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Spatial Analysis of Flood Prone Areas in Fena Leisela Subdistrict, Buru Regency

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ARTICLE INFO

Article history:
Received 13 April 2023
Revised 08 May 2023
Accepted 07 June 2023
Available online 26 June 2023

Keywords:
Floods
Buru
Fena Leisela
Topographic Wetness Index

IEEE style in citing this article:
P. C. Latue, "Spatial Analysis of Flood Prone Areas in Fena Leisela Subdistrict, Buru Regency," Journal of Innovation Information Technology and Application (JINITA), vol. 5, no. 1, pp. 65–73, Jun. 2023.

ABSTRACT

Fena Leisela sub-district is often hit by floods in the rainy season. Floods that often occur in the Siwalalat sub-district are caused by the overflowing of the Waegeren river. The research used DEMNAS data and analysis using the Topographic Wetness Index method. The results of the inundation potential analysis are divided into three classes, namely low potential class with an area of 92,196.09 or 63.04%, medium class of 45,769.48 ha or 31.29%, and a high potential class of 936.12 ha or 5.67%. Waelana-Lana village (3,291.78 ha), Wamana Baru (1,349.33 ha), and Waspait (936.12 ha) are villages that have the largest area in the high flood hazard class in Fena Leisela Sub-district. In the medium flood class, Raheriat village (8,243.39 ha) is the village that has the largest area presentation compared to other villages and for the low flood hazard class, Wamlana village (14,811.98 ha), Waemite village (12,305.48 ha) and Waelana-lana village (1,680.33 ha) are the villages that have the largest area compared to other villages in Fena Leisela Sub-district. The results of this study are expected to be a reference for the government and the community in handling future floods to minimize the impact that occurs.

1. INTRODUCTION

Flooding is a condition in which water flows over normally dry land surfaces, such as roads, rivers, and low-lying areas, due to a volume of water that is greater than its drainage or containment capabilities[1],[2]. Flooding can occur due to a variety of factors, including heavy rainfall, high tides, levee breaches, or drainage system failures[3],[4],[5]. Floods can cause damage to property and infrastructure, and endanger human and animal lives[6],[7]. Therefore, flooding is often considered a serious natural disaster.

On September 16, 2021, high-intensity rain triggered the overflow of the Waegeren River water discharge and heavy river currents resulting in flooding with a water level of up to 70 cm that hit five villages spread across two sub-districts, namely in Fena Leisela and Lolong Guba sub-districts [8]. The five villages include Waelana Lana Village, Silewa Preparation, and Wamana Baru in Fena Leisela Sub-district, and Waegeren and Wabolen Villages in Lolongguba Sub-district[8]. BPBD reported that 237 families evacuated to safe places, such as the Wamana village office hall and the local mosque. BPBD officers helped residents evacuate with rubber boats to safe points. In addition to affecting residents, the flood also submerged 364 houses, damaged water pipes, and submerged 6 vehicles [8].

Topographic Wetness Index (TWI) is one of the methods to measure the level of wetness or soil surface moisture in an area based on topographic characteristics [9], [10]. TWI is based on the calculation of a topographic index that includes the elevation and slope of an area [11]. Higher TWI values indicate higher moisture levels in the region, while lower TWI values indicate drier regions[9]. TWI can be used in various applications, including mapping flood-prone areas and watersheds, monitoring soil conditions for agricultural purposes, monitoring ecosystem conditions, and flood modeling [5]. Flood identification using the Topographic Wetness Index (TWI) method has previously been used by Nucifera, & Putro [12], to

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detect flood vulnerability in Kebumen Regency by emphasizing topographic conditions represented by Digital Elevation Model data. Muin et al., [5], in 2023 also used the Topographic Wetness Index (TWI) method to identify potentially flooded areas in Siwalalat District, East Seram Bangian Regency. Based on previous studies, the TWI method is quite good and simple in identifying potential flooding in an area because it only uses Digital Elevation Model (DEM) data.

Previously, there were no researchers who analyzed floods on Buru Island, including this research location. In 2023, Sofyan et al. conducted research on flood discharge analysis of the Way Apu dam embankment on Buru Island, Ambon using the ITB-1 method. This study used the Topographic Wetness Index (TWI) method is one of the popular methods used in flood analysis [13]; [14]. Some advantages of using the TWI method over other methods are that TWI combines topographic information with soil conditions to produce accurate moisture values. Thus, TWI can provide more accurate results in predicting floods than other methods that only rely on topography or soil condition information. TWI can be used in multi-scale analysis, from small-scale analysis to large-scale analysis [12]. This allows users to determine the most appropriate scale to understand flooding in a particular area. TWI can be easily implemented using freely available software, such as Geographic Information System (GIS) [10]. This allows TWI to be used by many people, including governments, non-governmental organizations, and the general public. TWI only requires topographic data and soil conditions, which are easily obtained through field surveys or satellite images [12]. TWI does not require complex or expensive data such as hydrological data, making it a more affordable alternative for budget-constrained users. TWI can be used in flood management, including scenario development and flood mitigation planning. This is because TWI can provide detailed information about areas that are vulnerable to flooding and the factors that influence the likelihood of flooding in a region [15]. TWI is an effective method in flood analysis. It has advantages in accuracy, multi-scale analysis capability, ease of implementation, ease of data use, and applicability in flood management [13]. Based on this description, this research aims to identify flood-prone areas using the Topographic Wetness Index method in Fena Leisela District, Buru Regency.

2. RESEARCH METHODS

This research was conducted in Fena Leisela District, Buru Regency, Maluku Province. Visually, the location of the research can be seen in Figure 1. The data used include the Indonesian Rupa Bumi (RBI) Map of Buru Regency Scale 1: 50,000, Indonesian Village Administration Boundaries, National Digital Elevation Model (DEM) data obtained from the official website of the Indonesian Geospatial Information Agency, Ina-Geoportal: https://tanahair.indonesia.go.id/portal-web. The software used in this research is Arc GIS and Microsoft Office. The method used to analyze this research is the Topographic Wetness Index (TWI).

The Topographic Wetness Index (TWI) was first developed by Beven and Kirby (1979) as part of runoff modeling. TWI assesses the effect of local topography on runoff generation [16]. TWI assessment can be widely used in modeling hydrological processes, biological processes, vegetation patterns, and forestry [9]. Based on Beven and Kirby (1979), the main formula used in TWI calculation is as follows [12]:

$$W = 1\text{n}\frac{a}{tanß}(1)$$

The W value is the wetness index where α is the accumulation of the upper slope that drains water at a point in each contour unit, while β is the slope angle at that point [12]. The index describes the tendency of water to accumulate at one point based on the force of gravity where water always flows to a lower place [17]. In this case, the water flows towards the lower slope. Thus the index value will be greater on very flat slopes and vice versa the index value is smaller on steep slopes [18]. If an area accumulates water flow then the soil will become water saturated. Water will stagnate because the soil pores are no longer able to hold water. Areas with high TWI values tend to be more prone to inundation flooding.

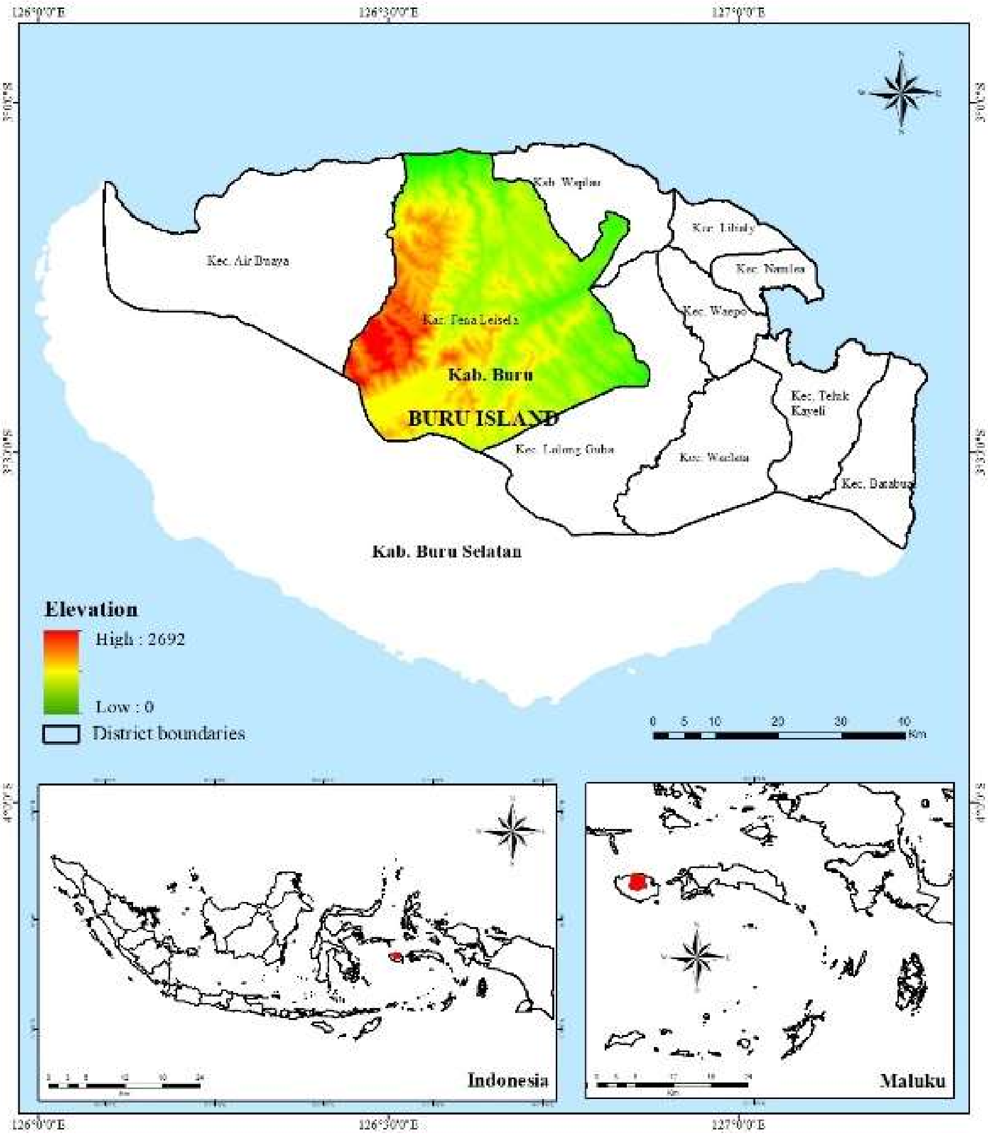

Figure 1. Research Location

The determination of flood-prone areas is based on the results of the TWI calculation after normalization. Normalization of TWI data is done to facilitate data analysis. Normalization of TWI values is carried out using the formula previously used by Nucifera & Putro [12], which is as follows:

$$Normalized\ TWI = \frac{a+(x-A)(b-a)}{(B-A)} \quad (2)$$

Value a = lowest normalized value, that is 0 b = highest normalized value, namely 1 x = TWI value A = lowest actual TWI value B = highest actual TWI value. The greater the TWI value, the greater the potential for inundation in an area [16]. The determination of areas prone to inundation flooding is also associated with the presence of rivers. The research stages can be seen in Figure 2.

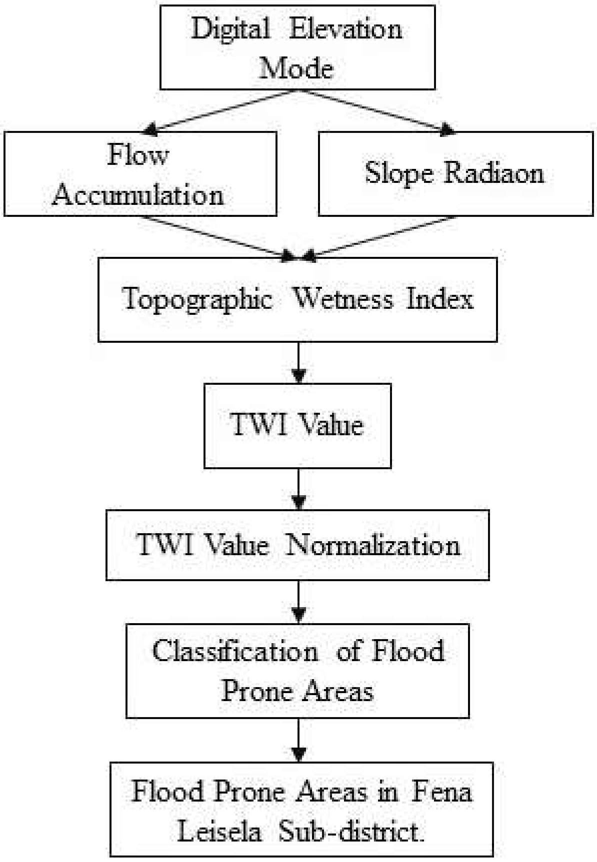

Figure 2. Workflow

The Digital Elevation Model (DEM) data obtained from BIG was then analyzed using Arc GIS Software with the help of Flow Direction and Flow Accumulation tools to analyze the accumulated direction of water flow and slope tools to analyze the slope of the slope which later the two variables were further analyzed using a raster calculator using the equation (1) to generate TWI (Topographic Wetness Index) values. The obtained Topographic Wetness Index values are then normalized using equation (2) to make it easier for further analysis. TWI values are normalized to a 0-1 interval. The TWI normalization results are then classified into three classes, namely low vulnerability, moderate vulnerability, and high vulnerability.

3. RESULTS AND DISCUSSION

Spatial Distribution (Topographic Wetness Index) TWI is a visual representation of the topographic moisture index in an area or region. The topographic moisture index describes the soil's ability to store and retain moisture, which can affect hydrological processes such as surface water flow, water infiltration into the soil, and erosion [16]. TWI values are determined based on topography. The TWI value calculation is based on the elevation value in the DTM data. The maximum TWI value is 21.5756 and the minimum value is 2.71986. Normalization of TWI values is done to simplify the analysis. TWI values were normalized to 0-1 intervals. Visually, the TWI analysis results before normalization can be seen in Figure 3 and the normalized TWI analysis results can be seen in Figure 3.

DOI:doi.org/10.35970/jinita.v5i1.1865

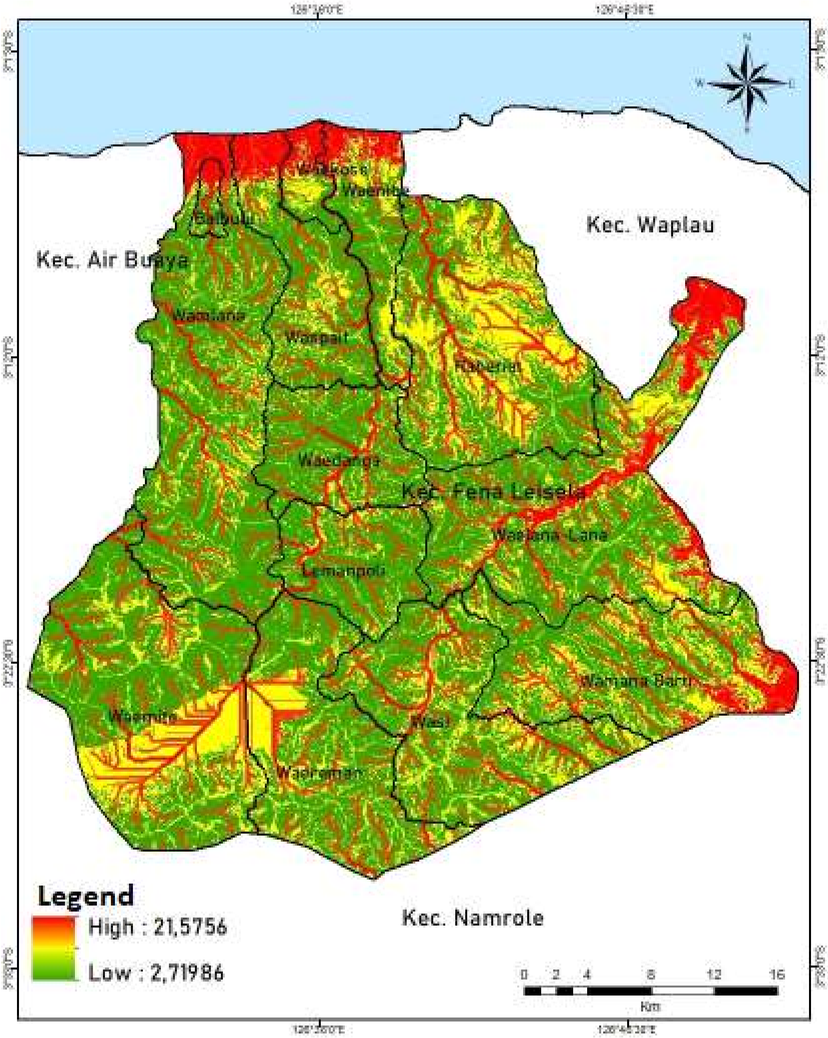

Figure 3. TWI analysis results before normalization

Potential flood levels can be predicted using the Topographic Wetness Index (TWI), which is an indicator to estimate the ability of the land to hold water. TWI can be calculated based on the elevation difference in an area and the level of rainfall in the area. The higher the TWI value, the higher the potential for flooding in the area. Areas with low TWI values usually have better drainage capabilities and less risk of flooding. In this case, TWI is used to measure the ability of the land to retain water and then drain the water into rivers or streams. Areas with high TWI values will most likely have a greater amount of water and thus, a higher risk of flooding.

Based on the results of the flood potential analysis using the Topographic Wetness Index (TWI) method in Fena Leisela District, the flood potential class is divided into three classes, namely the low potential class with an area of 92,196.09 or 63.04%, the medium class covering an area of 45,769.48 ha or 31. 29% and a high potential class of 936.12 ha or 5.67%. In Table 1 it can be seen that Waemite Village is the village that has the least flood potential compared to other villages in Fena Leisela District, while Waelana-Lana and Wamana Baru are villages that have the highest flood potential in Fena Leisela District. Detailed levels of potential flooding per village can be seen in Table 1, and a map of potential flood inundation can be seen in Figure 5.

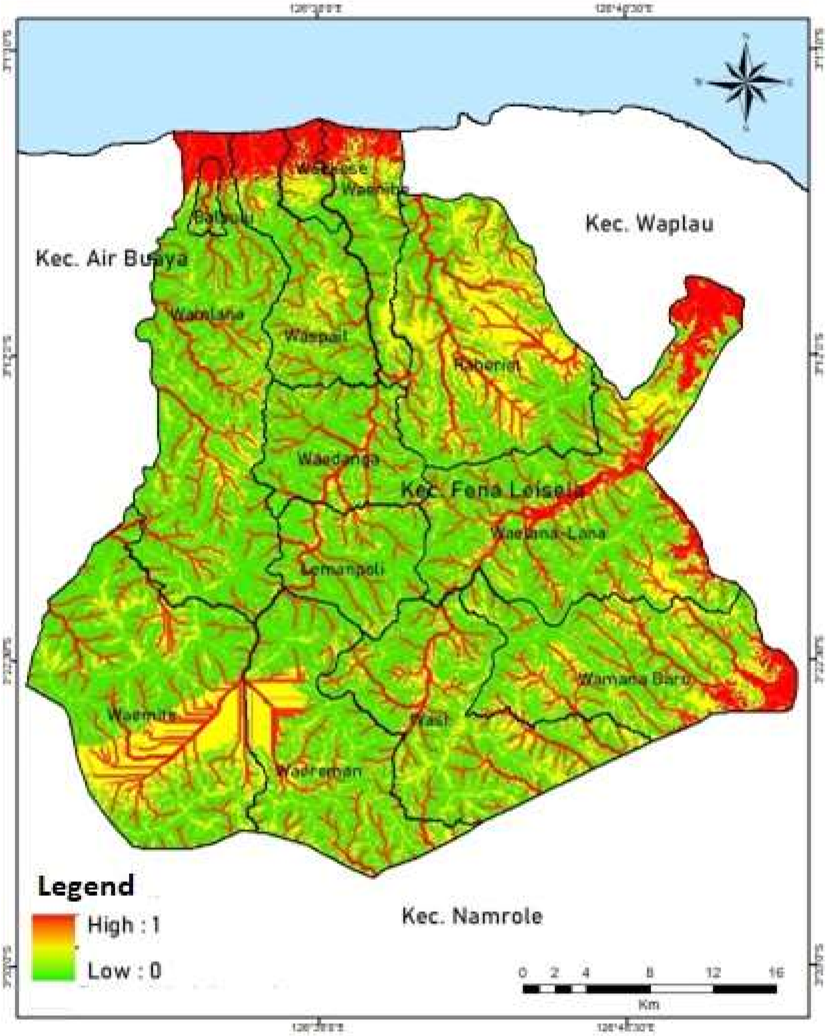

Figure 4. TWI analysis results have been normalized

Table 1. Level of Flood Vulnerability at Village Level

No	Village	Area of Flood Hazard Level (ha)		
		Low	Medium	High
1	Balbalu	387,15	159,72	216,76
2	Fena Leisela	5.765,94	1.412,75	80,90
3	Lemanpoli	4.951,44	1.230,21	-
4	Raheriat	8.360,43	8.243,39	-
5	Waekose	566,39	475,75	653,59
6	Waelana-lana	11.680,33	5.425,20	3.291,78
7	Waemite	12.305,48	7.541,40	-
8	Waenibe	2.641,78	1.493,34	928,77
9	Waereman	8.509,10	4.405,41	-
10	Wamana Baru	7.660,04	4.931,61	1.349,33
11	Wamlana	14.811,98	4.199,77	841,18
12	Wasi	9.395,68	4.487,23	-
13	Waspait	51.60,34	1.763,71	936,12

Total	92.196,09	45.769,48	936,12

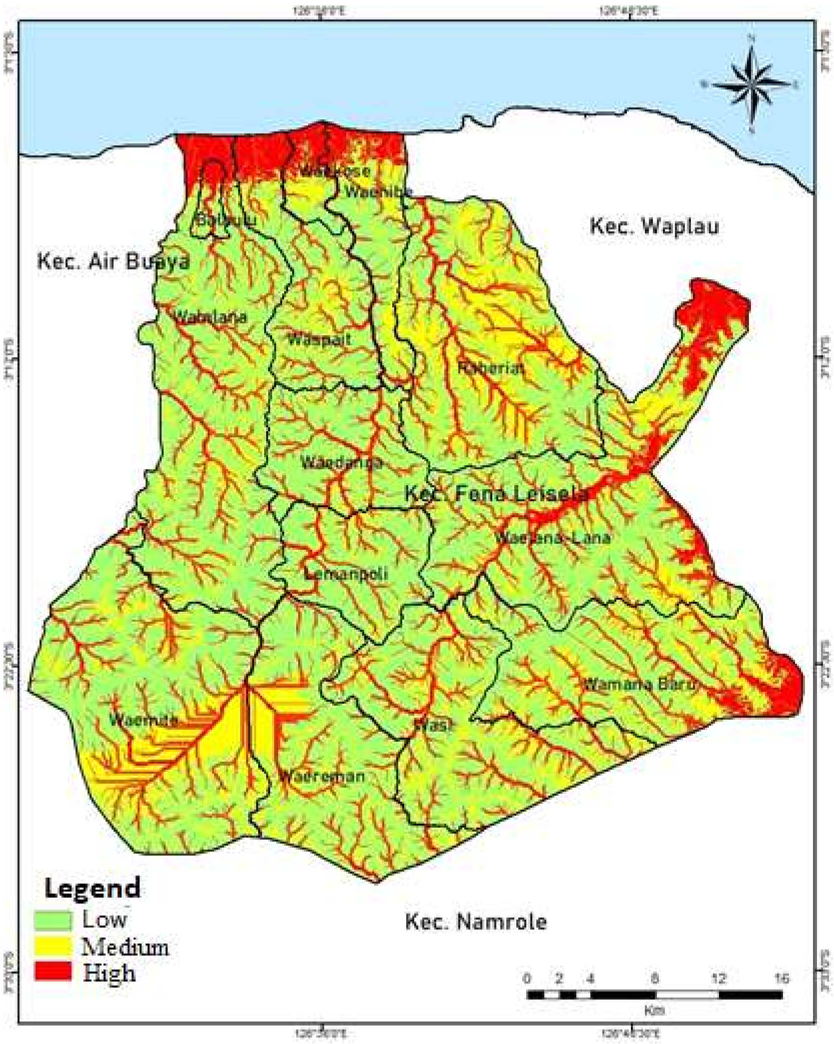

Figure 5. Map of Flood Prone Areas in Fena Leisela Sub-district

Analysis of flood-prone areas using the Topographic Wetness Index (TWI) has several benefits including identification of flood-prone areas, regional development planning, water resource management, disaster management, and hydrological model development. Berhanu & Bisrat [9], explained that using the Topographic Wetness Index (TWI) method can help in flood disaster management, such as by predicting areas that will be affected by flooding and determining safe evacuation routes. TWI can be used in the development of hydrological models to predict water flow and river discharge in an area [12]. By using TWI data, hydrological models can provide more accurate information about flood potential in Fena Leisela Sub-district.

The analysis of flood inundation in the Fena Leisela Sub-district can provide the following benefits:

1) Identification of flood-prone areas: A flood inundation analysis can help identify areas prone to flooding in Fena Leisela Sub-district. This can help the government and community in conducting better regional planning and development in the future.
2) Evaluation of the drainage system: Flood inundation analysis can help in evaluating the performance of the drainage system in Kecamatan Fena Leisela. By knowing the areas that are inundated, the government and community can assess whether the drainage system is adequate or needs to be improved.

3) Development of disaster risk reduction plans: Flood inundation analysis can help in developing disaster risk reduction plans. The data obtained from flood inundation analysis can be used to plan better infrastructure to reduce the impact of future floods.
4) Monitoring the success of flood mitigation programs: Flood inundation analysis can help in monitoring the success of flood mitigation programs that have been carried out in the Fena Leisela Sub-district. By monitoring flood inundation levels over time, the government and community can evaluate the effectiveness of flood mitigation programs that have been carried out.
5) Understanding of flood dynamics: Flood inundation analysis can help in understanding flood dynamics in Fena Leisela Sub-district. By studying the pattern of flood inundation over time, the government and community can better understand how flooding occurs and how it impacts the area. This can help in planning more effective measures to reduce the impact of flooding in the future.

4. KESIMPULAN

The flood potential class in Fena Leisela Sub-district is divided into three classes, namely the low potential class with an area of 92,196.09 or 63.04%, the medium class with an area of 45,769.48 ha or 31.29%, and high potential class with an area of 936.12 ha or 5.67%. The research results are expected to be a reference for the government and the community in handling future floods in Fena Leisela Sub-district, Buru Regency. Waelana-Lana (3,291.78 ha), Wamana Baru (1,349.33 ha), and Waspait (936.12 ha) villages have the largest area in the high flood hazard class in Fena Leisela Sub-district. In the medium flood class, Raheriat village (8,243.39 ha) is the village that has the largest area presentation compared to other villages and for the low flood hazard class, Wamlana village (14,811.98 ha), Waemite village (12,305.48 ha) and Waelana-lana village (1,680.33 ha) are the villages that have the largest area compared to other villages in Fena Leisela Sub-district. The results of this study are expected to be a reference for the government and the community in handling future floods to minimize the impact that occurs.

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