Spatial analysis of flood-prone areas and harvest failures in the Wanggu Southeast Sulawesi Watershed

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Abstract. Increased land-use change and geomorphological conditions such as rainfall factors, the level of slope, altitude of the place, soil texture, natural drainage density, and influence of infrastructure development affected to DAS hydrological response and caused of increased flood insecurity in the region. The study aims to analyze the factors of causes of flood insecurity and its impacts in the cities of Kendari and DAS Wanggu and to know the level and distribution of flooding in the area of DAS Wanggu by utilizing Geographic Information system (GIS) as well as knowing the loss of rice paddy and scattered rice. This research uses methods of surveying and scoring, weighted, and overlay on some parameters of the flood cause. The results showed that DAS Wanggu has a high rainfall of 200-360 mm per month and is categorized as a wetland, land use does not fit the class with a flat slope of 40.1%, soil texture medium to rough 82.3%, altitude place 26 m – 50 m 29.0%, medium drainage density is 89.3%, soil hydrological properties are inadequate. There are four classes of flood vulnerability dominated by the prone class-very prone to 17,857.12 ha (56.2%) 1) and the rest of the class safe 8,799.60 ha (27.7%) and somewhat prone to 5083.65 ha (16.0%). Loss of Stutty harvest due to flooding on rice paddy fields, corn, peanuts, and red chili with a total area of 6,499.4 ha amounting to Rp 105,508,937,000.

1. Introduction
Indonesia is very vulnerable to disasters because geographically and geologically, it is located on a tectonic plate with systemic activities that make Indonesia very vulnerable to floods, landslides, earthquakes, tsunamis, and other forms of natural disasters [1]. Natural disasters are unforeseen natural events that leave adverse and adverse impacts on humans, both physical and psychological, such as annual floods [2]. Flooding is a natural event that occurs in various watersheds in Indonesia due to land use activities that are not environmentally friendly. Increased changes in land use, settlement construction, and geomorphological conditions in the Wanggu watershed such as slope levels, altitude, soil texture, drainage density, rainfall will affect the hydrological response of the watershed and caused higher flood frequency in the region. Wanggu watershed plays a crucial and strategic role in Southeast Sulawesi Province because in the upstream there is a protected forest and people's cocoa plantations, in the middle area there is the Haluoleo field and irrigated rice fields, downstream of the watershed there are the city of Kendari, Kendari bay, pier, public harbor. The dynamics of land use in the Wanggu watershed in the period 1992-2016 have caused land degradation that has affected the disruption of the hydrological function of the area. The Wanggu watershed is included as one of the critical national priority watersheds in Southeast Sulawesi Province, which immediately requires treatment for its recovery [3].
Changes in land conditions from time to time make the threat of more significant flooding. The capacity of the river is getting smaller due to silting, fluctuations in water discharge between the rainy season and the higher dry season, conversion of forest land and natural buffer areas to agricultural land, livestock, settlements by ignoring conservation technology has caused damage to the catchment area, and development, regional infrastructure that is not environmentally friendly [4]. The water system is strongly influenced by the area of forests in the watershed area because of the function of forests as receivers, maintainers, and regulators of water flow [5]. Floods are one of the most common and most harmful natural threats. Therefore, handling surges is always a priority. Flooding can be caused by the influence of natural factors (rainfall, physiography of the river / geophysical area) and human influence factors include changes in land use, poor drainage, garbage disposal, etc. [6]. The study of the main causes of flooding in an area is critical because the incidence of flooding between one region and another can be different.

Kendari City is one of the areas whose flood frequency has increased from year to year because it is located in the downstream region of the Wanggu River Basin. A Geographic Information System (GIS) technology is needed to analyze the condition of a watershed that has the potential to experience a flood by utilizing the ability to analyze spatial data. It is one step to help provide new information in making policies on flood management and management of the Wanggu River Basin in controlling floods in the city of Kendari. Major floods occurred in July 2013 and 2017 due to the overflow of Wanggu river water, which resulted in damage to public facilities and infrastructure, gardens, rice fields, and residential areas, especially in the downstream regions of the Wanggu River Basin. The problem from this study is the increase in rainfall and land-use changes in the Wanggu watershed have resulted in increased flood vulnerability in the Wanggu and the spatial distribution of flood-prone areas and the impact of flooding on the failure of 2017 paddy rice harvests.

2. Method

2.1. Location and time
The research was carried out in Wanggu watershed, covering an area of 31,740.39 ha, which is administratively located in the districts of South Konawe, Konawe and Kendari City of Southeast Sulawesi, geographically located at 30°56'54" - 40°10'24" South Latitude and 122°22'300 BT - 122°35'12" East Longitude from July 2017 to December 2017.

2.2. Materials and tools
Materials used in this research are: Wanggu River Basin Administration Map, River Map, Soil Type Map, Rainfall Map, Slope Slope Map, Land Use Map, Contour Map, and Wanggu River Basin Network Map. The tools used in this study are: 1) a set of computers consisting of hardware and software for entering data, processing data and outputting data, including hardware in the form of a notebook computer with 1 gigabyte of memory capacity, 1 gigabyte of ram and a printer for map printing and software, using ArcGIS 10.3 software, GoogleEarth Pro, and Microsoft Office Excel. Also, a set of survey tools, consisting of a Global Position System (GPS), a 50 m meter roll, a Digital Camera, and writing stationery.

2.3. Research methods
This study uses survey methods and data analysis using Geographic Information Systems (GIS) in mapping the level of flood hazard in the Wanggu watershed and Kendari city. Determination of maximum discharge (Qmax) using the Rational Method [7] and determination of the capacity of maximum river discharge capacity (Qmax-S) empirical equation method.

2.4. Data sources and types
Sources of data used are primary data with direct observation in the field of the object under study, based on the map of land units obtained as many as 34 sample points for the ground check.
Furthermore, at the sample point, the coordinates are taken using GPS on the observation plot to validate the flood hazard map data generated by matching the conditions directly in the field, and secondary data obtained from relevant agencies which are relevant data such as a) slope map/topography, soil type, land use and contour maps obtained from Sampara BPDAS, and b) annual rainfall data collected from the Sulawesi River Basin IV. Types of data in the study consist of quantitative data in the form of a) coordinate points and b) total rainfall data annual rainfall and monthly rainfall also qualitative data obtained from interviews, document analysis, FGDs, observations and images from photographs or video recordings.

2.5. Data collection techniques (Methods)
Data collection techniques include: 1) recording and direct observation in the field of the factors causing floods, river cross-section measurements (width, height) and flow velocity, 2) literature study is conducted to obtain the theory and actual information that supports research and 3) methods The interview contains questions related to the history of flood events in the people who live.

2.6. Research procedure

![Diagram of research procedure]

**Figure 1.** Stages of making flood-prone simulation map.

2.7. Research variable
Research variables include rainfall, slope, soil texture, land use, altitude, drainage density, road construction, flood-prone levels, and spatial distribution of flood-prone areas and maximum flood discharge (Qmax-s).
2.7.1. Rainfall includes rainfall data divided into five classes

Table 1. Classification of rainfall classes.

| No | Rainfall (mm) | Classification | Score |
|----|---------------|----------------|-------|
| 1  | > 3,000       | Monthly > 250  | Really wet | 9 |
| 2  | 2,501 – 3,000 | Annual 200 – 250 | Wet | 7 |
| 3  | 2,001 – 2,500 | 150 – 200 | Moderate/moist | 5 |
| 4  | 1,501 – 2,000 | 100 – 150 | Dry | 3 |
| 5  | < 1,500       | < 100 | Very dry | 1 |

2.7.2. Land slope. Slope class, soil texture, land use class (table 2).

Table 2. Classification of the slope, soil texture, and land-use class.

| No | Class slope (%) | Soil texture class | Land use class | Score |
|----|----------------|--------------------|----------------|-------|
| 1  | Flat 0–8       | Very smooth        | Sh, Tt, Ta (D & S) | 9 |
| 2  | Wavy 8–15      | Smooth             | PLK, P, Hm     | 7 |
| 3  | Hilly 15–25    | Is                 | Sk, B, Al      | 5 |
| 4  | Mountains of 25 - 40 | Rough | Plantation | 3 |
| 5  | Steep mountainous> 40 | Very rough | Forest | 1 |

Information: Al = reed, B = shrub, Hm = mangrove forest, P = settlement, PLK = dryland agriculture, Sh = paddy field, Sk = bush, Tt = open land, T = pond, Ta = body of water (D = lake, S = river.

2.7.3. Place height. The elevation class of the place and the drainage density class (table 3).

Table 3. Classification of altitude and grade of drainage density.

| No | Place height class (m)* | Score | Drainage density class ** | Classification |
|----|-------------------------|-------|---------------------------|----------------|
| 1  | 0.0 – 12.5              | 9     | < 0.62                    | Rarely         |
| 2  | 12.6 – 25.0             | 7     | 0.62 – 1.44               | Rather rare    |
| 3  | 26.0 – 50.0             | 5     | 1.45 – 2.27               | Is            |
| 4  | 51.0 – 75.0             | 3     | 2.28 – 3.10               | Meeting        |
| 5  | 76.0 – 100.0            | 1     | > 3.10                    | Very tight     |
| 6  | >100                    | 0     |                           |                |

Note: * = Full Month Source, 2008, ** = Source Linsley, 1999 and Paimin, 2010

2.7.4. Spatial analysis. The spatial analysis used in this study is the classification/reclassification used for spatial data or attribute data into new spatial data using specific criteria, to facilitate the subsequent analysis process. Overlay, this process is an interaction or a combination of several maps. Overlay of some of these maps will produce new information. Dissolve, this analysis is used to generate views based on one of the attributes we choose.

2.7.5. Analysis of flood hazard rate. To determine the level of flood hazard done by adding up the product of the weight value (B) and score (S) in each parameter class [3] using the formula:

\[
\text{Total value} = B_c x S_c + B_p x S_p + B_t x S_t + B_k x S_k + B_l x S_l
\]  \( (1) \)
Information:
B = Weight
c = Rainfall
k = Slope
l = Height of place
p = Land use
S = Score
t = Soil texture

Determination of the weight for each thematic map based on consideration, how likely flooding is affected by each geographical parameter, will be used in the GIS analysis. The weighting of flood parameters based on geographic parameters, such as rainfall weight 30, land use 20, slope 20, soil texture 20, and height 10. Classification of the level of flood vulnerability at the study site is done by calculating the interval of flood hazard class by multiplying the weight with the value of each parameter:

\[ I = \frac{R}{n} \]

Information:
I = interval width
R = Difference between the maximum score and the minimum score
n = Number of flood hazard classes, namely (1) Very vulnerable, (2) vulnerable, (3) Rather vulnerable, and (4) Not vulnerable (Table 4).

Highest Scores = \( 3 \times 30 + 7 \times 20 + 9 \times 20 + 9 \times 20 + 9 \times 10 \) is 680
Lowest score = \( 3 \times 30 + 3 \times 20 + 1 \times 20 + 0 \times 20 + 0 \times 10 \) is 190
The class interval = 680 - 190: 4 is 122.5

| No | Class               | Total value   |
|----|---------------------|---------------|
| 1  | Very vulnerable     | 557.6 - 680   |
| 2  | vulnerable          | 436 – 557.5   |
| 3  | Rather vulnerable   | 312.6 – 435   |
| 4  | Safe                | 190 – 312.5   |

Table 4. Classification of flood hazard classes.

2.8. Analysis of losses due to flooding
Calculating the total area of paddy fields and fields that failed to harvest due to flooding, the number of paddy fields production for one year (2 growing seasons), the failure of harvest one planting season year-1, losses of houses that were washed away seven houses and fatalities of 3 people. Rice yields are expressed in 1 kg of dry unhusked paddy (GKG) rice with a unit of Rp 4,200 kg⁻¹, and the results of dry fields are based on interviews with dry-land farmers at the flood site regarding the sale of their first-year harvest.

3. Results and discussion
The results of the analysis of several mapping parameters of flood vulnerable areas in the Wanggu watershed include rainfall, land use, slope, soil texture, altitude, and drainage density are described as follows:

3.1. Rainfall
The results of monthly rainfall analysis in the Wanggu watershed show that there are three categories of rainfall classes namely: 1) very wet months on August, 2) wet and humid months in February, March, April, May, June, December and 3) dry months in January, September, October and November.
in Graph 1. Rainfall is the main factor causing flooding in the watershed area. The hydrological modeling for the identification of flood-prone areas is influenced by rainfall in landforms, slope, soil type, and rock type, the factor which has the most significant role in rainfall [8]. Furthermore, [7,9,10] states that rain is the most crucial factor in determining the amount of run-off in a watershed area.

**Figure 2.** Graph of monthly average rainfall in the Wanggu watershed (mm/month).

3.2. Land use
Land use in the Wanggu watershed is presented in table 5 and figure 2.

**Table 5.** Types of land use in the Wanggu watershed in 2017.

| No | Land use          | Large (ha) | (%) |
|----|-------------------|------------|-----|
| 1  | The waters        | 14.26      | 0.04|
| 2  | Reeds             | 1,797.47   | 5.66|
| 3  | Thicket           | 2,145.76   | 6.76|
| 4  | Forest            | 10,891.19  | 34.31|
| 5  | Mangrove forest   | 45.87      | 0.14|
| 6  | Mixed Gardens     | 775.95     | 2.44|
| 7  | Meadow            | 535.39     | 1.69|
| 8  | Settlement        | 1,223.28   | 3.85|
| 9  | Dryland farming   | 333.34     | 1.05|
| 10 | Rice fields       | 1,746.64   | 5.50|
| 11 | Bush              | 1368.72    | 4.31|
| 12 | Pond              | 219.05     | 0.69|
| 13 | Moor              | 10,643.41  | 33.53|
|    | Total             | 31,740.39  | 100 |

Source: BPDAS-HL Sampara (2016) and GIS analysis results [11]
Land use such as forests, agroforestry is an essential factor in influencing the level of flood vulnerability because forests can irrigate, store/hold, and control the flow of water from excessive rain, thus reducing the occurrence of flooding in the Wanggu watershed. Reduced forest area has caused an increase in run-off (C) coefficients, causing floods in the rainy season and drought in the dry season [5,6,8,12,13].

### 3.3. Slope

The slope in the Wanggu watershed consists of 4 classes, each presented in Table 6. The slope affects the surface water flow velocity. The higher rainfall intensity and the slope make water faster to run off. On the contrary, making the watershed area flat, the smaller the run-off so that the flooding can be even greater. The Wanggu watershed is dominated by slopes surging 1,606.89 ha (5.06%), hilly 6,518.93 ha, (20.53%), and steep mountains of 10,871.41 ha (34.25%) of the Wanggu watershed area. The topography is in the upstream and a little central part of the watershed. High rainfall intensity caused the run-off speed to be higher. Also, the shorter flow concentration-time and causes flood vulnerability in the middle region and more fabulous in the downstream area (outlet). This is as stated by [5,7,13] the higher the slope and rainfall make the higher of run-off speed, the shorter the flow concentration-time, causing flooding in the flat areas downstream of the watershed.

| No | Slope class | Slope (%) | Area (ha) | Area (%) |
|----|-------------|-----------|-----------|----------|
| 1  | Flat        | 0-8       | 12,743.14 | 40.14    |
| 2  | Wavy        | 8-15%     | 1,606.89  | 5.06     |

Table 6. Slope area in the Wanggu watershed in 2017.
3.4. Soil texture

The results of soil texture analysis in the Wanggu watershed include three classes of soil texture, such as coarser sand, silt, and clay. The silt class was the most dominating texture of 17,142.85 ha (54%) areas, followed by the coarser sand texture class of 8,982.17 ha (28.29%) and clay class 5,615.36 ha (17.69%) of the total area of the watershed. More can be seen in Table 7 and Figure 4. Based on Table 7 shows that the soil in the Wanggu watershed according to the United States Soil Conservation Service (SCS) method, classified as a soil hydrology class A, B and C has a soil infiltration capacity classified as fast to very slow and the finer or smallest particles of soil, the slower infiltration capacity and the coarser particles of soil, the higher infiltration capacity [7,12].

Table 7. Soil texture in the Wanggu watershed.

| No | Soil Texture | Area (ha) | (%) |
|----|--------------|----------|-----|
| 1  | Coarser      | 8,982.17 | 28.29|
| 2  | Silt         | 17,142.85| 54   |
| 3  | Clay         | 5,615.36 | 17.69|
|    | Total        | 31,740.39| 100  |

Source: BPDAS-HL Sampara (2016) and GIS analysis results [11]

A map of the slope class and slope area in the Wanggu watershed is shown in figure 4.

Figure 4. Map of the slope class and slope area in the 2017 Wanggu watershed
3.5. Place height. The altitude classes in the Wanggu watershed is divided into 6, namely, classes 0.0 m -12.5m, 12.6m-25m, 26m-50m, 51m-75m, 76m-100m, and > 100m (table 8 and figure 5).

Table 8. Data on altitude in the Wanggu watershed.

| No | Height (m) | Large (ha) | (%) |
|----|------------|------------|-----|
| 1  | 0.0 – 12.5 | 2,595.55   | 8.2 |
| 2  | 12.6 – 25.0| 8,385.69   | 26.4|
| 3  | 26.0 – 50.0| 9,211.56   | 29.0|
| 4  | 51.0 – 75.0| 3,707.56   | 11.7|
| 5  | 76.0 – 100.0| 2,611.96  | 8.2 |
| 6  | > 100.0    | 5,228.05   | 16.5|
|    |            | 31,740.39  | 100 |

Source: BPDAS-HL Sampara (2016) and GIS analysis results [11]

Figure 5. Map of soil texture in the Wanggu watershed in 2016.
3.6. Drainage density

Based on the analysis of drainage density maps in the Wanggu watershed, ten sub-watersheds are obtained with a relatively equal density level and are divided into two classifications: medium density in sub-watersheds 1, 2, 3, 4, 5, 6, 8, 9, 10 and classification Meetings in sub-watershed 7 (Table 9 and Figure 6). The drainage density means that the volume and velocity of water that flows in a river body are classified as moderate to large. This condition is also influenced by the dominant coarser texture soil (28.29%), medium or silt soil 54.0%, and clay (17.69%) of the area of the watershed so that there is a great chance of flooding. Accordance with the opinion [12,14,15] that the higher of drainage density, made the flow of water faster so that the faster the flow is drained. Conversely, the lower the drainage density, the area always experiences inundation, and the drainage is poor.

| Flow Density (km/km²) | Sub-watershed | Density | Area (Km/Km²) | (%) |
|-----------------------|---------------|---------|---------------|-----|
|                       | 1             | 2.11    | 28.98         | 9.13|
|                       | 2             | 2.19    | 22.37         | 7.05|
|                       | 3             | 2.24    | 29.51         | 9.30|
| Medium                | 4             | 2.23    | 29.88         | 9.42|
|                       | 5             | 2.1     | 28.70         | 9.04|
|                       | 6             | 1.77    | 28.26         | 8.90|
|                       | 8             | 2       | 46.48         | 14.64|
|                       | 9             | 1.8     | 29.61         | 9.33|
|                       | 10            | 2.15    | 39.55         | 12.46|
| Tight                 | 7             | 2.37    | 34.04         | 10.73|
|                       |               |         | Total         | 317.40|

Table 9. Classification of drainage densities in the Wanggu watershed.
3.7. Flood hazard levels in the Wanggu watershed in 2017

The results of the analysis show the level of flood vulnerability in the Wanggu watershed is divided into four classes, namely safe class, rather vulnerable, vulnerable, and very vulnerable class. Wanggu watershed is dominated by vulnerable classes 10,360.98 ha (32.6%). Then successively very vulnerable 7496.14 ha (23.6%), safe 8779.60 ha (27%), and the lowest is a rather vulnerable class 5083.65 (16.0%) of the total watershed area (Table 11 and Figure 7). The complete classification of hazard and flood distribution is presented in Appendix 1 of Table 14. The high level of flood vulnerability in the Wanggu watershed area and Kendari city from rather vulnerable, vulnerable and very vulnerable is caused by the biophysical conditions of the region namely high rainfall (CH) > 150 - 330 mm per month (December, February, March, April, June, and August), land use is not in accordance with the capability of the land, especially mixed gardens, dry fields, dryland agriculture, and partial destruction of the forest area of 10,891.19 ha (34.31%), the dominant flat slope is 12,743.14 ha (40.14%), erosion-sensitive soil type (dominant coarse-medium texture) of 26,125.02 ha (82.29%) of the watershed area, and moderate and dense drainage density. This is, as stated by [6,7,12,15], states that the rainfall factor is high, land-use change is not appropriate; soil type is easily eroded, flat topography, and drainage density is not supportive. Kodoatie and Sjarief, 2008 subsequently add it; Maryono, 2002 that slums also cause floods along river banks/drainage, garbage disposal into rivers and mistakes in land use planning.

Table 10. Classification of flood hazard levels in the Wanggu watershed.

| No | Classification       | Total score | Area (ha) | (%) |
|----|---------------------|-------------|-----------|-----|
| 1  | Safe                | 190.0 – 312.5| 8,799.60  | 27.7|
| 2  | Rather vulnerable   | 312.6 – 435.0| 5,083.65  | 16.0|
| 3  | vulnerable          | 436.0 – 557.5| 10,360.98 | 32.6|
| 4  | Very vulnerable     | 557.6 – 680.0| 7,496.14  | 23.6|
|    | **Total**           |             | **31,740.39** | **100**|

Source: BPDAS-HL Sampara (2016), and GIS analysis results [11]
3.8. Analysis of the impact of floods on food crop failure in the 2017 Wanggu River basin

The results of the analysis of the impact of flooding on crop failure in 2017 are presented in Table 12. Table 12 shows the number of losses due to crop failure in lowland rice, corn, and long beans and red chilies amounting to Rp 105,508,937,000.

**Table 11.** Types of food crops failing due to flooding in the Wanggu watershed in 2017.

| No | Type of plant | LTG (ha) | MT x (ha^{-1}) | GP | Loss Production (ton) | Price (Rp kg^{-1}) | Total (Rp) x 10^3 |
|----|---------------|----------|----------------|----|-----------------------|-------------------|-------------------|
| 1  | Paddy field   | 1,475.6  | 2              | 2,951.2 | 11,804.8               | 4,200             | 49,580,160        |
| 2  | Corn          | 4,470.2  | 2              | 8,940.5 | 26,821.4               | 7,663,300        | 22,989,900        |
| 3  | Long beans    | 511.0    | 1              | 511.0   | 1,708.1                | 9,000             | 15,372,000        |
| 4  | Red chili     | 42.6     | 2              | 85.2    | 187.44                | 15,000           | 17,566,877        |

Total 6,499.4 105,508,937

Note: LTG = crop area failure, MT = planting season, GP = crop failure, Pps = lowland rice production

4. Conclusions

Southeast Sulawesi Provincial Government PERDA is needed regarding 1) Utilization of land use in Wanggu river border and reforestation of damaged forests, 2) Standard operational procedures (SOP) for flood management and early warning of flood hazards in areas classified as very vulnerable and vulnerable flooding in the Wanggu watershed, immediate handling of drainage and the creation of giant reservoirs in areas classified as very prone and flood-prone in the districts of Kadia, Kambu,
Mandonga, Poasia, Wua-Wua, Baruga, Konda, Ranomeeto and North Moramo District and the dredging of the Kendari bay

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