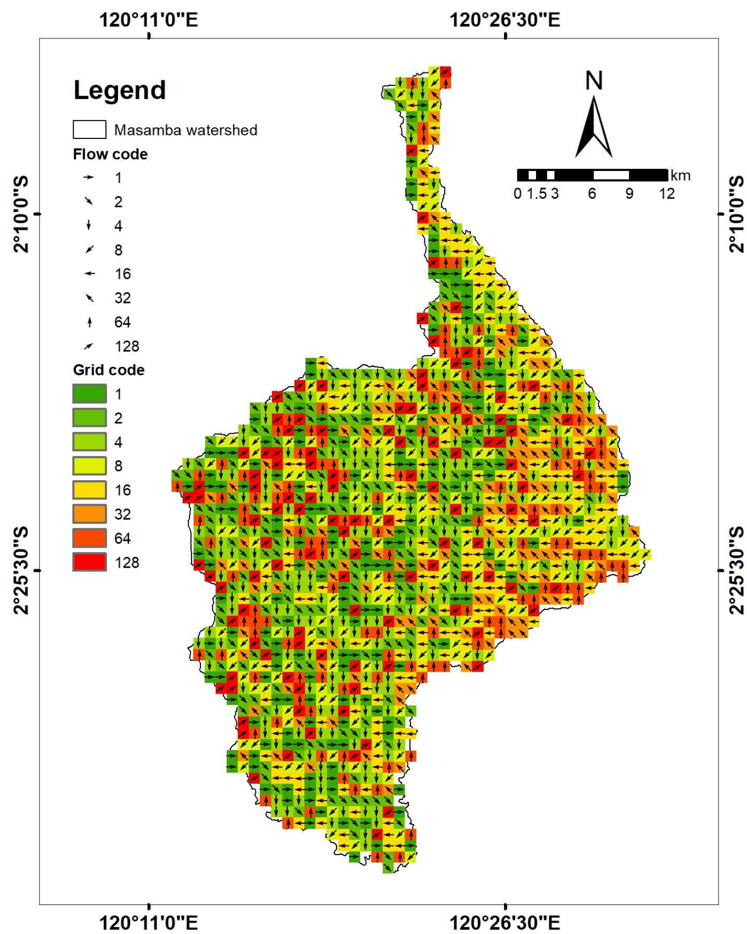

Figure 5: Cell neighbourhood

4.0 Methodology

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4.1 Framework

Extracting drainage networks from DEMs is carried out using spatial analysis methods. By applying the Fill, Flow Direction, and Flow Accumulation tools, a raster of accumulated flow can be created for each cell by summing the weights of all cells that drain into it (Yang et al., 2010). The drainage network lies within the watershed (Mohammad et al., 2024). The flowchart of the process is shown in Figure 6.

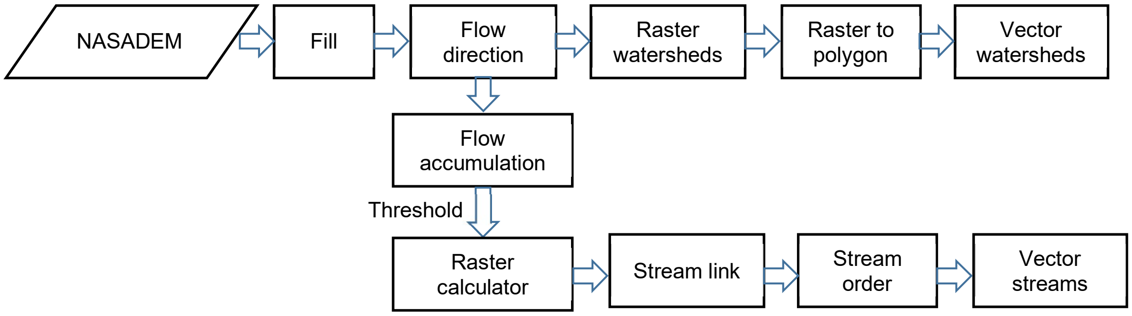

Figure 6: Flowchart of extracting drainage networks

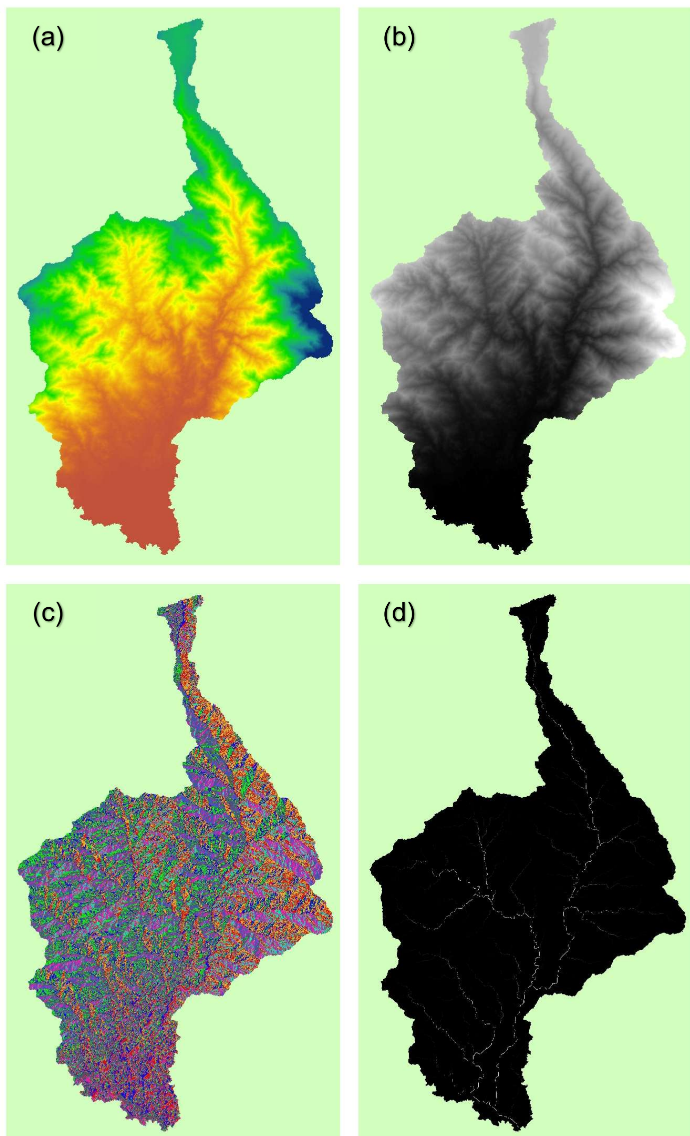

Figure 7: Extraction stages: (a) NASADEM; (b) fill; (c) flow direction; and (d) flow accumulation

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The extraction stages are shown in Figure 7, the first stage is fill, then continued by the flow direction stage and the flow accumulation stage. The description of these stages is as follows:

4.2 Fill

Depressions in DEMs, known as sinks, are generated during data collection in the field. Sinks represent no-data values, and their occurrence depends on the technique used for DEM generation (Imran et al., 2019). The Fill process functions to correct the elevation grid in DEM data by removing anomalies where the elevation differs sharply from the surrounding cells (Asih et al., 2012). Sinks are removed to eliminate discontinuities in the drainage network. To calculate a drainage network, a grid must be created in which each cell is coded according to the direction of surface drainage (Ahmed et al., 2010).

4.3 Flow direction

The D8 approach is the earliest, simplest, and most commonly used method for specifying drainage directions in grid-based digital elevation models (DEMs). It assigns a pointer from each cell to one of its eight neighboring cells, in the direction of the steepest downward slope. However, the D8 approach has limitations due to the discretization of flow into only eight possible directions, each separated by 45° (Moussa, 2009).

4.4 Flow accumulation

Flow accumulation is the next step in hydrologic modeling. Watersheds are spatially defined by the geomorphological property of drainage. To generate a drainage network, the ultimate flow path of every cell in the landscape grid must be determined. Flow accumulation is used to derive the drainage network based on the flow direction of each cell. The network is then extracted by selecting pixels with values greater than a defined threshold, determined through a trial-and-error approach (Ahmed et al., 2010).

5.0 Results

A river system can be viewed as a network consisting of main rivers and their tributaries. The analysis results show that the drainage network of the Masamba watershed contains six stream order hierarchies, with the sixth-order streams emptying into Bone Bay. A major river is typically larger and longer, while tributaries exist at various levels, smaller tributaries merge to form larger ones, which eventually flow into the main rivers. Spatial analysis indicates that the Masamba watershed exhibits a combined drainage pattern. In the upstream area, some sub-watersheds have tributaries joining the main river at right angles, forming a trellis pattern. Other segments display parallel drainage patterns. However, the overall drainage pattern of the Masamba watershed is predominantly dendritic. The drainage network map is shown in Figure 8.

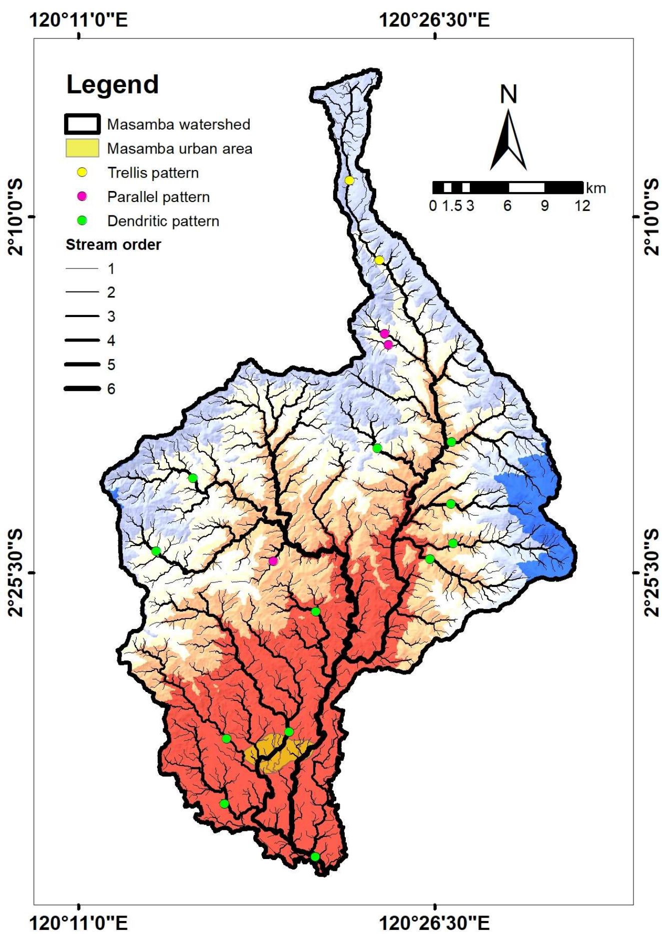

Figure 8: Drainage patterns of the drainage networks

6.0 Discussion

NASADEM is the successor to SRTM, with improved accuracy achieved by incorporating auxiliary datasets such as ASTER, ICESat, and GLAS. Therefore, NASADEM was selected as the primary dataset for this research. However, drainage network extraction and watershed boundary delineation can also be performed using ASTER DEM data. DEM data processing generally involves several steps: filling sinks, determining flow direction, calculating flow accumulation, defining stream order, segmenting streams, delineating the watershed grid, and generating the watershed polygon (Jothimani et al., 2020). Drainage networks are among the main inputs for estimating rainfall–runoff, predicting flood levels, and managing water resources (Liu et al., 2016). The Priority-Flood algorithm is widely recognized as an efficient and versatile method for drainage network extraction from DEMs (Wu et al., 2019). Within a watershed's drainage network, several types of drainage patterns may be found. These patterns are classified based on their form and texture, which are influenced by slope and geological structure. Their development reflects the local topography and subsurface geology (Zhang et al., 2012). The drainage pattern of the Masamba watershed is predominantly dendritic. In dendritic systems, rock resistance is relatively uniform and commonly associated with sandstone lithology and flat terrain (Adamsyah et al., 2024; Wan et al., 2022).

Based on topographic conditions, the catchment area is characterized by tributaries forming a dendritic pattern in the upstream region, and an elongated pattern aligned with the slope direction in the midstream region leading to the main river. This shape influences flood dynamics: runoff from the upstream tributaries arrives at different times, slowing the flood response, but water flows more rapidly once it converges into the elongated channel towards the main river (Osok et al., 2020). The Masamba River experienced a flash flood disaster on July 13, 2020, caused by high-intensity rainfall lasting approximately three days. The flood severely impacted the Masamba urban area, resulting in damage to residential facilities, infrastructure, and agricultural land (Ma et al., 2024). The urban area lies in the downstream portion of the Masamba watershed, where three major rivers, the Baliase, Masamba, and Radda rivers, flow in parallel across the city (Nganro et al., 2025).

Given the flood disaster in Masamba and the drainage characteristics of the watershed, it can be concluded that watersheds with trellis and parallel drainage patterns in their upstream sections are highly vulnerable to flash floods in downstream areas dominated by dendritic patterns. The Masamba urban area, located downstream in the dendritic section, was particularly affected by the 2020 event. Finally, the threshold used in drainage pattern analysis is limited by the computational capacity of the processing system. Adjusting the threshold values can yield more detailed representations of drainage patterns.

7.0 Conclusions

The drainage pattern of the Masamba watershed was determined from a drainage network extracted using NASADEM data. The analysis indicates that the watershed exhibits a combined drainage pattern, consisting of trellis patterns in the upstream area, parallel patterns, and dendritic patterns in the middle and downstream sections. The flash floods that struck the urban area of Masamba in 2020 are closely related to these drainage patterns. In addition, morphometric factors such as drainage density, watershed shape, and circularity ratio also influence flood occurrences. Therefore, further analysis incorporating all morphometric parameters of the Masamba watershed is urgently required.

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Conflicts of Interest: The authors declare no conflicts of interest.

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