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Impact of Land Use Change on Flood Inundation Areas

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Abstract: The recent flood disasters in Indonesia between 2020 and 2023 resulted in more than 1,500 incidents annually. These flood events have become more widespread in terms of the areas affected, duration, depth, and frequency. The increasing scale of flooding can have a significant impact on the inundation area. This research examines the changes in the flood inundation area each year due to the consequences of land use alterations in the watershed, which are responsible for the flood disasters. The research methodology consists of literature study and analysis of land use change based on the satellite Citra in 2014, 2015, and 2021; the research location is in the Karangmumus watershed, Talangsari sub-watershed in Samarinda. The findings indicated that the rainfall depth was 70 mm, and the area inundated to a depth greater than 0.7 m was 4.6 ha; the area inundated to a depth greater than 0.5 m was 7.54 ha, and the area inundated to a depth greater than 0.3 m was 21.56 ha. Changes in the extent of flood inundation have an effect on the level of the flood inundation zone. The findings from this study can serve as a basis for establishing the guidelines for watershed region usage.

Keywords: flood, land use, inundation area, disaster.

土地利用变化对洪水淹没区的影响

摘要：印度尼西亚最近在2020年至2023年期间发生的洪灾导致每年发生1,500多起事件。这些洪水事件在受影响的区域、持续时间、深度和频率方面变得更加普遍。洪水规模的扩大会对淹没区域产生重大影响。这项研究考察了由于流域土地利用变化导致的每年洪水淹没面积的变化，而流域土地利用变化是造成洪灾的原因。研究方法包括文献研究和基于2014年、2015年和2021年卫星西特拉的土地利用变化分析；研究地点在三马林达的卡朗穆穆斯流域、塔朗萨里子流域。研究结果表明，降雨深度为70毫米，淹没深度超过0.7米的面积为4.6公顷；0.5米以上淹没面积为7.54公顷，0.3米以上淹没面积为21.56公顷，洪水淹没范围的变化对洪水淹没区的高度有影响，本研究结果可作为制定流域区域使用准则的依据。

关键词：洪水、土地利用、淹没区、灾害。

1. Introduction

Floods are among the most prevalent disasters, resulting in substantial damage and frequently causing substantial loss to cities that serve as social and economic hubs [1]. Floods, landslides, and droughts have emerged as recurring natural disasters in Indonesia, annually inundating and overwhelming the country. According to the data provided by the Indonesia Disaster Information (http://dibi.bnph.go.id), which is managed by the National Disaster Countermeasures Institution (BNPB), floods are the most common natural disasters in Indonesia. It is reported that between 2010 and 2018, 17,076 disaster events occurred in the country. Out of these, floods occurred 6,247 times, which accounts for approximately 36.58% of all disaster events during this period. This makes floods the most prevalent type of disaster events, surpassing tornadoes (19.47% or 5,079 events) and landslides (24.24% or 4,140 events).

Flooding typically arises from a convergence of natural and human-induced factors [2, 3]. Natural causes of flooding include erosion, sedimentation, rainfall, river physiography or geo-physics, inadequate drainage, the effects of ebb and flow, land subsidence and erosion, and damage to flood control structures [4]. Human activities that can lead to flooding include land use change, waste disposal, slum areas along rivers or drainage, improper design of flood control measures; inadequate drainage systems, weirs, and water structures; and damage to flood control structures [5-7]. According to Smith's [7] classification, flood reason factors are typically grouped into four categories, including climatology, land subsidence, land use change, and population growth. The transformation of land use that frequently occurs is the conversion of a recharge area to a developed area, which cannot be avoided due to the fact that most flood plains possess the potential to serve as sites for urban, industrial, economic, or residential development.

The growth of a city is principally driven by population expansion [8]. Consequently, the economic and social activities of the populace also experience development. As the carrying capacity of the city is surpassed, a range of issues arise, including the increasing demand for infrastructure facilities. Land use changes negatively impact the city, particularly by reducing the level of comfort due to limited available space. Specifically, these changes lead to increased flooding and inundation, which become more frequent [9]. The reasons for the flooding issue in Samarinda, like in other cities in Indonesia, are outlined in [10]. There are at least five factors contributing to flooding in Indonesia: rainfall, destruction of watershed retention, planning errors in river channel development, river shallowing, and territorial, means, and infrastructure errors [11, 12].

Most flood-prone areas in Samarinda are in the Karangmumus watershed. Three significant occurrences transpired in the Karangmumus watershed during June 2019. Notably, the flood persisted for an unprecedented duration of 19 days, and the affected populace reached 52 million individuals [13]. In 2020, two flood incidents took place in January and May, resulting in a flood duration of 20 days and impacting an area of 919.90 ha and 1,181.4 ha, respectively [14]. The need for a more extensive effort to manage the hydrological and policy aspects of the Karangmumus watershed is crucial in light of the increasing frequency of floods. It is essential to take comprehensive measures to address this issue effectively [15]. In this case, it is necessary to conduct a study on the impact of land use change on the flood inundation area.

2. Materials and Methods

2.1. Materials

In this research, the following materials such as maps and data were used:

1. The DEM Nas map was employed to ascertain watershed attributes, including the area of the watershed, the length of the primary river, the distance between the watershed weight point and the outlet, and the average slope of the watershed. The DEM Nas map utilized in this study was obtained from the Geo-spatial Information Institution (BIG).
2. LiDAR map serves as the foundation for flood routing in regions susceptible to flooding. The LiDAR map employed is the one generated in 2021.
3. The following text has been rephrased to use a formal tone while maintaining the original content and structure.The rainfall data for the study were collected from a station located in the Karangmumus watershed, which is the primary river in the research area. Specifically, the data were sourced from five rainfall stations: Temindung, Tanah Merah, Pampang, Sei Siring, and Sempaja. To analyze the area rainfall, the Isohyet method was employed utilizing the rainfall data obtained from these stations.
4. The Citra satellite map utilizes two datasets, namely the mapping results from 2010 and 2021, to identify land cover in the research area.

2.2. Research Locations

The research was conducted in two sub-watersheds in Samarinda:

1. Talangsari, with a sub-watershed area of 6.60 km^2
2. Sempaja, with a sub-watershed area of 14.79 km^2

The two sub-watersheds are in the Karangmumus watershed. The selection of the two research locations was primarily based on the consideration that they are prone to flooding, which is an issue that becomes increasingly prevalent. This flood problem has a significant impact on the activity of society in both the prone to flooding area and the surrounding regions. The prone to flooding area encompasses the watershed center up to the downstream of the sub-watershed.

Maps of the sub-watersheds are shown in Fig. 1 and 2.

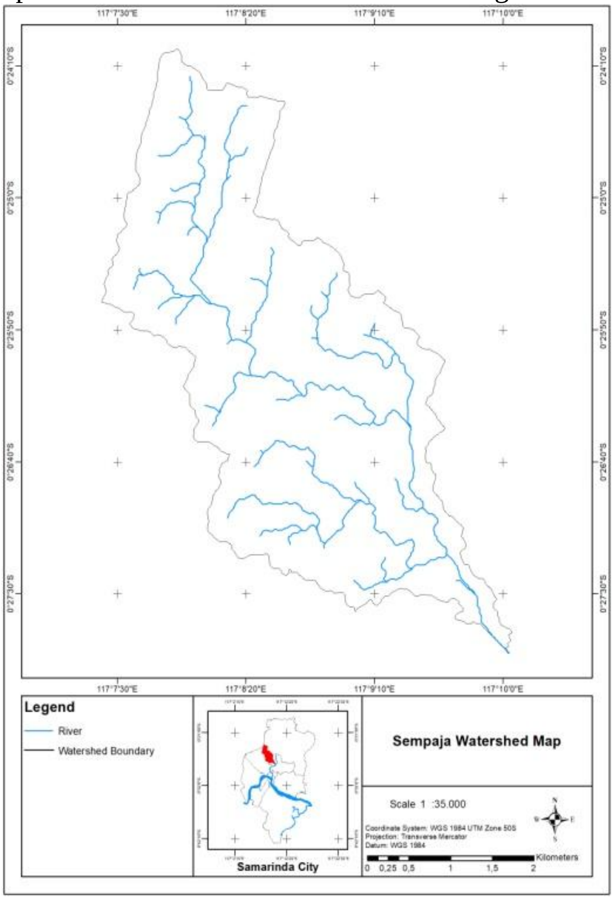


Fig. 1 Sempaja sub-watershed (The authors)

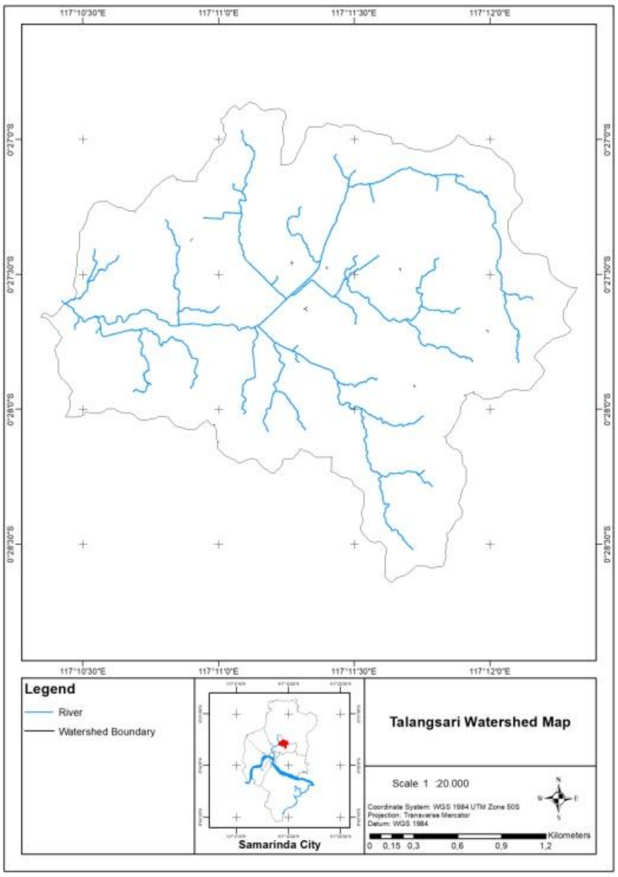
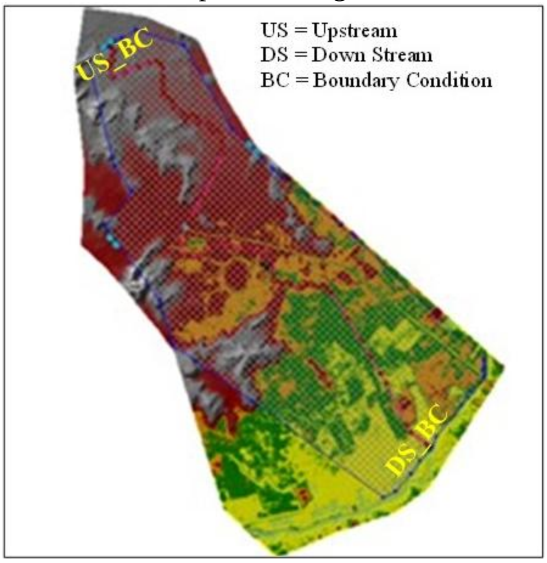


Fig. 2 Talangsari sub-watershed (The authors)

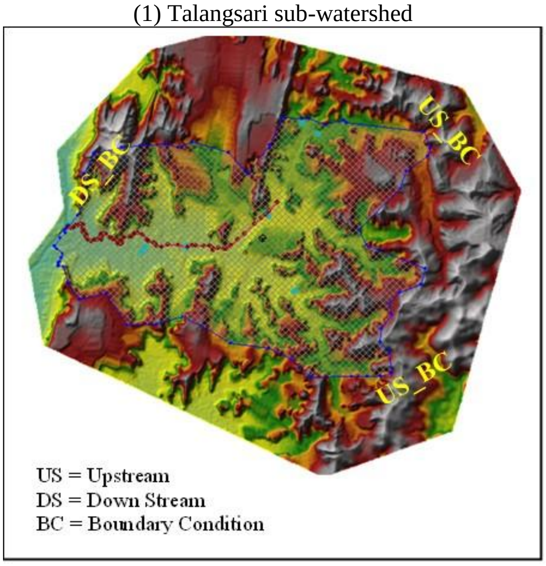
2.3. Methodology

2.3.1. Model

A model is a representation of a real form; however, a system is a mutual connectedness among elements that build unity. Models are usually built to achieve a certain objective. The aim of modeling is to analyze and provide predictions that are close to reality before the system is applied to the field. Modeling is a representation that depicts a complex reality through a logical sequence of events. This research builds a model to predict areas prone to flooding in the Talangsari and Sempaja sub-watersheds. Modeling of areas prone to flooding will be the input to the HEC-RAS 6.1 software. The LiDAR map was employed to delineate the areas susceptible to flooding. The modeling was subsequently integrated into HEC-RAS 6.1, taking into account the findings from the flood-prone region analyses of the Talangsari and Sempaja sub-watersheds, as depicted in Fig. 3.



(1) Talangsari sub-watershed



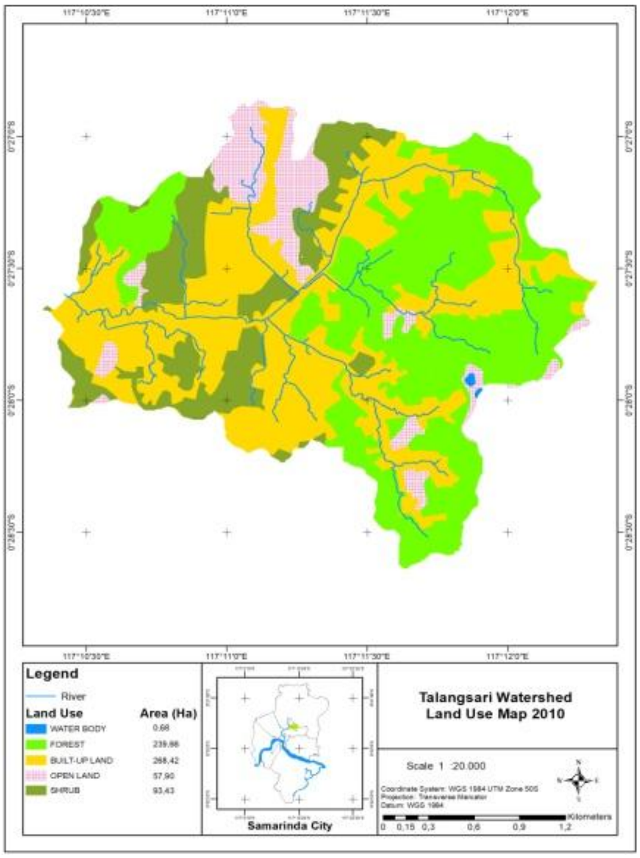
(2) Sempaja sub-watershed

Fig. 3 Models of the inundation areas (The authors)

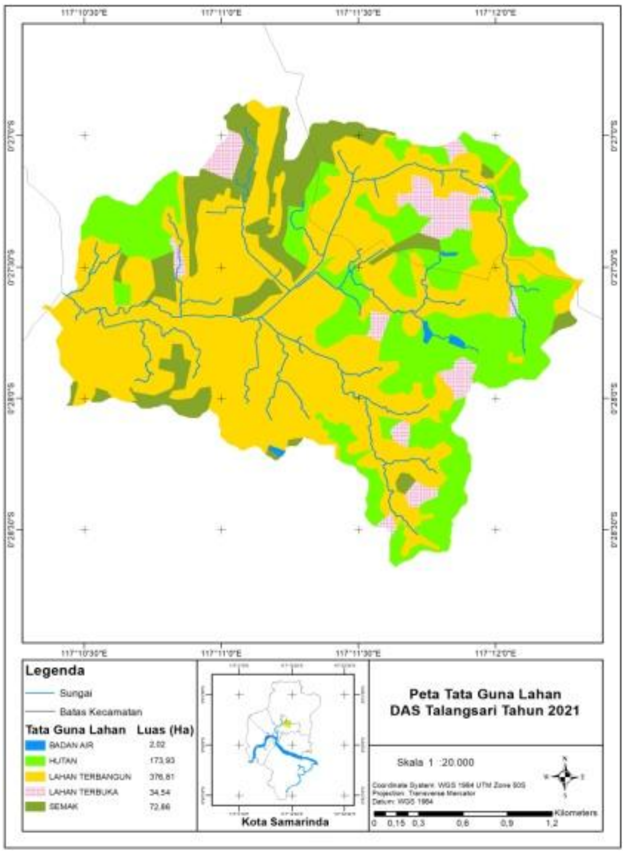
The completion of the inundation area models involves the use of upstream and downstream boundaries, which serve as points that are assumed to be the starting points of the flood hydrograph as it flows downstream. In these models, the downstream boundary is set to a normal depth, assuming that it is not affected by the ebb and flow of the main river. On the other hand, the upstream boundary is assumed to be the point where the flood hydrograph begins to enter the sub-watershed flow system.

2.3.2. Land Use Change

In this study, land cover change was examined by means of a thorough analysis of a land cover map. The area use analysis is divided into several types of land cover. The land use map in this study is examined with respect to two annual timeframes: 2010 and 2021. This land use map was an input to the run-off analysis. Land use analysis for the Talangsari and Sempaja sub-watersheds was conducted using the ArcGIS software, with the Citra satellite map serving as the base map. Fig. 4 and 5 depict the categorization of land cover into five groups: 1) developed areas, 2) open areas, 3) bushes, 4) forests, and 5) water bodies. Fig. 4 and 5 present the pattern maps of the land cover in the two sub-watersheds.

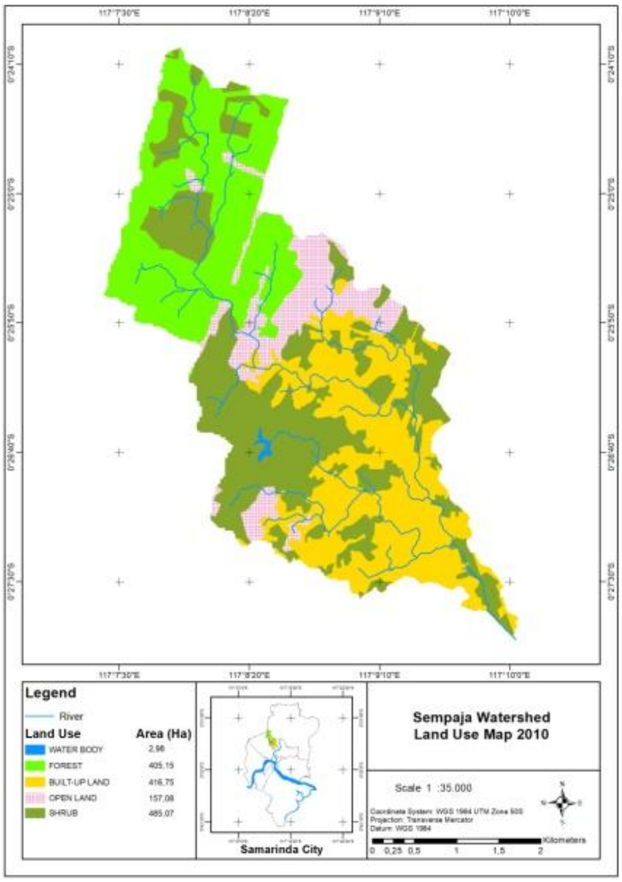


(1) Land cover in 2010

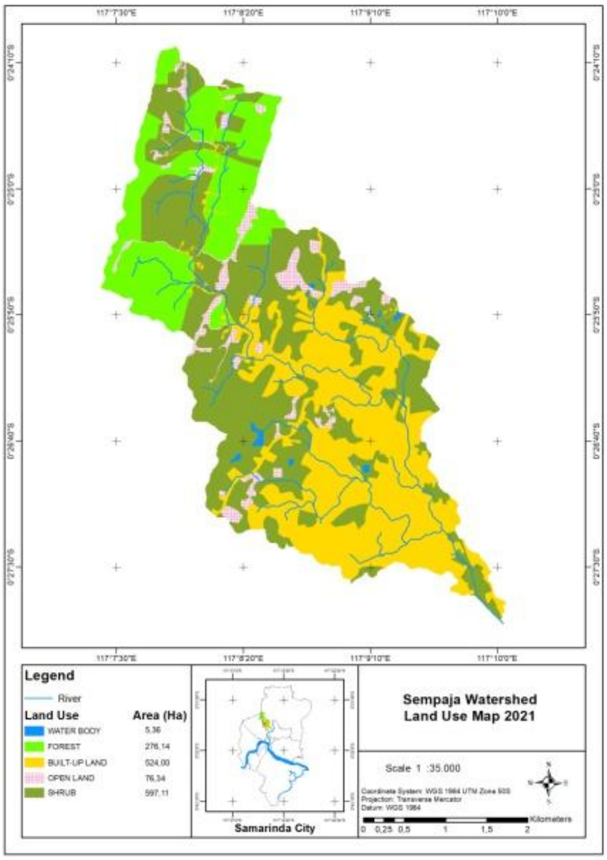


(2) Land cover in 2021

Fig. 4 Map of land cover change in the Talangsari sub-watershed (The authors)



(1) Land cover in 2010



(2) Land cover in 2021

Fig. 5 Map of land cover change in the Sempaja sub-watershed (The authors)

The land cover map's identification results in the two sub-watersheds reveal that the majority of them are characterized by developed land covers, such as residences, shops, shopping centers, and roads. The developed region in the Sempaja watershed is situated in the central and downstream areas. In contrast, the Talangsari sub-watershed exhibits a more extensive development across its sub-watersheds.

2.3.3. Flood Hydrographs

Runoff refers to rainfall that fails to infiltrate the land and instead flows off the surface. In areas with impermeable soil, it is generally accepted that the runoff is equal to the amount of rainfall minus the amount of evaporation. However, when the land has been saturated, the infiltration rate decreases, resulting in an increased amount of runoff for the same amount of rainfall, depending on the soil moisture content [16]. Surface runoff refers to rainfall that accumulates as a thick layer on the surface and flows into ditches and drains, eventually joining other affluents and eventually forming a river [17]. Rainfall that falls within a watershed flows toward a river, demonstrating a connection between rainfall, flow discharge, and watershed characteristics [18].

In this study, the transformation of rainfall data into discharge data is conducted to obtain the flood discharge. This process is accomplished through the examination of a synthetic unit hydrograph, as there are no available records of daily or hourly discharge. The return period of the design flood used in this research refers to the Ministry Rule of PUPR No. 28/2015, which states that the design flood for rivers in the capital of a province must be based on a 20-50 year flood discharge [19]. In this case, a design flood with a 20-year return period is utilized. The Limantara synthetic unit hydrograph was used in this research as follows [20]:

$$Q_p = 0{,}042A^{0.451}L^{0{,}497}L_c{}^{0{,}456}S^{-0{,}131}n^{0{,}168} \qquad (1)$$

where:

Qp - flood peak discharge of the unit hydrograph (m^3/s/mm)

A - watershed area (km^2)

L - length of the main river (km)

Lc - river length until the watershed weight point (km)

S - main river slope

n - roughness coefficient of the watershed

0.042 - coefficient for unit conversion ($m^{-0,25}$/s)

Equation of the rising curve:

$$Q_n = Q_p\left[\left(\frac{t}{T_p}\right)\right]^{1{,}107} \qquad (2)$$

where:

Q_n - discharge at the rising curve equation (m^3/s/mm)

t - hydrograph time (jam)

T_p - time of the peak of the hydrograph (h)

Equation of the recession curve:

$$Q_t = Q_p.10^{0{,}175(T_p-t)} \qquad (3)$$

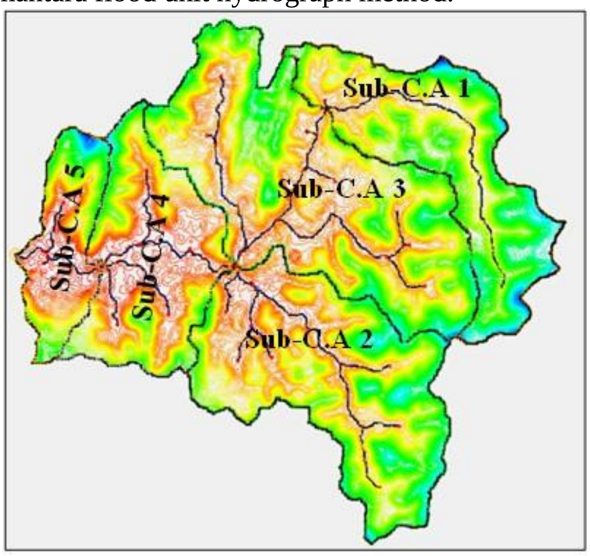
where:

Q_t - discharge at the recession curve equation (m^3/s/mm)

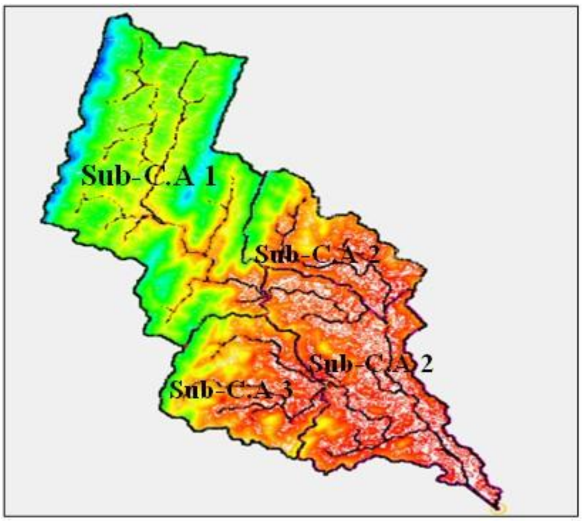
t - hydrograph time (h)

0.175 - time of the peak of the hydrograph (s^{-1})

Fig. 6 and Table 1 provide information about the characteristics of the Talangsari and Sempaja sub-watersheds, which are crucial for inputting data into the Limantara flood unit hydrograph method.



(1) Talangsari sub-watershed



(2) Sempaja sub-watershed
Fig. 6 Physical characteristics of the sub-watersheds (The authors)

Table 1 Physical parameters of the Talangsari and Sempaja sub-watersheds (The authors)

No.	Sub Catchment Area	Area (Km^2)	L (Km)	S	Lc (Km)	Note
A.	Talangsari					
1	Simpang 3 Lempake	1.24	2.258	0.0072	1.371	
2	Mugirejo	1.67	1.965	0.0067	1.139	
3	Simpang 3 Mugirejo	2.10	1.776	0.0028	0.925	
4	Simpang 3 Damanhuri	1.07	1.173	0.0040	0.347	
5	Alaya	0.53	0.652	0.0032	0.387	
B.	Sempaja					
1	Sempaja Hulu	6.74	5.417	0.0098	2.931	
2	SPMA	1.90	3.203	0.0045	1.418	
3	AW Syahrani	2.42	2.557	0.0084	1.650	
4	Perjuangan	3.72	5.356	0.0024	2.734	

2.3.4. Flood Routing

The objective of flood routing in this study is to determine the water level profile along the river channel and flood plain area. Specifically, the parameters that were analyzed include water depth and inundation area for certain depths. The physical processes occurring in river flow can be illustrated by the St. Venant equation, which comprises the continuity and momentum equations. The continuity equation is based on the principle of mass conversion; however, the momentum equation is based on the principle of momentum conversion. The St. Venant equation is expressed in the form of a partial differential equation as follows [21, 22]:

Continuity equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} - q\ell = 0 \tag{4}$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \tag{5}$$

Routing a simple steady flow:

$$S_f = \frac{n^2|Q|Q}{A^2R^2} \tag{6}$$

where:
A - total flow cross-section area
Q - flow discharge
ql - lateral discharge per unit length
V - flow velocity
g - gravitation
x - distance (measured in the same direction with flow)
z - water level elevation
t - time
Sf - friction slope
n - manning roughness coefficient
R - hydraulic radius

Routing unsteady flow:

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} + q = 0 \tag{7}$$

In subsequent simulations, the present study employs unsteady flow mechanisms for flood routing. In this case, the input is the flood hydrograph from each sub-watershed. To analyze the flood routing, the HEC-RAS 6.10 software was used.

3. Results and Discussion

According to the watershed land cover outcomes, the corresponding land cover areas are determined. Through the multiplication of the land cover and run-off coefficient for each type of land cover, the composite land cover coefficient is obtained, as depicted in Table 2.

Table 2 Analysis of the composite runoff coefficient in the Talangsari sub-watershed (The authors)

No.	Land Cover	Runoff Coefficient	Area 2010 (Ha)	Composite Runoff Coefficient	Area 2021 (Ha)	Composite Runoff Coefficient
1	Developed Land	0.85	268.42	0.346	376.91	0.485
2	Open Land	0.70	57.90	0.061	34.54	0.037
3	Bush	0.50	93.43	0.071	72.86	0.055
4	Forest	0.35	239.76	0.127	173.87	0.092
5	Water body	0.80	0.68	0.001	2.02	0.002
	Total		660.20	0.61	660.20	0.67

Upon examining the land cover analysis results in the Talangsari sub-watershed, it is evident that developed areas constitute 40.65% of the total land cover, making it the most extensive land cover type in the region. The composite run-off coefficient for the sub-watershed in 2010 was recorded at 0.61, but it experienced a rise to 0.67 in 2021. The increased coefficient value can be primarily attributed to the expansion of developed areas. This increase in the coefficient will lead to an increase in run-off for the Talangsari sub-watershed, consequently resulting in an enlarged flood inundation area. Table 3 presents the analysis of the composite runoff coefficient for the Sempaja sub-watershed.

Table 3 Composite runoff coefficient analysis for the Sempaja sub-watershed (Own study)

No.	Land Cover	Runoff Coefficient	Area 2010 (Ha)	Composite Runoff Coefficient	Area 2021 (Ha)	Composite Runoff Coefficient
1	Lahan terbangun	0.85	416.75	0.240	524.00	0.301
2	Lahan Terbuka	0.70	157.08	0.074	76.34	0.036
3	Semak	0.50	485.07	0.164	597.11	0.202
4	Hutan	0.35	417.05	0.099	276.14	0.065
5	Badan Air	0.80	2.98	0.002	5.36	0.003
	Total		1,478.93	0.578	1478.94	0.607

The Sempaja sub-watershed has a total area of 14.79 km^2. Bush land cover accounts for the largest proportion, comprising 32.8% of the land cover. Developed area and forest each make up approximately 28.2% of the land cover. Over the past 15 years, the water body land cover has undergone the most significant changes, despite the relatively small size of the sub-watershed. The forest and opened area land covers experienced the greatest decrease in area. The analysis of the composite run-off coefficient for the Sempaja sub-watershed in 2010 yielded a value of 0.578, while the value in 2021 was 0.607. The increase in the coefficient is attributed to the expansion of developed area land cover. The flood hydrographs of the Talangsari and Sempaja sub-watersheds are shown in Tables 4 and 5.

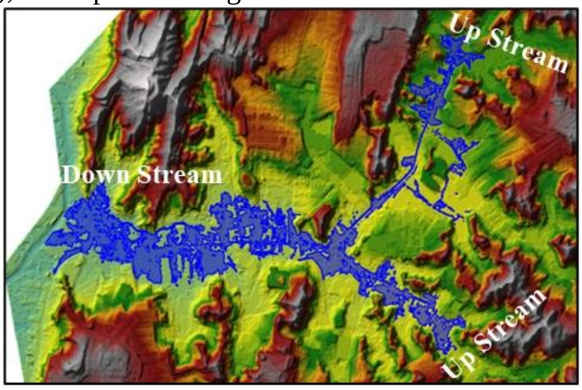
Table 4 Flood hydrograph recapitulation for every sub-sub-watershed in Talangsari (Own study)

Time	Flood Hydrograph 2010					Flood Hydrograph 2021				
	Lempake	Mugirejo	Citra Land	Damanhuri	Alaya	Lempake	Mugirejo	Citra Land	Damanhuri	Alaya
0	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1	0.659	0.840	1.023	0.652	0.433	0.709	0.909	1.112	0.701	0.458
2	1.510	2.000	2.494	1.419	0.821	1.653	2.196	2.744	1.552	0.888
3	7.061	9.691	12.351	6.767	3.561	7.809	10.725	13.676	7.482	3.927
4	6.321	8.364	10.396	5.207	2.679	6.989	9.253	11.507	5.753	2.949
5	4.376	5.749	7.113	3.560	1.857	4.831	6.354	7.867	3.926	2.037
6	2.991	3.909	4.820	2.445	1.307	3.295	4.313	5.324	2.690	1.428
7	2.065	2.679	3.288	1.701	0.940	2.269	2.949	3.625	1.864	1.021
8	1.447	1.857	2.264	1.203	0.695	1.583	2.037	2.489	1.312	0.748
9	1.033	1.307	1.579	0.870	0.531	1.124	1.428	1.730	0.943	0.567
10	0.757	0.940	1.122	0.648	0.421	0.818	1.021	1.222	0.697	0.445
11	0.572	0.695	0.816	0.499	0.348	0.613	0.748	0.883	0.532	0.364
12	0.449	0.531	0.612	0.400	0.299	0.476	0.567	0.657	0.422	0.309
13	0.366	0.421	0.475	0.334	0.266	0.384	0.445	0.505	0.348	0.273
14	0.311	0.348	0.384	0.289	0.244	0.323	0.364	0.404	0.299	0.249
15	0.274	0.299	0.323	0.260	0.229	0.282	0.309	0.336	0.266	0.233
16	0.250	0.266	0.282	0.240	0.220	0.255	0.273	0.291	0.244	0.222
17	0.233	0.244	0.255	0.227	0.213	0.237	0.249	0.261	0.230	0.215
18	0.222	0.229	0.237	0.218	0.209	0.225	0.233	0.241	0.220	0.210
19	0.215	0.220	0.225	0.212	0.206	0.216	0.222	0.227	0.213	0.207
20	0.210	0.213	0.216	0.208	0.204	0.211	0.215	0.218	0.209	0.204
21	0.207	0.209	0.211	0.205	0.203	0.207	0.210	0.212	0.206	0.203
22	0.204	0.206	0.207	0.204	0.202	0.205	0.207	0.208	0.204	0.202
23	0.203	0.204	0.205	0.202	0.201	0.203	0.204	0.205	0.203	0.201
24	0.202	0.203	0.203	0.202	0.201	0.202	0.203	0.204	0.202	0.201

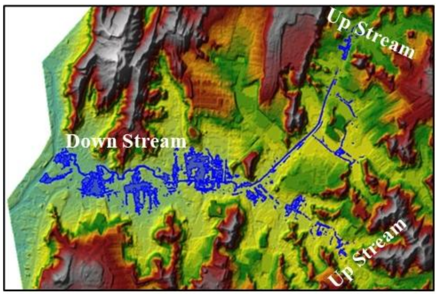
Table 5 Flood hydrograph recapitulation for every sub-sub-watershed in Sempaja (Own study)

Time	Flood Hydrograph 2010				Flood Hydrograph 2021			
	Sempaja Hulu	SPMA	AWS	Perjuangan	Sempaja Hulu	SPMA	AWS	Perjuangan
0	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1	2.428	0.795	1.010	1.163	2.540	0.825	1.051	1.211
2	7.460	1.971	2.543	3.330	7.828	2.061	2.661	3.489
3	35.902	9.289	12.388	15.609	37.707	9.749	13.004	16.389
4	42.961	9.191	11.455	18.572	45.124	9.646	12.024	19.501
5	30.096	6.392	7.904	13.040	31.607	6.706	8.294	13.689
6	20.181	4.339	5.349	8.782	21.191	4.548	5.609	9.216
7	13.554	2.966	3.641	5.935	14.229	3.106	3.815	6.225
8	9.125	2.049	2.500	4.033	9.576	2.142	2.616	4.227
9	6.165	1.436	1.737	2.762	6.467	1.498	1.815	2.891
10	4.187	1.026	1.227	1.912	4.388	1.068	1.279	1.999
11	2.864	0.752	0.887	1.344	2.999	0.780	0.921	1.402
12	1.981	0.569	0.659	0.965	2.071	0.588	0.682	1.004
13	1.390	0.447	0.507	0.711	1.450	0.459	0.522	0.737
14	0.995	0.365	0.405	0.542	1.036	0.373	0.415	0.559
15	0.732	0.310	0.337	0.428	0.759	0.316	0.344	0.440
16	0.555	0.274	0.292	0.353	0.573	0.277	0.296	0.360
17	0.437	0.249	0.261	0.302	0.449	0.252	0.264	0.307
18	0.359	0.233	0.241	0.268	0.367	0.235	0.243	0.272
19	0.306	0.222	0.227	0.246	0.311	0.223	0.229	0.248
20	0.271	0.215	0.218	0.230	0.274	0.215	0.219	0.232
21	0.247	0.210	0.212	0.220	0.250	0.210	0.213	0.221
22	0.232	0.207	0.208	0.214	0.233	0.207	0.209	0.214
23	0.221	0.204	0.205	0.209	0.222	0.205	0.206	0.210
24	0.214	0.203	0.204	0.206	0.215	0.203	0.204	0.206

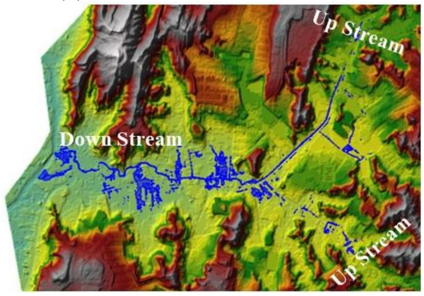
The outcomes of flood routing for each sub-watershed, taking into account the design flood with a 20-year return period and categorized by water depth (more than 20 cm, less than 50 cm, and more than 70 cm), are depicted in Fig. 7.



(1) Inundation area of 34.25 ha



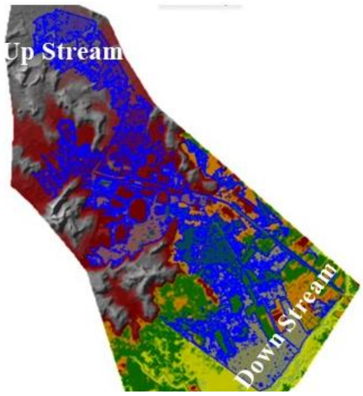
(2) Inundation area of 12.15 ha



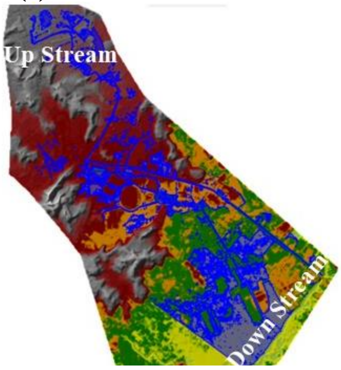
(3) Inundation area of 6.47 ha

Fig. 7 Inundation area in the Talangsari sub-watershed for land use in 2010: (1) inundation exceeding 20 cm, (2) inundation surpassing 50 cm, (3) inundation surpassing 70 cm (The authors)

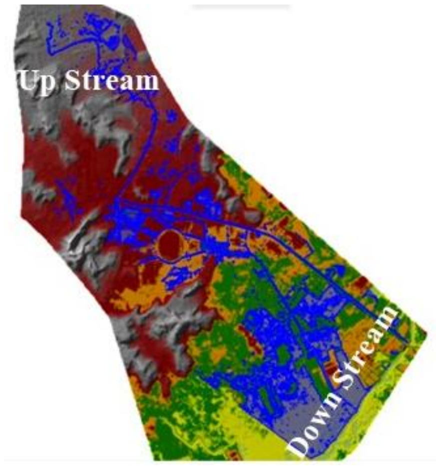
Based on the flood routing results for the Talangsari sub-watershed, the areas at risk of flooding are located in the valley of the sub-watershed and extend downstream. This is illustrated in Fig. 8(1), which shows that flooding with water depths exceeding 20 cm can cause inundation along the river channel and even spill over onto the main road in the flood-prone area. Fig. 3(2) and (3) also indicate that the flood inundation area becomes narrower for water depths greater than 50 and 70 cm.



(1) Inundation area of 165.4 ha



(2) Inundation area of 83.2 ha



(3) Inundation area of 74.5 ha
Fig. 8 Flood inundation in the Sempaja sub-watershed with respect to land use in 2010: (1) inundation exceeding 20 cm, (2) inundation exceeding 50 cm, (3) inundation exceeding 70 cm (The authors)

According to the results of flood routing in the Sempaja sub-watershed, the largest area susceptible to flooding is located in the downstream region, which is currently characterized by bushes and gradually transformes into a swamp. As depicted in Fig. 3(1), floods with a water depth of over 20 cm result in inundation along the Sempaja river channel and spill over into the main river in the area prone to flooding. Fig. 8(2) and (3) illustrate that the flood inundation area becomes narrower for water depths exceeding 50 and 70 cm, respectively.

According to Fig. 7 and 8 and Tables 6 and 7, the outcome of the flood routing analysis conducted using the HEC-RAS 6.1 software for the land use condition in 2010, with a 20-year return period for the design flood, reveals the extent of inundation in the Talangsari and Sempaja sub-watersheds. Specifically, the inundation area with a depth exceeding 20 cm in the Talangsari sub-watershed amounts to 34.25 ha, while in the Sempaja sub-watershed, it covers an area of 165.4 ha. Flood routing in the Talangsari sub-watershed based on land use in 2021 shows that the flood inundation area for depth more than 20 cm is 35.42 ha; however, in the Sempaja sub-watershed, it is 168.00 ha. Based on the flood mapping results for 2010 and 2021 (Tables 6 and 7), there was an increase in the flood inundation area for depths greater than 20 cm in 2021. Specifically, in the Talangsari sub-watershed, the increase was approximately 3.42%, while in the Sempaja sub-watershed, the increase was around 1.57%.

Table 6 Comparison of flood inundation areas between 2010 and 2021 (Own study)

No.	Name	Catchment Area (Ha)	2010 20 cm	2010 50 cm	2010 >70 cm	2021 20 cm	2021 50 cm	2021 >70 cm
1	Talangsari	6,600.00	34.25	12.15	6.47	35.42	14.02	7.15
2	Sempaja	1,479.00	165.4	83.2	74.5	168.00	84.6	75.9

Table 7 Increasing percentage of C coefficient and inundation from 2010 to 2021 (Own study)

No.	Name	Procentage of increasing			
		C	>20 Cm	>50 Cm	>70 Cm
1	Talangsari	10.90%	3.42%	15.39%	10.51%
2	Sempaja	5.06%	1.57%	1.68%	1.88%

4. Conclusions

This study aimed to examine the changes in the flood inundation area annually due to the land use change-induced flood disaster in the watershed. The research focused on the two sub-watersheds located in the Karangmumus watershed. The selection of these two locations was based on the fact that they experience a flood problem every year, which continues to worsen. This flood issue significantly impacts the activities of society in the flood-prone areas and the surrounding regions. The flood-prone zone extends from the watershed center to the downstream of the sub-watershed.

The research conducted demonstrated that the change in land use from 2010 to 2021 has a significant influence on the rise of the run-off coefficient. Consequently, an increase in the run-off coefficient leads to an expansion of the flood inundation area. The relationship between the run-off coefficient and the inundation area is not directly proportional, and it is also influenced by the topographic characteristics of areas prone to flooding. The difference in flood inundation area between the Sempaja and Tawangsari sub-watersheds is notable, with the Sempaja sub-watershed exhibiting a more gradual and lower incline compared to the Tawangsari sub-watershed. This suggests that the flood-prone areas in the Sempaja sub-watershed are relatively flat when contrasted with those located further downstream in the Tawangsari sub-watershed. According to the flood mapping results for 2010 and 2021, there was a rise in the extent of flood inundation for depths greater than 20 cm in 2021. Specifically, in the Talangsari sub-watershed, the increase is approximately 3.42%, while in the Sempaja sub-watershed, the increase is around 1.57%.

To closely examine the mapping of areas prone to flooding based on the design flood with a 20-year return period, it is necessary for the government to establish policies that prevent the development of these areas. If development is carried out in these areas, flooding is likely to become more widespread. Further research can be conducted to evaluate the impact of flood inundation area and depth on the flood inundation level, particularly in areas where there are population, regional economy value, economy area value, transportation access inundation value, and available infrastructure damage value.

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