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Flood mitigation of Bila River in Sidrap Regency Indonesia based on eco-drainage retention pond

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ABSTRACT

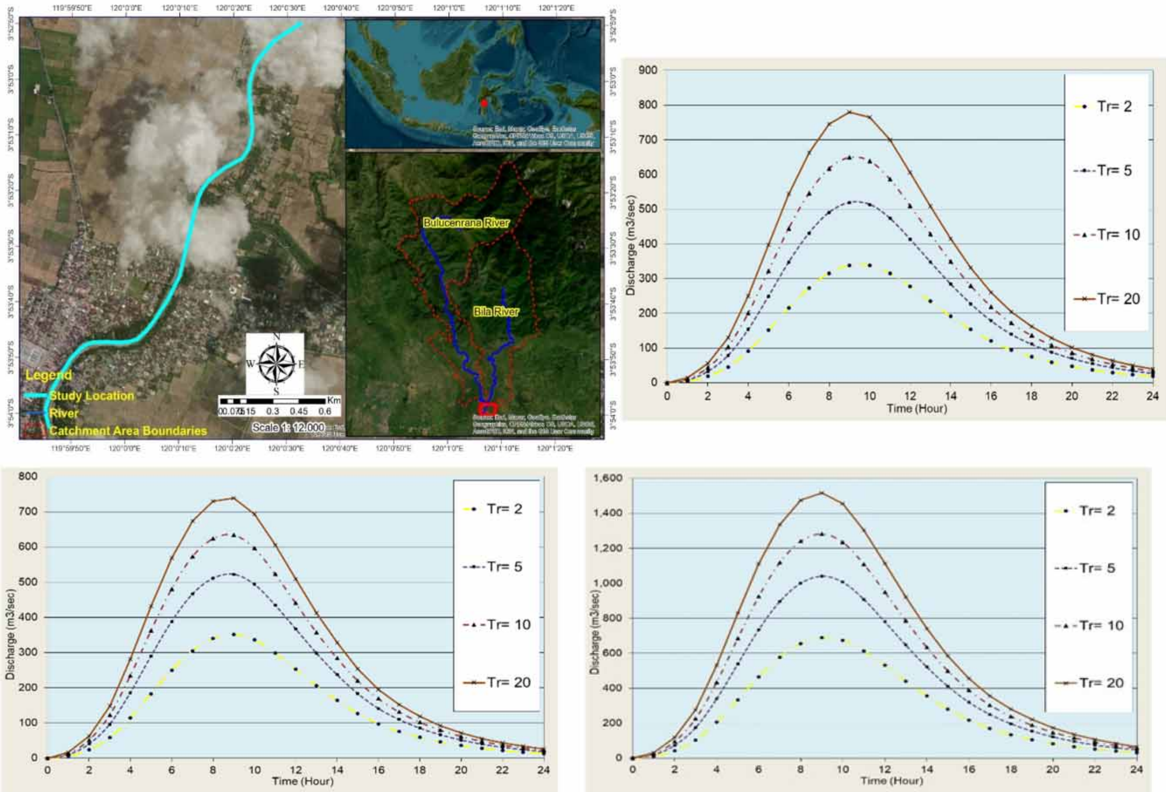
This study aims to analyze the distribution of floods in the Bila River and its countermeasures in reducing the impact that occurred in Sidrap Regency. The study performs hydrological analysis using the Bila watershed rainfall data, calculates the planned flood discharge using the HSS Soil Conservation Service (SCS) model, and simulates the flood flow profile using the HEC-RAS 2D numerical model. It is found that the Q_{20} flood discharge of the Bila and the Bulucenrana Rivers entered the Bila River downstream calculated from the HSS SCS analysis are 738.60 and 779.50 m^3/s, respectively. The overflow of the Bila River flood affects nine villages, namely Kalola Village (0.06 km^2), Sogi Village (0.01 km^2), Kalosi Alau Village (0.32 km^2), Kampale Village (0.11 km^2), Salomalori Village (0.42 km^2), Tanru Tedong Village (2.12 km^2), Kalosi Village (0.91 km^2), Salobukkang Village (1.70 km^2), and Taccimpo Village (4.01 km^2). It is proposed that the best solution to deal with the issue is by introducing an eco-drainage system, namely by constructing a retention pond with a maximum storage volume of 3.81 million m^3 or with a normal storage of 2.4 million m^3. The existence of a retention pond can reduce the inundated area around 8.28 km^2 or 85.71%.

Key words: 2D HEC-RAS, eco-drainage, numerical model, retention pond

HIGHLIGHTS

- The distribution of floods in the Bila River was investigated.
- The Bila watershed rainfall data were used to simulate the flood flow profile.
- The finding of this study provides a solution to overcome the flood issue in Sidrap Regency.
- The study suggests for constructing a retention pond with a maximum storage volume of 3.81 million m^3.
- Retention pond can reduce the inundated area around 8.28 km^2 or 85.71%.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Calamities of all kinds, including natural disasters, are common in Indonesia (Soemabrata *et al.* 2018). Natural disasters are natural phenomena that can cause environmental damage and destruction which in turn can cause loss of life, loss of property, and the destruction of infrastructures that have been built so far. Natural disasters that occur as a result of excessive exploitation of land, forest, and water natural resources as well as due to changes in global weather or climate have resulted in an increase of critical land that is susceptible to floods, droughts, landslides, forest, land fires, erosion, and sedimentation. One of the disasters that often occur is flood (Suryana *et al.* 2018; Sholihah *et al.* 2020).

Floods are a rather regular type of natural disaster in Indonesia, especially during the rainy season, as nearly every city in Indonesia experiences flooding (Halim 2018). The problem has not yet been resolved, despite the fact that this calamity virtually invariably occurs every year. With time, the flood's frequency, magnitude, depth, and duration all tend to increase (Surapto 2011; Hijriah 2013; Surminski 2014; Moftakhari *et al.* 2018).

According to Torti (2012), flooding can have very negative effects on people, including loss of life and property destruction. As a result, the flooding problem in Indonesia needs to be resolved right away. To reduce the risk of damage and losses due to flooding, flood prevention needs to be implemented in a real way (FAG 2018). Studying the river's current circumstances and its flood characteristics is one option for resolving the issue. By doing so, one can identify which river segments are at risk of flooding and create the best strategy possible based on hydraulic feasibility (Nanlohy *et al.* 2009; Khalil *et al.* 2020; Serra-Llobet *et al.* 2022).

Area development to meet various needs such as housing, agriculture, trade, industry, offices, roads, and others from year to year is increasing as a result of population growth and the development of its activities. This causes a decrease in environmental quality including a decrease in the quality of watersheds that cause losses. The most obvious losses are drought in the dry season and floods in the rainy season (Pambudi 2019; Syafri *et al.* 2020; Purwanto 2021).

This condition also occurs in the Bila River, marked by events around the Bila River in the form of reduced river capacity, increased flood discharge, and overflow of the Bila River and its tributaries which resulted in damage to public facilities, rice fields, gardens, and residential areas. This is exacerbated by the scouring of the river flow which causes damage to the river banks and threatens important facilities in the vicinity (Wahyuddin Qadri *et al.* 2016; Staddal *et al.* 2017).

Almost every year, the river is affected by floods, but the worst floods occurred on 9 and 13 June 2019. It was reported that three sub-districts in Sidrap Regency, South Sulawesi, were submerged due to the inundation of the Bila River (Tanru Tedong). The sub-districts that were inundated were Dua Pitue (eight villages), Pitu Riawa (six villages), and Pitu Riase (two villages). The main cause of this flood is that some of the embankments on the banks of the river are broken and also the high intensity of rainfall (BNPB 2022).

In order to stop the flood in the Bila River and minimize damages, flood catastrophe mitigation is required as anticipation program. Mitigation is defined as a sequence of actions taken to lower the risk of disasters, including structural improvements, public awareness campaigns, and the development of response capabilities (non-structural) (Pancasilawan 2020). By managing flooded areas with the aid of dams, weirs, river embankments, riverbed dredging, river normalization, etc., structural efforts can be made concrete. While non-structural efforts are made to map potential risks and risks of flooding, provide socialization and early warning rescues, make spatial arrangements so that environmentally unfriendly land use in flood-prone areas and water catchment areas can be controlled, and offer to counsel to the community, especially those who live in flood-prone areas (El Anshori 2020; Havinga 2020; Iskandar *et al.* 2021; Nugraheni *et al.* 2022).

Following the research background, the goal of this study is to examine the distribution of floods in the Bila River area and flood mitigation to lessen the impact of flood disasters. This information can later be used by managers to improve flood control structures and by residents of floodplain areas to be vigilant during the rainy season.

2. MATERIALS AND METHODOLOGY

The Bila River is the main location for flood mitigation research in Dua Pitue, Pitu Riawa, and Pitu Riase sub-districts, which is geographically between 3°52′49.82″S and 120°0′32.07″E to 3°54′2.53″S and 119°59′45.56″E, in the other words, starting from the confluence of the Bulucenrana and Bila rivers up to 2 km downstream. Figure 1 shows the location of the study.

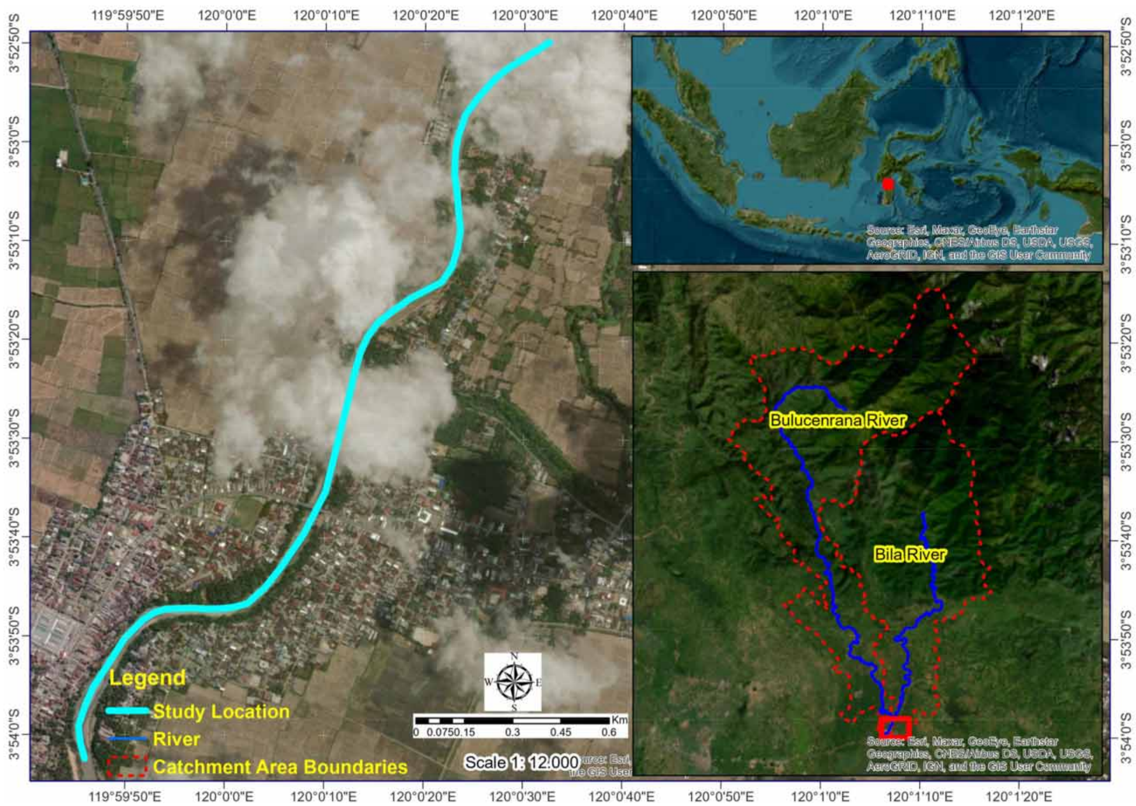


Figure 1 | Research location.

The data used in this research include

(1) The Tropical Rainfall Measuring Mission (TRMM) rainfall data were obtained from the National Institute of Aeronautics and Space for 1998–2020. There were a total of five rainfall stations used in this study, which were dispersed throughout the Research Watershed region.
(2) Soil type data used is FAO – UNESCO Soil Map of World in 2007.
(3) Land usage data used is the Land Usage Map of BIG (Geospatial Information Agency) in 2022.
(4) For flood tracking, river topography data along 2 km is combined with DEM (Digital Elevation Model) with 2.7 ArcSecond resolution from BIG.

The unit hydrograph technique is used as one of the important foundations of a method for estimating the flood hydrograph of a design rainfall. Synthetic unit hydrograph methods that are currently commonly used in Indonesia include the Snyder-SCS, Snyder-Alexeyev, Nakayasu, GAMA-1, HSS-$\alpha\beta\gamma$, and Limantara methods (Natakusumah *et al.* 2011; Habibi S A *et al.* 2021). In making flood hydrographs for rivers where there are no or very few flood hydrograph observations, it is necessary to look for the characteristics or parameters of the catchment area first, for example, the time to peak hydrograph (time to peak magnitude), bed width, area, slope, the length of the longest channel, the runoff coefficient, and so on (Habibi S A *et al.* 2021; Mustamin *et al.* 2021). Usually, we use synthetic hydrographs that have been developed in other countries, the parameters of which must be adjusted to the characteristics of the catchment under consideration. The synthetic hydrograph used in this modeling is SUH SCS Curve Number (HEC-HMS) following the results of previous studies at the same location, indicating that this method is the closest to field conditions (Suleman *et al.* 2021).

The Soil Conservation Service (SCS) synthetic unit hydrograph was developed by the U.S. Department of Agriculture (USDA SCS). The SCS synthetic unit hydrograph method is used to calculate the magnitude of the planned flood discharge associated with land use in a watershed. This hydrograph is the same as the rational method which has a component of the magnitude of the influence of land use and soil type expressed in a value, namely the Curve Number (Deby R 2021). Hydraulics modeling using HEC-RAS software, with 2D Unsteady Flow equations. HEC-RAS is software that has been widely applied for flood distribution mapping and has obtained quite good results with large-resolution DEM data (Ongdas *et al.* 2020; Afifah R *et al.* 2021; Pamungkas R C *et al.* 2021; Yakti B P *et al.* 2021; Karamma *et al.* 2022). To describe the inundation in the Bila River, researchers used Floodplain Mapping in the RAS Mapper application which can directly describe the resulting inundation. To make the simulation results more informative, the simulation results are then processed in the ArcGIS application to become a map.

Alternative countermeasures are carried out when the capacity of the river is insufficient. The alternative is in the form of eco-drainage, namely retention ponds. The application of eco-drain can be done in several ways. Retention methods are divided into two types, namely 'off-site retention', for example making ponds or reservoirs, and 'on-site retention', for example, retention on building roofs, parks, parking lots, open fields, and yards. The method of 'infiltration' is by making artificial recharge in certain areas in the form of infiltration wells, infiltration ditches, infiltration areas, and water-permeable pavements (Karamma *et al.* 2021). However, this study uses the off-site retention method which is related to the handling of the Bila watershed.

3. RESULTS AND DISCUSSION

3.1. Design flood discharge analysis

The stages in the design flood discharge analysis begin with an analysis of the maximum rainfall in the last 23 years at five rain posts that are located or represent rainfall conditions in the study location. The rainfall data is then used in calculating regional rainfall at the research location. The results of the analysis of rainfall become the basic data used in the calculation of the design flood discharge. The results of regional rainfall calculations in the Bila and Bulucenrana watersheds can be seen in Tables 1 and 2.

Furthermore, the calculation of the planned flood discharge in this study was carried out using the SCS synthetic unit hydrograph (HSS SCS) for return periods of 2, 5, 10, and 20 years. The results of the calculation of the planned flood discharge in the Bila and Bulucenrana watersheds can be seen in Figures 2–4. Based on the results of calculations and synthetic unit hydrograph charts in the study of two rivers, it can be concluded that the Bulucenrana River has a discharge of 779.50 m^3/s and the Bila River is 738.60 m^3/s. Therefore, the cumulative flood discharge that enters the downstream of the Bila River, namely by the superposition method, becomes 1.518.10 m^3/s. The results of the calculation of the design discharge in this study were then validated with

Table 1 | Recapitulation of rainfall calculation results for the Bila watershed area

No.	Years	Rainfall maximum					
		Post 1	Post 2	Post 3	Post 4	Post 5	
Coefficient		0.15	0.64	0.08	0.08	0.06	Regional rain
1	1998	82	84	78	91	78	83.59
2	1999	113	109	103	95	100	107.37
3	2000	56	72	81	75	75	71.08
4	2001	99	122	98	112	102	114.58
5	2002	75	79	70	83	68	77.17
6	2003	118	144	200	173	224	151.45
7	2004	102	104	100	87	103	101.68
8	2005	103	97	142	141	164	109.18
9	2006	95	68	83	70	91	74.77
10	2007	88	95	98	102	102	95.01
11	2008	88	86	101	80	87	87.32
12	2009	82	115	85	82	82	103.08
13	2010	76	74	91	81	84	76.89
14	2011	63	60	69	79	68	63.09
15	2012	97	163	120	114	83	141.62
16	2013	67	96	93	101	84	91.36
17	2014	72	70	73	76	76	71.10
18	2015	61	61	54	65	49	59.87
19	2016	69	72	78	76	80	72.98
20	2017	96	122	108	86	79	111.96
21	2018	80	67	87	70	79	71.57
22	2019	69	72	84	68	67	72.02
23	2020	57	104	98	96	118	97.21

previous research data using rainfall data for 1994–2019 to obtain a design discharge Q_{20} of 1.602.60 m^3/s. Based on the results of a comparison using the mean absolute percentage error (MAPE) method, a percent error of 5.27% was obtained (Suleman *et al.* 2021).

From the results of these calculations, it can be concluded that the Bulucenrana River is a river that provides the largest volume of water that enters the downstream Bila River and also has great potential to experience overflow or flooding along its flow.

3.2. Existing condition hydraulic analysis

Hydraulic analysis was carried out using a 2D unsteady flow model with the help of the HEC-RAS application. The Bila River is located in the district/city capital area where the design flood discharge requirements used are Q_{10}–Q_{20} (Suleman *et al.* 2021) so in this study, the flood simulation uses a 20-year return period flood. The map of the Bila River flood simulation results can be seen in Figure 5.

Based on the results of mapping the flood-prone areas of the Bila River in Sidrap Regency, it can be seen that the performance of the existing conditions is not able to accommodate the existing flood discharge. The flood-affected areas based on village boundaries in Sidrap Regency can be seen in Table 3. Table 3 shows that the village most affected by the overflow of the Bila River is Taccimpo Village with an area of 4.01 km^2.

3.3. Flood management with retention basins

Looking at the results of the flood simulation and the results of the field survey, it can be concluded that the main cause of flooding in the Bila River is the inability of the river to accommodate the flood discharge from two rivers,

Table 2 | Recapitulation of rainfall calculation results for the Bulucenrana watershed area

No.	Years	Rainfall maximum				
		Post 1	Post 2	Post 4	Post 5	
Coefficient		0.73	0.00	0.23	0.04	Regional rain
1	1998	82	84	91	78	83.75
2	1999	113	109	95	100	108.62
3	2000	56	72	75	75	60.81
4	2001	99	122	112	102	101.93
5	2002	75	79	83	68	76.49
6	2003	118	144	173	224	134.31
7	2004	102	104	87	103	98.56
8	2005	103	97	141	164	114.10
9	2006	95	68	70	91	89.23
10	2007	88	95	102	102	91.80
11	2008	88	86	80	87	85.98
12	2009	82	115	82	82	81.61
13	2010	76	74	81	84	77.34
14	2011	63	60	79	68	66.95
15	2012	97	163	114	83	100.58
16	2013	67	96	101	84	75.74
17	2014	72	70	76	76	73.36
18	2015	61	61	65	49	61.61
19	2016	69	72	76	80	71.16
20	2017	96	122	86	79	93.01
21	2018	80	67	70	79	77.49
22	2019	69	72	68	67	68.38
23	2020	57	104	96	118	68.18

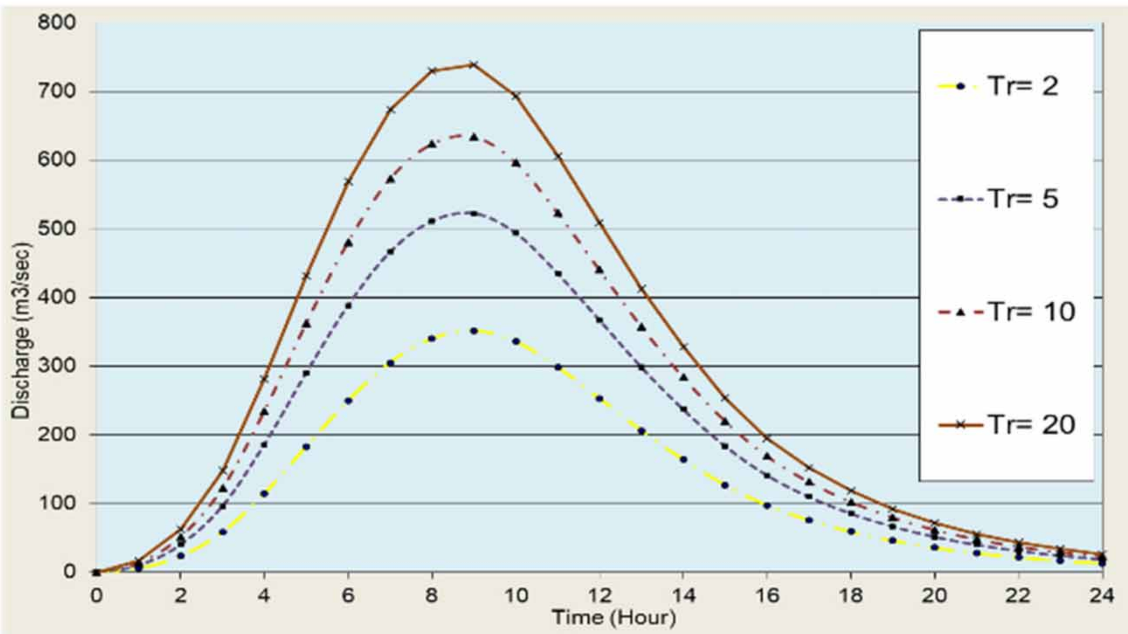


Figure 2 | Hydrograph of the Bila River SCS synthetic unit.

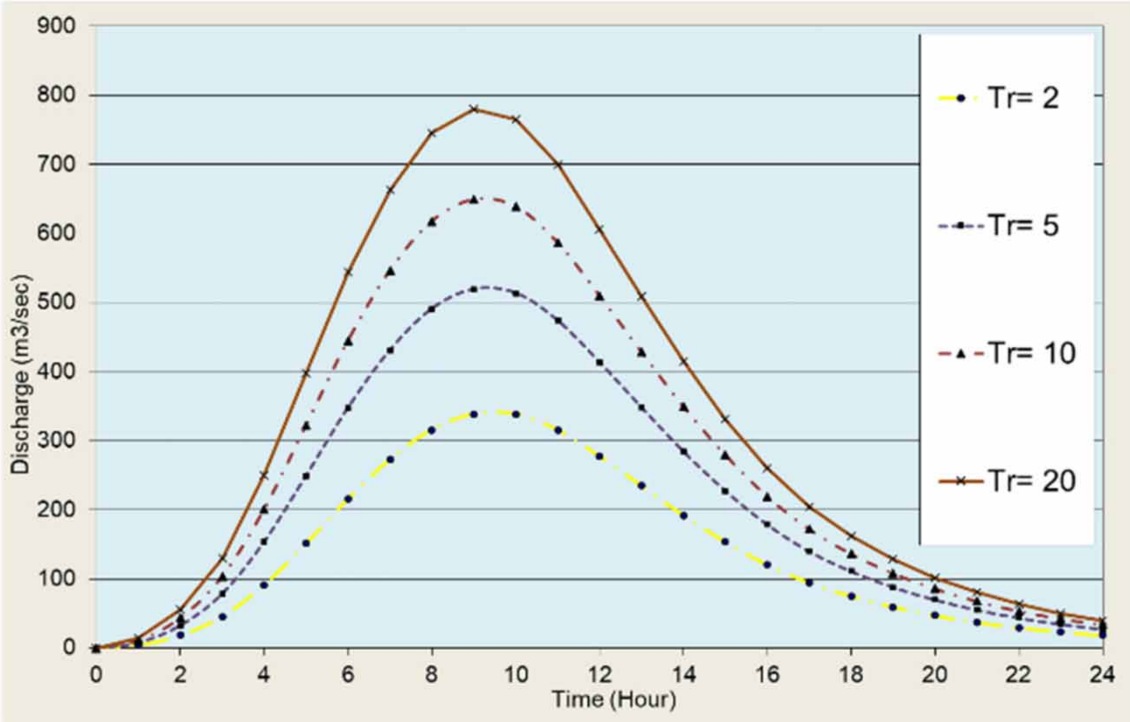


Figure 3 | Hydrograph of the SCS synthetic unit of the Bulucenrana River.

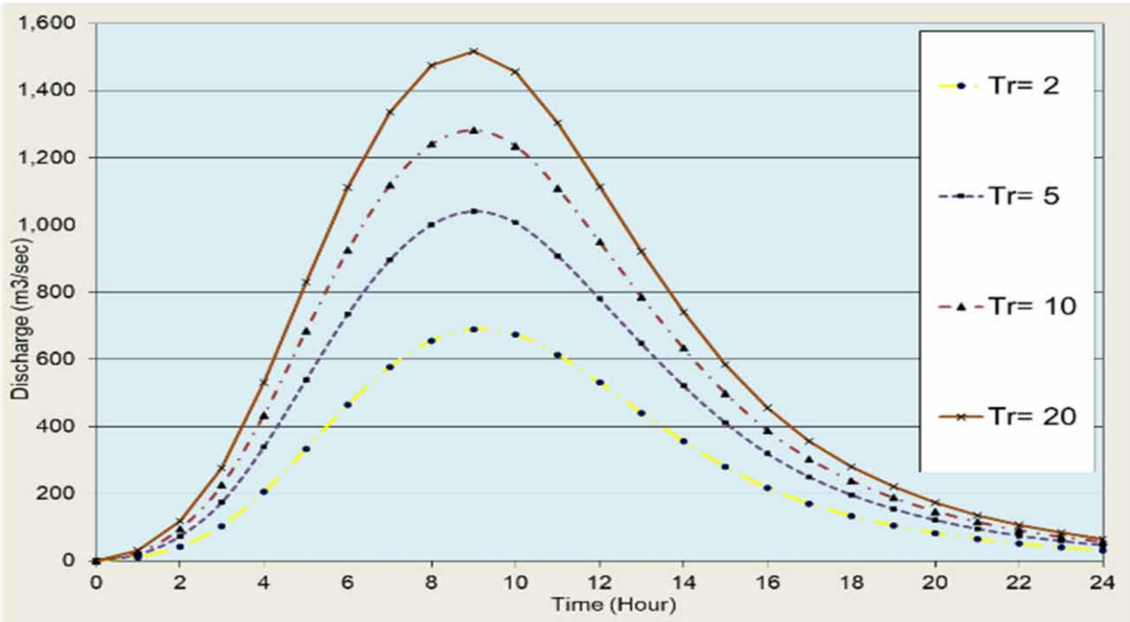


Figure 4 | Superposition SCS synthetic unit hydrograph.

namely the Bulucenrana River and the Bila River, so it is very necessary to revitalize the Bila River with an eco-drain, namely a retention basin.

The main consideration in determining the location of the retention pond in this study is in the upstream section by utilizing the old river channel to accommodate flood discharge and can also reduce flood discharge leading to the river estuary, namely Lake Tempe, given the complexity of flooding in the lake.

The retention pond is planned at the confluence of the Bila and Bulucenrana Rivers, namely in Taccimpo Village, Dua Pitue District at coordinates 3°53′3.18″S and 120°0′33.86″E. Details can be seen in Figure 6.

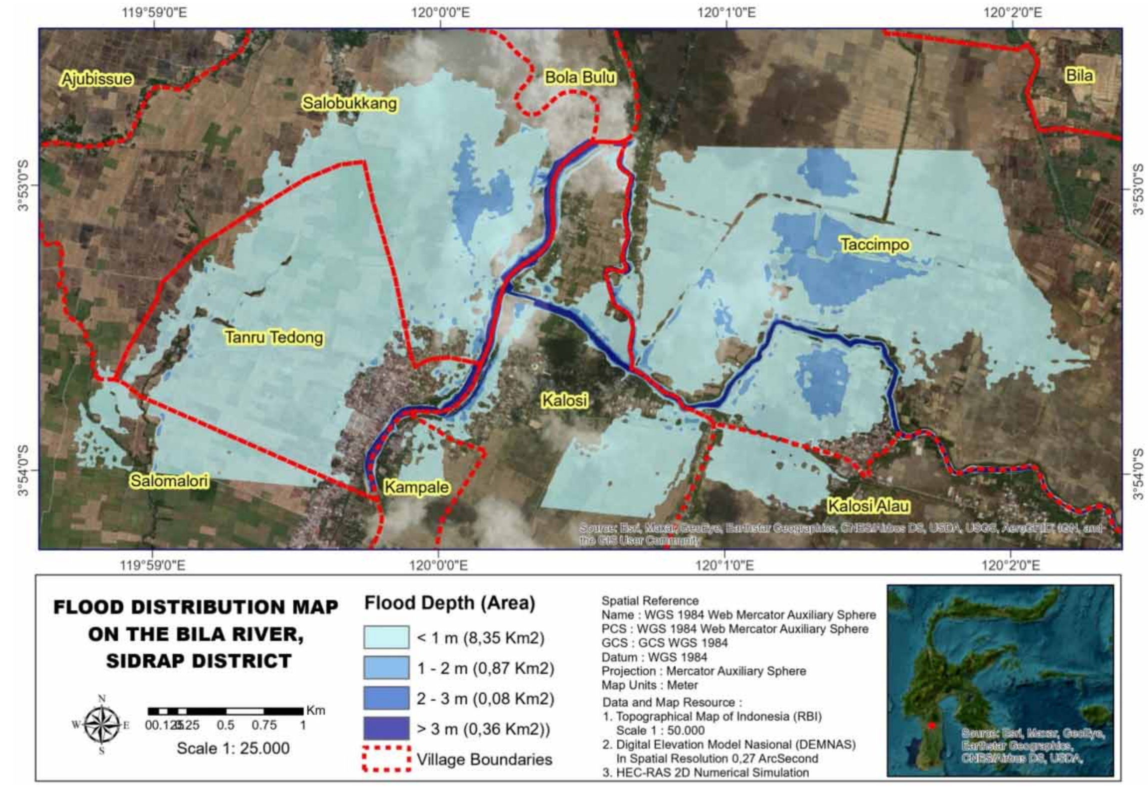


Figure 5 | Map of the flood distribution of the Bila River.

Table 3 | Affected areas based on village boundaries in Sidrap District

No.	Locations	Areas (km^2)
1	Desa Kalola	0.06
2	Desa Sogi	0.01
3	Desa Kalosi Alau	0.32
4	Desa Kampale	0.11
5	Kelurahan Salomalori	0.42
6	Kelurahan Tanru Tedong	2.12
7	Desa Kalosi	0.91
8	Desa Salobukkang	1.70
9	Desa Taccimpo	4.01
Total		9.66

Figure 6 shows the planned data for the Bila River retention pond where the maximum storage is 3.81 million m^3 and the normal storage is 2.4 million m^3. The simulation results of flood handling with regulation ponds can be seen in Figure 7.

The results of the Q_{20} flood inundation simulation with retention pond handling obtained a total inundation area of 1.38 km^2. Based on Figures 5 and 7, it can be seen that the differences in areas affected by flooding before and after the existence of retention ponds both in terms of flood depth and inundation area, in more detail, can be seen in Figure 8 and Table 4. Table 4 shows the total area of inundation that can be reduced after treatment is 8.28 km^2 or 85.71% of the area of inundation before the retention pond. There are only a few spots that are still experiencing overflow, but the height and area of the inundation that has occurred have been greatly reduced from the previous one.

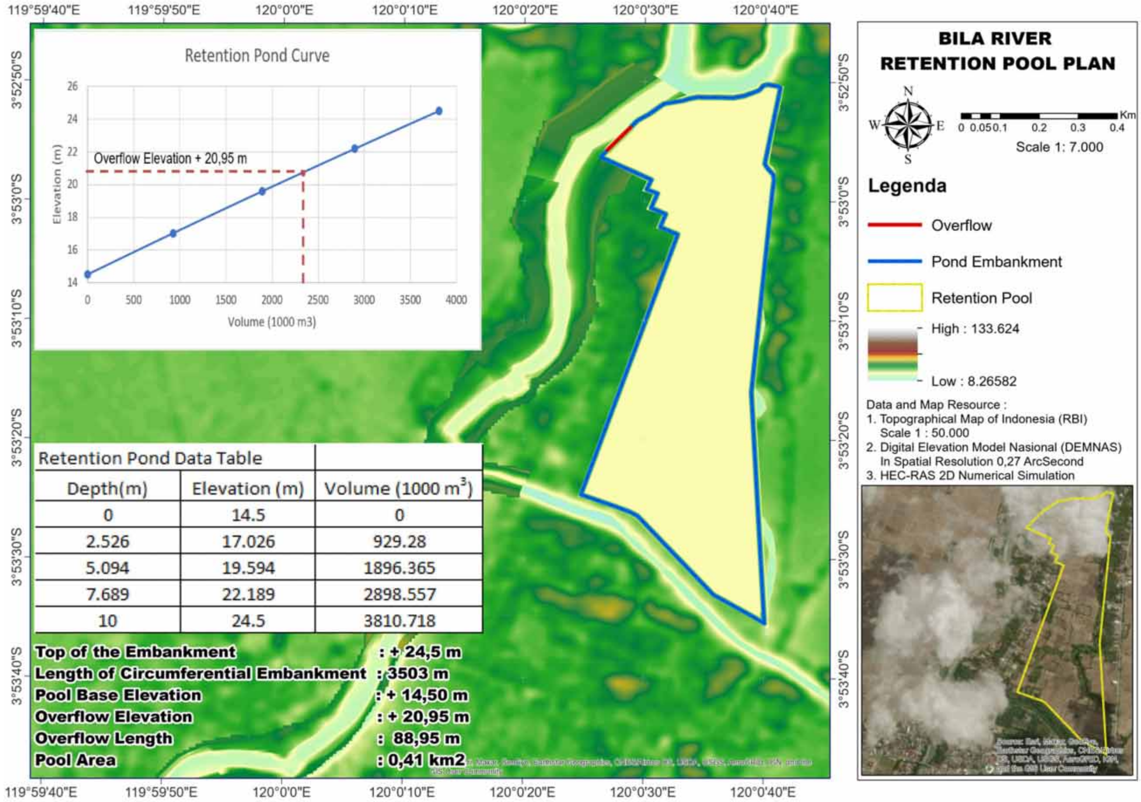


Figure 6 | Bila River retention basin plan.

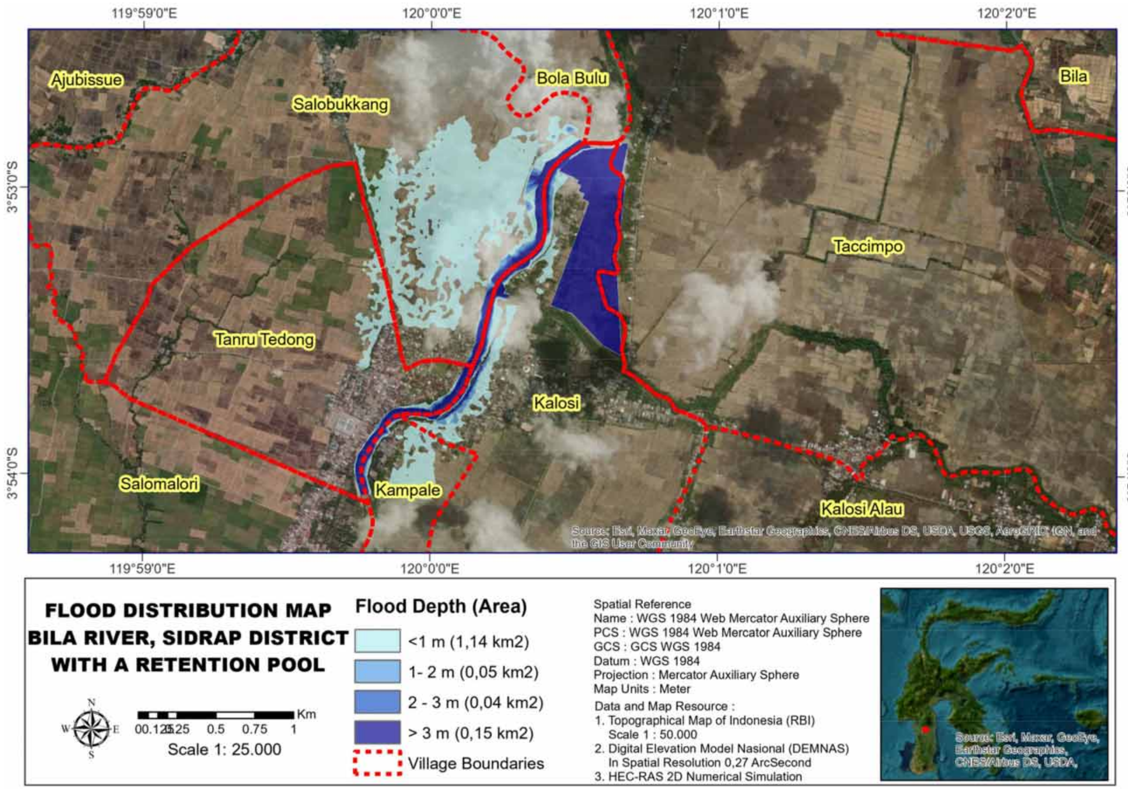


Figure 7 | Map of river flood distribution when after retention basins.

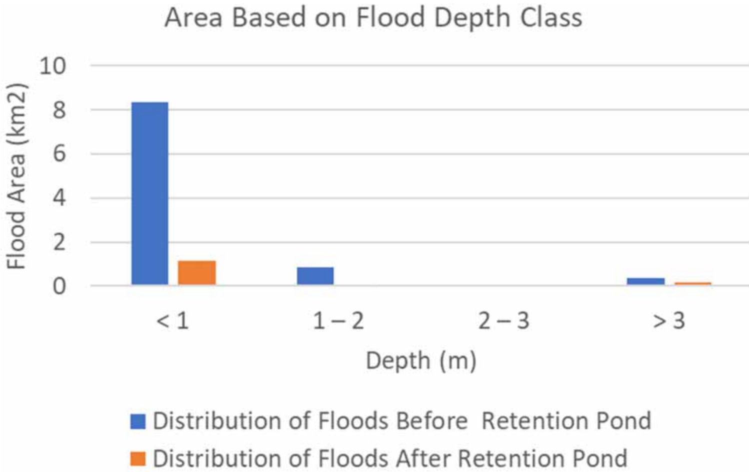


Figure 8 | Graph of area based on flood depth.

Table 4 | Affected areas before and after retention basins

No.	Locations	Flood-affected areas before retention basins (km^2)	Flood-affected areas after retention basins (km^2)	Difference (km^2)
1	Desa Kalola	0.06	–	0.06
2	Desa Sogi	0.01	–	0.01
3	Desa Kalosi Alau	0.32	–	0.32
4	Desa Kampale	0.11	0.11	–
5	Kelurahan Salomalori	0.42	–	0.42
6	Kelurahan Tanru Tedong	2.12	0.13	1.99
7	Desa Kalosi	0.91	0.18	0.73
8	Desa Salobukkang	1.70	0.96	0.74
9	Desa Taccimpo	4.01	–	4.01
Total		9.66	1.38	8.28

4. CONCLUSION

Based on the results of the research conducted, it can be concluded that the flood discharge from the HSS SCS analysis that enters the Bila Hilir River consists of the Bila and Bulucenrana Rivers with a flood discharge of $Q_{20} = 738.60\ m^3/s$ and $Q_{20} = 779.50\ m^3/s$, respectively. The overflow of the Bila River flood affected nine villages, namely Kalola Village (0.06 km^2), Sogi Village (0.01 km^2), Kalosi Alau Village (0.32 km^2), Kampale Village (0.11 km^2), Salomalori Village (0.42 km^2), Tanru Tedong Village (2.12 km^2), Kalosi Village (0.91 km^2), Salobukkang Village (1.70 km^2), and Taccimpo Village (4.01 km^2). So that the total area affected is 9.66 km^2. The solution to addressing the Bila River flood is with an environmentally sound drainage system, namely by planning to build a retention pond with a maximum storage volume of 3.81 million m^3 and a normal storage of 2.4 million m^3 which can reduce around 8.28 km^2 or 85.71% of the area inundation prior to the presence of a retention pond.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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