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The Role of Three Rivers Crossing the Urban Area on the Masamba 2020 Flash Floods

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Abstract: Masamba, the capital of North Luwu Regency in South Sulawesi Province, Indonesia, experienced a devastating flash flood in 2020. The disaster caused casualties, extensive damage to infrastructure and facilities, and the displacement of residents. This event resulted from a combination of high-intensity rainfall, topographical factors, and soil characteristics, which led to river overflows. From an environmental geography perspective, Masamba's urban area is intersected and flanked by multiple rivers. The floodwaters carried landslides and debris, including large chunks of wood, which accumulated in residential areas, damaging agricultural land and urban infrastructure. As the Earth's surface is entirely divided by river basins, Masamba's urban area is part of a watershed. A watershed, defined by ridges at its highest points, consists of interconnected rivers, where water naturally flows from higher elevations to lower areas (upstream to downstream), influencing the occurrence of flash floods. This study aims to identify the watersheds and rivers flowing through Masamba's urban area. The research utilized NASADEM data and a detailed spatial plan (RDTR) map of Masamba. A Digital Elevation Model (DEM) was employed for spatial analysis to map the region's topography. The findings revealed that three rivers—the Baliase River, the Masamba River, and the Radda River—cross the Masamba urban area. These rivers belong to a single watershed, the Masamba watershed, which covers 104,946.96 hectares. This research is vital for both the government and the community in protecting and maintaining watershed and river ecosystems from upstream to downstream. It also underscores the importance of river boundary policies and regional spatial planning in mitigating future flood risks.

Keywords: River; Watershed; Flash floods; Masamba; urban area

1.0 Introduction

The 2020 flash floods in Masamba urban area, North Luwu Regency, resulted in 39 fatalities, 9 missing persons, 106 injuries, the destruction of 1,545 houses, and the displacement of 20,447 people (Ma'mur et al., 2024). Heavy rainfall caused rivers to overflow, carrying landslides and debris from upstream, which buried residential areas, agricultural land, and infrastructure. Many homes were damaged or washed away by the overflowing river (Band et al., 2020). This disaster caused significant socio-economic and environmental losses for both the government and the community, along with severe human casualties (Thober et al., 2018). Flood events are classified based on their time of occurrence, duration, affected area, and severity (Tarasova et al., 2019). Figure 1 illustrates the flash flood incident in Masamba urban area.

Source: Tempo, July 17th 2020 Source: Detiknews, July 17th 2020

Figure 1: Flash flood conditions in Masamba urban area.

Climate change has globally altered rainfall patterns, increasing the frequency and intensity of heavy rainfall, which leads to flash floods in urban areas (Ancona et al., 2014; Farhan et al., 2016). Flash floods are among the most destructive natural disasters worldwide, posing significant dangers due to their sudden and unpredictable nature (Youssef et al., 2011). Globally, they cause more than 5,000 deaths annually, four times higher than other types of flooding (Modrick et al., 2015). When rainwater falls on the Earth's surface, some infiltrates into the ground, forming retention basins in flat areas, while the rest flows as surface runoff (Nganro et al., 2019; Nganro et al., 2020). Flooding occurs when a watershed system receives unusually intense and prolonged rainfall, causing river flow to exceed its capacity (Nastiti et al., 2015; Blöschl et al., 2015). Flash floods are typically characterized by high-speed flows due to the rapid response of water catchments to intense rainfall (Liang et al., 2016).

Other factors contributing to flooding include land cover, topography, slope gradients (Sudirman et al., 2017), watershed characteristics, and the capacity of both natural and artificial drainage systems (Kusumastuti et al., 2015). Additionally, flooding can occur when rainfall falls on already saturated soil (Arnell et al., 2016). There is a strong relationship between changes in average water infiltration into the soil and runoff in river networks (Alfieri et al., 2015). The hydrological characteristics and cycles of watersheds are under significant pressure

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due to the reduction of natural landscapes, such as vegetation and dense forests (Baig et al., 2022; Ozdemir et al., 2014). Watersheds are ecosystems composed of various interconnected components, including water, soil, vegetation, and human activities. They are naturally bounded by ridges and mountains, which function to collect, store, and channel water into lakes and rivers before eventually discharging into the sea (Sudirman et al., 2018).

A river is a natural water drainage system that flows from its upstream source to its estuary, bordered by riverbanks on both sides along its course. A watershed encompasses the entire river system, including all rivers and tributaries within a specific drainage area. Watersheds are commonly referred to as drainage basins (Amini et al., 2011; Halim, 2014; Sobatnu et al., 2017). A watershed does not necessarily correspond to a single river system; rather, it defines the boundary between two or more interconnected river systems. Most of the world's freshwater flows through river basins before eventually reaching the ocean. However, in some cases, a watershed does not drain into the sea but instead empties into an internal body of water, a condition known as an endorheic basin. Globally, nearly one billion people reside in lowland areas near rivers due to the accessibility of freshwater resources for drinking and agriculture, as well as the presence of fertile land (Alfieri et al., 2017). However, these conditions also increase flood risk, particularly in the face of extreme weather events.

This research is important because the river network passing through Masamba urban area serves as the primary flash flood route during the 2020 disaster. Currently, spatial information is needed to describe the position of Masamba urban area in relation to the river network system from upstream to downstream. Such information can serve as a guideline for formulating development policies, particularly those related to adaptation and mitigation efforts against future flash flood threats. Therefore, this study aims to identify the rivers that cross Masamba urban area.

2.0 Study Area

This research was conducted in Masamba urban area, South Sulawesi Province, Indonesia. Geographically, Masamba urban area is located between 120°18′–119°22′ E and 2°32′–5°34′ S. Indonesia is a vast archipelagic country (Nganro et al., 2024), consisting of tens of thousands of islands with diverse topography, including highlands and lowlands. Masamba urban area is situated at an altitude of 67 meters above sea level (BPS, 2021). This region is highly vulnerable to flooding due to water flow from upstream during periods of intense rainfall (Ma'mur et al., 2024). The study area map is shown in Figure 2.

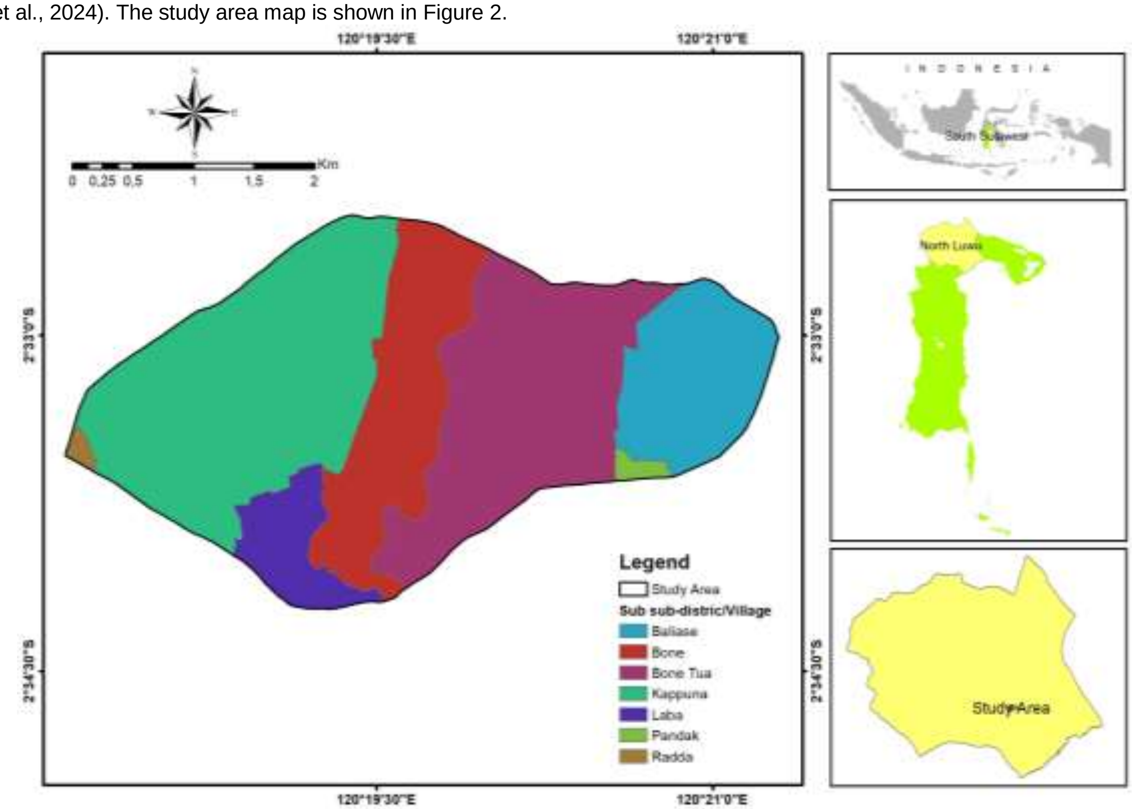

Figure 2: Masamba urban area, South Sulawesi Province, Indonesia.

3.0 Materials and Methodology

3.1 Materials

The research data was obtained from NASADEM through the web portal https://dwtkns.com/srtm30m/. NASADEM is an updated version of the Digital Elevation Model (DEM) and associated products derived from Shuttle Radar Topography Mission (SRTM) data (Dehkordi et al., 2022; Ahmed et al., 2010; Ramadan et al., 2022; Fan et al., 2023; Aziz et al., 2023; Uuemaa et al., 2020). Interferometric SAR data from SRTM was reprocessed using an optimized hybrid processing technique to produce enhanced data products. A Digital Elevation Model (DEM) is a digital representation of land surface elevation relative to a reference datum. The term DEM is often used to describe any digital representation of a topographic surface (Balasubramanian, 2017). Topography is a fundamental attribute of the Earth's surface, and DEMs are widely used in various applications, including terrain parameter extraction, water flow modeling, relief map creation, geomorphological and physical geography analyses, watershed studies, and slope analysis (Abrams et al., 2020; Welde, 2017). The data is presented in Figure 3.

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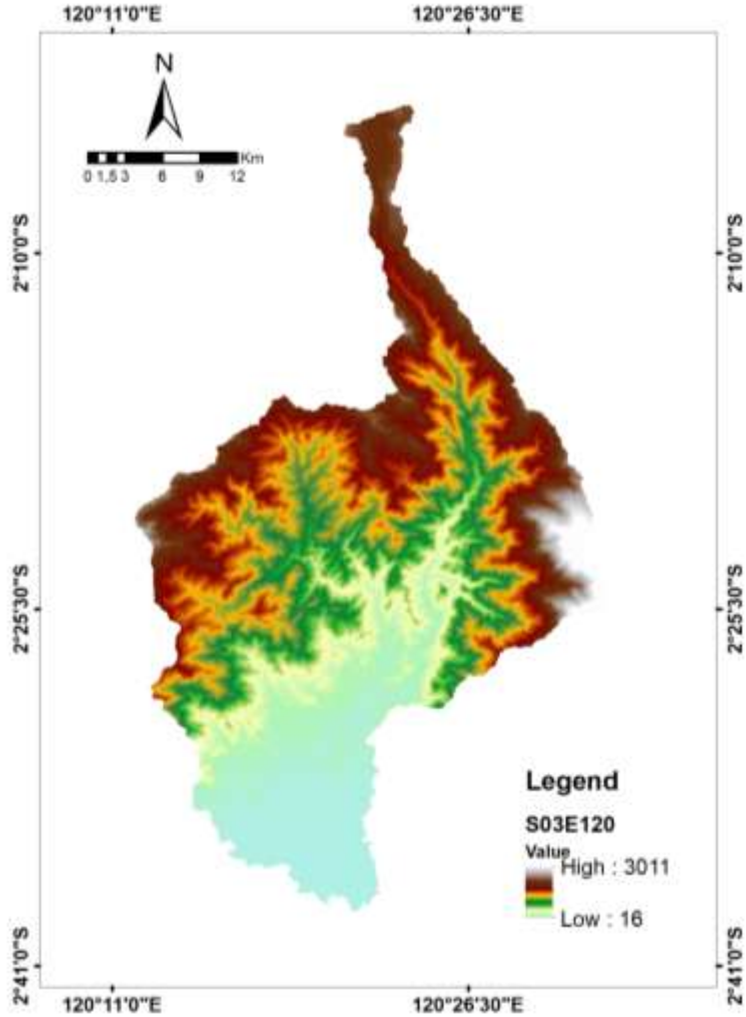

Figure 3: Digital Elevation Model (DEM) of the study area.

3.2 Methodology/Framework/Theory

3.2.1 Morphometry

Morphometry refers to the quantitative measurement of characteristics related to the geomorphological aspects of an area. Watershed morphometry is a term used to quantitatively describe the structure and properties of a river channel network. These characteristics influence the process of draining rainwater within a watershed. A watershed is an area that collects precipitation and channels it into a river system. Its size can be estimated by measuring the area on a topographic map. The boundary between watersheds is defined by ridges on the Earth's surface, which separate and direct rainwater into different drainage basins. These boundaries are determined based on contour changes observed in topographic maps (Sobatnu et al., 2017).

The network of rivers and tributaries resembles a branching tree. Small ditches merge to form larger channels, which then combine to create tributaries. Multiple tributaries eventually converge to form the main river. River networks can be systematically classified based on the hierarchy of river channels and their positions within the network. The classification is determined by the size of the channel and its location. The lowest level consists of the smallest channels, which serve as the headwaters, while higher levels correspond to larger channels found in downstream areas.

Strahler (1952) states that the outermost tributary is classified as a first-order river. When two tributaries of the same order merge, the resulting stream increases by one order. For example, when two first-order tributaries meet, they form a second-order river. Similarly, the confluence of two second-order rivers creates a third-order river, and so forth. However, if a river of a certain order joins a river of a lower order, the higher-order river remains unchanged. For instance, if a first-order river merges with a second-order river, the downstream confluence remains a second-order river (Triatmodjo, 2013; Osok et al., 2020; Hakim et al., 2019; Nurfaika, 2015).

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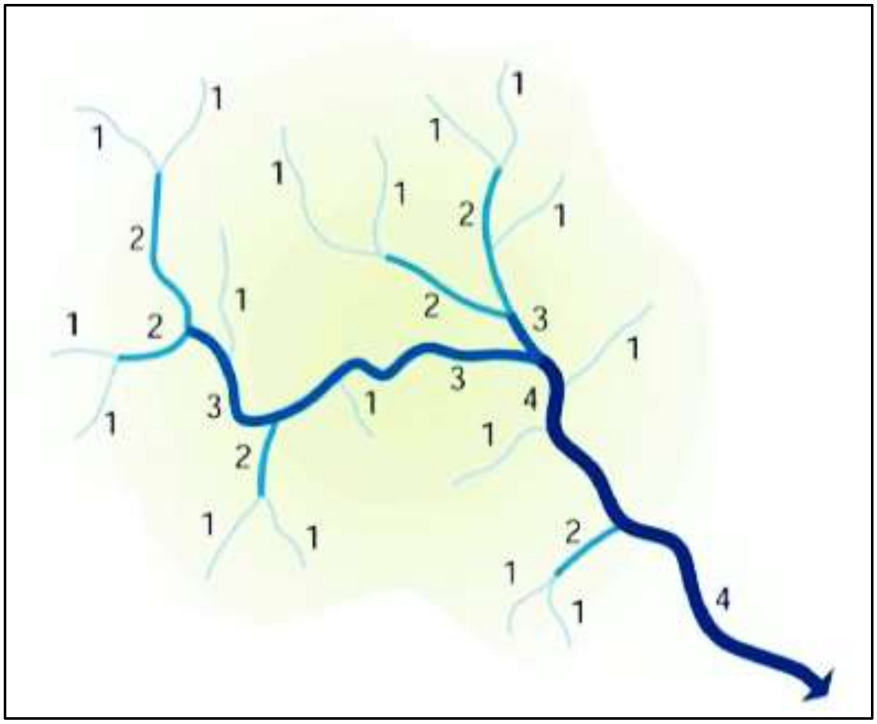

Figure 4: Strahler river system.

3.2.2 Framework

To identify the river that crosses the Masamba urban area, a structured framework for the study was developed. The process begins with downloading the Digital Elevation Model (DEM) data from the web portal using code S03E120. The data is referenced to WGS 84; therefore, it must be projected into the UTM 51S coordinate system (Ahmed et al., 2010). The watershed analysis involves several stages, including filling, flow direction, flow accumulation, basin delineation, and map algebra (Sudirman et al., 2018). Subsequently, spatial analysis was conducted to delineate the watershed and detect the river flow network. To determine the river network that intersects the study area, an overlay analysis was performed between the detailed spatial plan (RDTR) map and the watershed map. The research framework is illustrated in Figure 5.

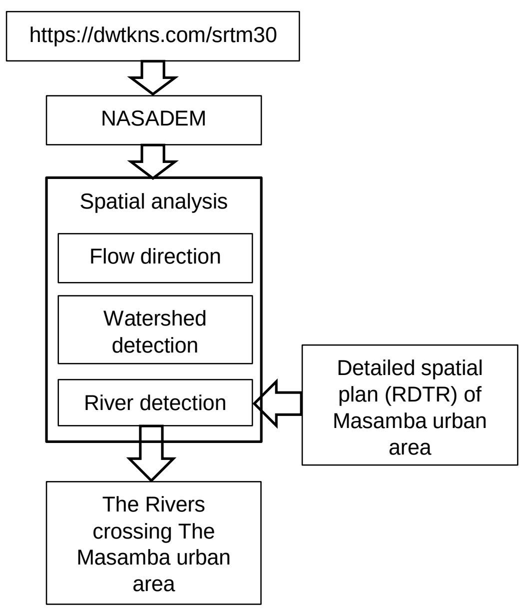

Figure 5: Framework of spatial analysis

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3.2.3 River flow

The pattern of river flow is influenced by several factors, including slope and the location of the river, which impact the formation of its flow pattern. The steeper the slope, the more irregular the river flow will be. Conversely, a gentler slope results in a more regular river flow pattern. Slope plays a crucial role in shaping river flow patterns, as its structure significantly affects the direction and characteristics of water movement. Although the natural direction of river flow is often difficult to determine, it can be modeled using Digital Elevation Models (DEM) (Yamazaki et al., 2009). DEM-based topographic analysis serves multiple functions, including flow routing for hydrological and geomorphological applications (Seibert & McGlynn, 2007). The watershed flow pattern is illustrated in Figure 6.

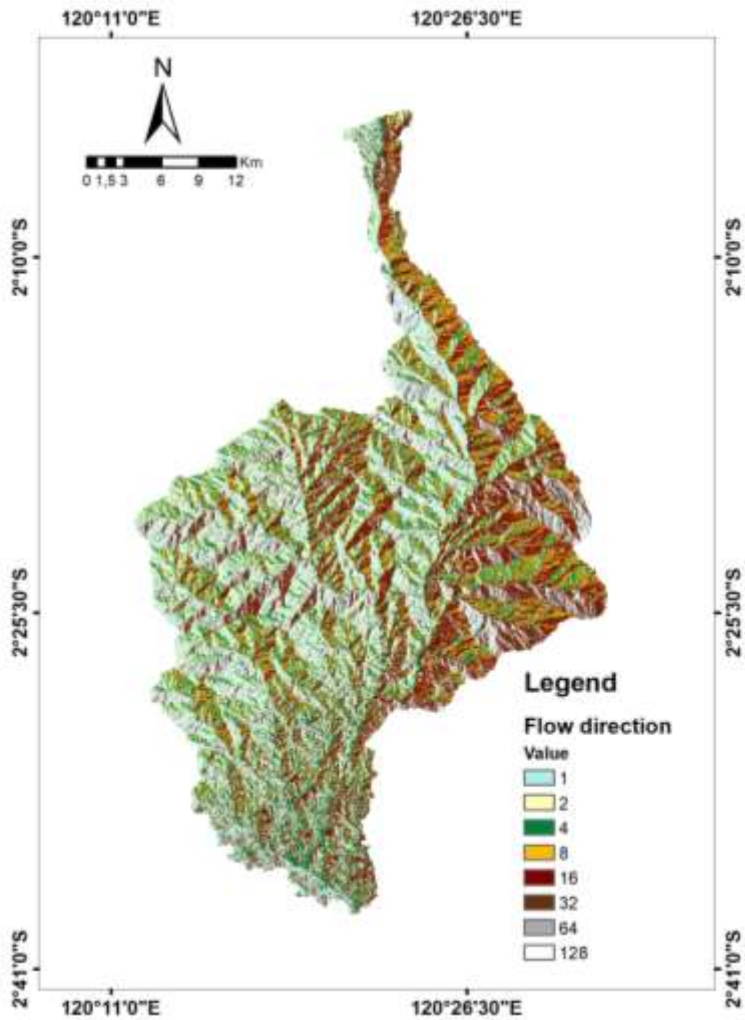

Figure 6: Flow direction of the watershed.

4.0 Results

Masamba urban area is intersected by three river systems: the Baliase River, the Masamba River, and the Radda River. All three river systems discharge into the Masamba River. Therefore, this study identifies these river systems as part of a single watershed—the Masamba watershed, which covers an area of 1,094.47 square kilometers. Data indicate that the highest elevation in the upper reaches of the Masamba watershed is 3,011 meters above sea level, while the downstream area is at an elevation of 16 meters. Masamba urban area itself is situated at 67 meters above sea level. The significant elevation difference between upstream and downstream regions can contribute to flooding in low-lying areas. This is due to the river flow speed, which is influenced by the river slope, channel length, and flow duration. Based on the analysis, the Baliase River extends 282.45 km, the Masamba River is 54.20 km long, and the Radda River measures 16.24 km. There is a direct relationship between river length and the severity of flash flood impacts in Masamba urban area. Observations indicate that areas along the Baliase River, which has the longest river length, experience more severe flood-related disasters compared to those along the Masamba and Radda Rivers. Empirically, longer rivers tend to have larger watershed areas, increasing their capacity to collect and discharge water. During periods of extreme rainfall, these rivers receive and transport large volumes of water, leading to flash floods in downstream areas. Further details regarding the rivers that cross Masamba urban area are illustrated in Figures 7 and 8.

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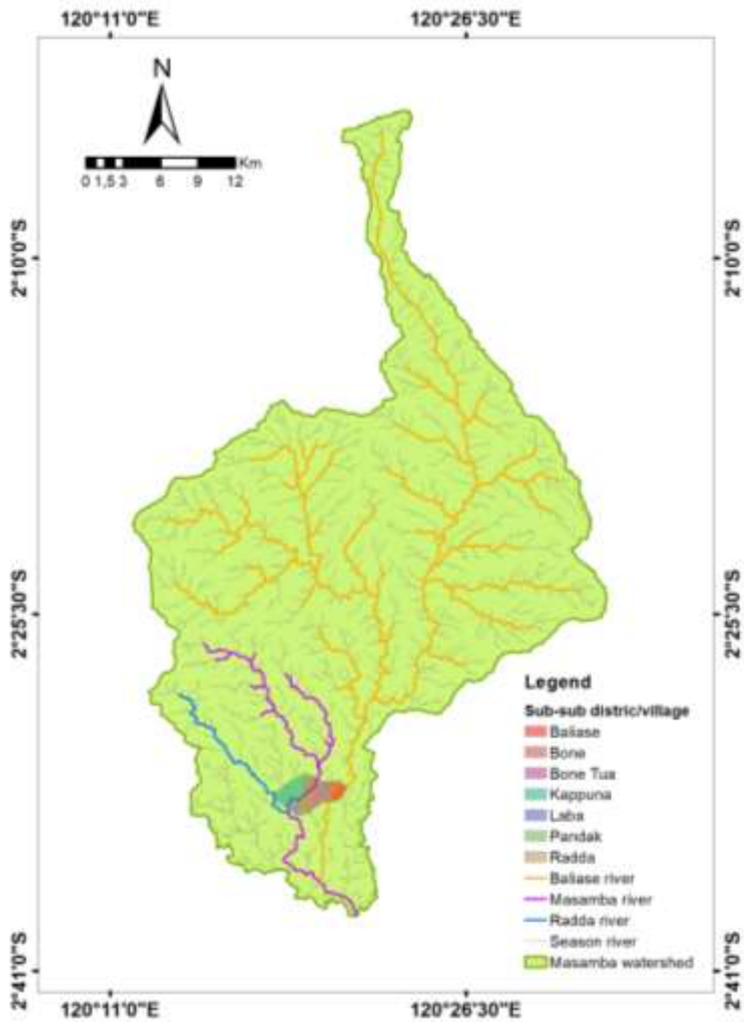

Figure 7. Masamba watershed.

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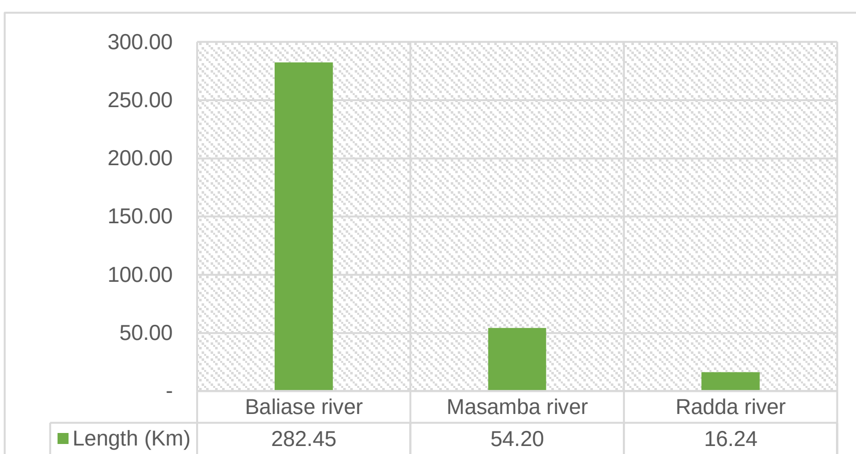

Figure 8: Length of rivers in the Masamba watershed.

To validate the analysis results with the actual river flow conditions in the field, the researcher obtained an image of the Masamba urban area using Google Earth data. The data confirm that the Baliase River, Masamba River, and Radda River cross the Masamba urban area, as visually represented in Figure 9.

Figure 9: Visualisation of the rivers via Google Map.

5.0 Discussion

Over the past few decades, global climate change has been ongoing and is associated with an increase in the frequency and magnitude of flash flood hazards worldwide (Band et al., 2020). This is one of the key reasons why intervention in the protection of forest ecosystems is necessary. As the global population continues to grow, flash flood intensity patterns are changing, particularly in developing countries. Flash floods cause significant socio-economic damage, including the loss of human settlements, fatalities, destruction of infrastructure, and damage to agricultural land. In May 2010, Tennessee experienced 344.7 mm of rainfall. The heavy and prolonged rainfall led to flash floods that resulted in 11 deaths (Moore et al., 2012). Flash floods frequently occur in arid regions due to excessive rainfall and can sometimes cause severe loss of property and life (Bajabaa et al., 2014).

Although flash floods are often linked to heavy rainfall, they are influenced by multiple factors, including meteorological conditions, climate, physiography, rainfall intensity, topography, and soil characteristics (Modrick et al., 2015). While rivers contribute significantly to economic development, they can also pose serious threats to human safety. For example, the Yangtze River flood in 1998 caused thousands of deaths and immense economic losses, making it one of the most severe flooding events of the 20th century in the basin (Li et al., 2020). Flood hazard mapping is essential for proper land use planning in flood-prone areas. It provides easily accessible charts and maps that help mitigate flood impacts. In the case of Makassar City, understanding its position within the watershed and the rivers that flow through it is crucial (Sudirman et al., 2018). This enables both the government and the community to implement effective adaptation and mitigation strategies against flash floods.

Adaptation and mitigation measures that can be undertaken include restoring forests and ecosystems, constructing water reservoirs in multiple locations, revitalizing drainage systems, implementing preventive measures, and increasing community and stakeholder participation in flood management (Ghozali et al., 2016). Green infrastructure in urban areas (Grafakos et al., 2019), urban renewal interventions (Revi, 2008), and international negotiations (Ayers & Huq, 2009) also play key roles in adaptation and mitigation. Efforts should primarily focus on three areas: reducing greenhouse gas (GHG) emissions, lowering temperatures, and enhancing flood resilience (Charlesworth, 2010). Similarly, regarding the flash flood that occurred in Masamba urban area in 2020, it is essential to develop watershed and river network maps to understand the factors contributing to flash floods. This will enable both the government and the community to make informed decisions when formulating regional development policies. This study is limited to the analysis of watersheds and rivers crossing Masamba urban area. Future research should consider additional variables such as land use changes, contour variations, and slope characteristics to achieve a comprehensive understanding of the factors causing flash floods.

6.0 Conclusions

Flash floods in Masamba urban area have resulted in social, economic, and environmental losses. From the perspective of sustainable development, which encompasses three key aspects—social, economic, and environmental—it can be stated that floods and sustainable development share a reciprocal relationship. Addressing flood risks while achieving the Sustainable Development Goals (SDGs) requires comprehensive and integrated efforts. In the context of watershed management, the upstream area plays a crucial role as a conservation zone, helping to maintain water quality, preserve vegetation, and sustain water storage capacity. Vegetation in the upper reaches of the river helps retain water and reduce surface runoff during rainfall events. As a result, the flow of water into the river is regulated, preventing it from exceeding the river's capacity. Additionally, vegetation in upstream areas helps control erosion.

Following the flash flood, large deposits of soil were visibly observed in urban areas, particularly along the Baliase River. This indicates that the floodwaters transported soil particles from the upstream areas of the river. This research has generated valuable spatial information, including maps of river basins and river networks passing through Masamba urban area. These maps can serve as essential references for formulating flood control policies. As a recommendation, infrastructure development policies should consider the construction of a dam in the upper reaches of the Baliase River. This dam could function as a flood control measure, provide irrigation water for agriculture, and serve as a source of clean water for the residents of North Luwu Regency.

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Conflicts of Interest: The authors declare that there are no conflicts of interest.

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