RESEARCH PAPER

CONTRIBUTED INDICATORS TO FLUVIAL FLOOD ALONG RIVER BASIN IN URBAN AREA OF INDONESIA

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ABSTRACT. Flooding is the most common disaster in Indonesia, it is classified as a disaster if it affects humans causing physical and financial losses. Flood damage depends on the type of flood, flow velocity, and duration. The increase in population will cause an increase in infrastructure that will affect the environment, including the carrying capacity of rivers and catchment areas, while flooding in urban areas will also have an impact on infrastructure and assets, increasing flood damage. This study discusses the factors that cause flooding (rainfall, topography, soil type, land slope, distance from rivers, river waste, population density, etc.), as well as various types of floods that occur. The method used in this research was based on the qualitative analysis of the information from the government and literature over the last five years obtained from online databases and search engines. The results of this study can provide a reference for the theory regarding disaster risk assessment and flood hazard prediction in watersheds. This research was conducted in the Ciliwung Watershed (DAS), where the factors and the dominant type of flooding were determined. Knowing the contributing factors can be beneficial for flood risk management. This research focuses on identifying factors that contribute to fluvial flood events and understanding their influence so that a more integrated flood risk management that takes into account the upstream, middle, and downstream parts of the watershed can be arranged in other areas based on the example of measures implemented by the local government in the Ciliwung watershed. This conceptual effort provides a much-needed foundation for developing better mitigation efforts in watersheds.

KEYWORDS: Flood Hazard, Contributing Factor, Flood type, Distance from the river, conceptual study

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INTRODUCTION

According to the United Nations World Health Organization (WHO), a disaster is defined as an event that disrupts normal conditions and causes a level of suffering that exceeds the ability of the affected population to adapt. According to Law No. 24/2007 of the Republic of Indonesia, a disaster is a series of events that threaten and disrupt people's lives and livelihoods caused by natural, non-natural, and man-made factors. According to Omena et al. (2020), disasters can be categorized into natural and non-natural disasters, and as long as an event impacts the functions of the community so that human activities cannot run normally, it can be categorized as a disaster. Based on the above, a flood is classified as a disaster if it causes financial and physical losses, as well as loss of human life. Meanwhile, increased vulnerability to flooding cannot be solely attributed to climate, as it is also affected by population growth, rapid urbanization, and urban sprawl (Pornasdoro et al. 2014). As a result, even though a city is densely populated and has a high economic value, disasters caused by floods can cause a setback in its development for several years (Tingsanchali 2012).

Flood damage depends on the type of flood, flow velocity, and duration. Increased population density coupled with flood-affected infrastructure and assets in cities increases the likelihood of urban flood damage, while the uncontrolled growth of urban settlements reduces their drainage capacity (Tingsanchali 2012). This paper will discuss the definition of flood hazard, flood event, and flood disasters and the differences between fluvial flooding, flash flooding, and coastal flooding based on flood events that occurred in Indonesia to identify their generic and specific indicators, as well as the methods for their assessment based on event parameters. The study also analyzed flood events in the Ciliwung river basin in order to develop better mitigation efforts in flood management based on the factors that influence flood events in the area, particularly the characteristics of the river, which include its width, order, slope, and other factors that affect the watershed.

MATERIALS AND METHODS

Study Location

This research was conducted on the Ciliwung river, which passes through Bogor Regency, Bogor City, Depok City, South Jakarta, and East Jakarta, and flows into Jakarta Bay. Geographically it spans from 6^{0} 6′ 00″ to 6^{0} 46′ 12″ S and from 106^{0} 48′ 36″ to 107^{0} 00′ 00″ E (Fig. 1). Its watershed has an area of 386 km^2 and an average slope of 8%, while the average river slope is 0.0146 meters.

Method

This research was conducted based on field observations and a literature review. Field observations were carried out to assess the morphometry characteristics of the watershed. The analysis of watershed morphometry was also carried out using Geographical Information Systems (GIS) for mapping and analyzing land use changes in the Ciliwung watershed over the period of 30 years. The literature search was performed using online databases and search engines. The review includes journals and conference papers identified from SCImago and Google Scholar, reports published by the World Meteorological Organization and government agencies, as well as other reports identified online with a Google search.

This research paper covers the development of a general framework for flood management based on its constituent factors, it discusses several types of floods, such as fluvial, coastal, and flash floods, and focuses on specific and general indicators as well as data sources considered for the establishment of a decision support system in flood management. The general flowchart of the research is presented in Fig. 2 below.

The time frame of the study was limited to the period from 2002 to 2022. The goal of the literature review was to determine contributing factors, assess their magnitude, and identify flood events in various areas in Indonesia, including in the Ciliwung watershed, to distinguish between different types of flooding.

The research followed the flowchart (see Fig. 2) to determine the contributing factors for each flood type based on the literature review and identify the indicator variables. River characteristics were determined using QGIS by mapping USGS satellite data combined with data from the ministry of public works represented by the Ciliwung Cisadane River Basin Center (BBWS Cilincis) and guidelines for watershed characteristics (Ministry Of Forestry Directorate General Of Watershed Development Management And Social 2013). River morphometric characteristics were also estimated based on the river order, which can be determined using the Horton, Strahler, Shreve, and Scheidegger methods. In general, the Strahler method is easier to implement than the other methods. In this method, the upstream river channel without tributaries is assigned an order of 1, after it intersects with another stream of the same order, it is assigned an order of 2, and so on. As a result, the highest order number will correspond to the downstream of the main river (see Fig. 9). The number

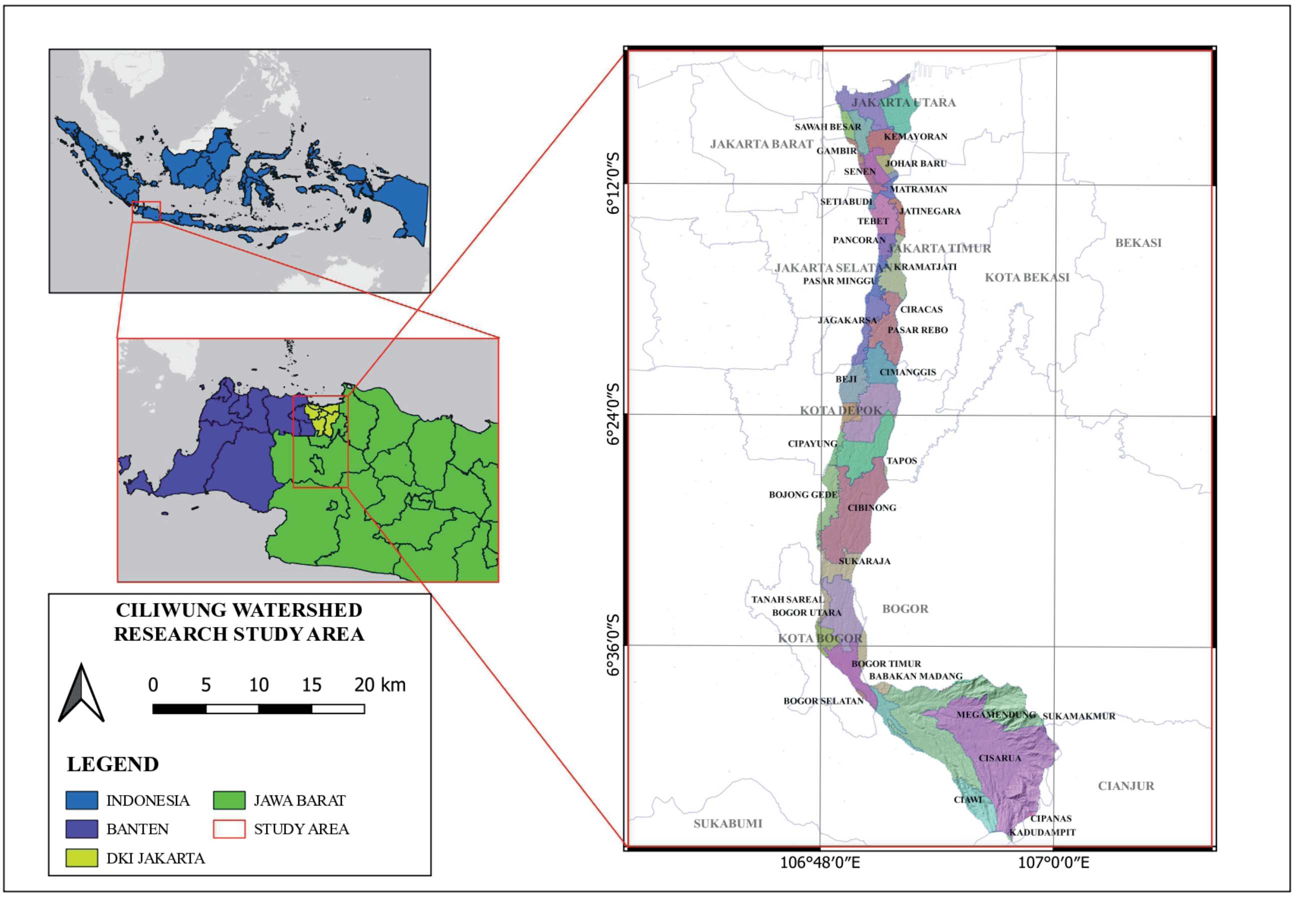

Fig. 1. Study Area

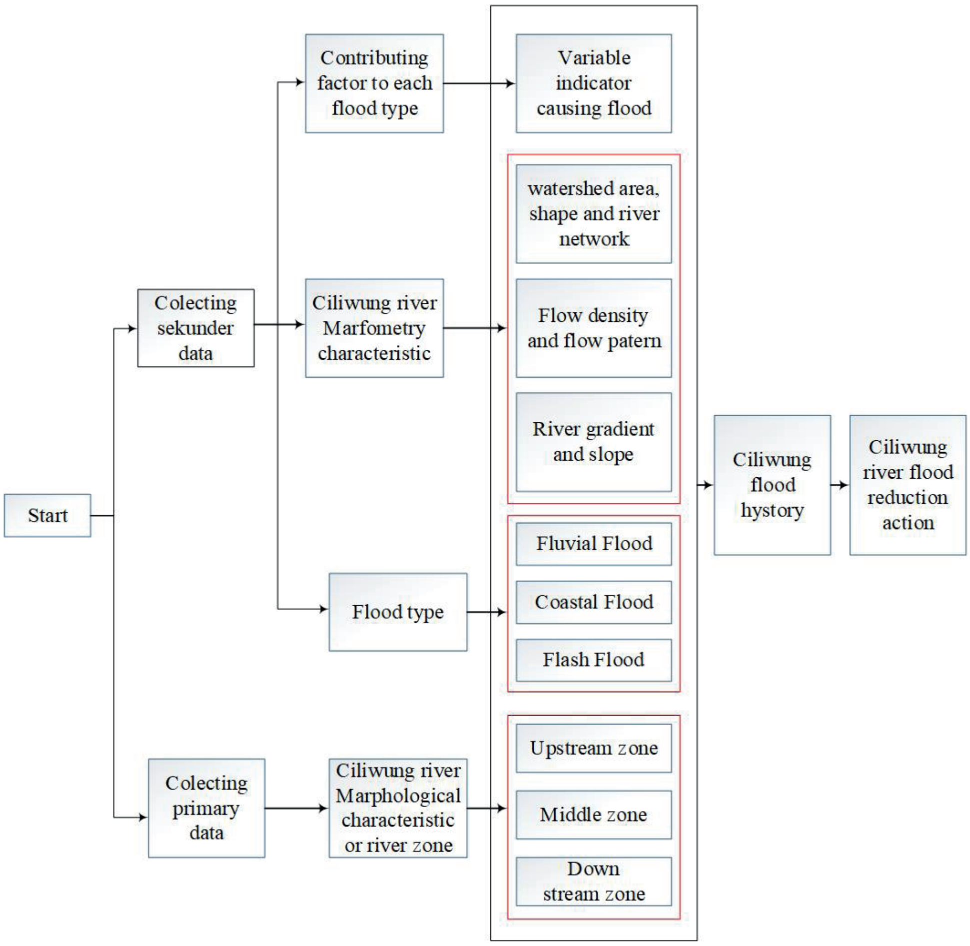

Fig. 2. Research Flowchart

of streams of a certain order can be determined from the bifurcation ratio (Rb) using the following formula:

$$Rb = \frac{N_u}{N_{U+1}} \quad (1)$$

Where:
Rb = River branching rate index
N_u = The number of streams for the order u
N_{U+1} = The number of streams for the order (u+1)

River density is an index that characterizes the drainage network of a watershed and is calculated as the total length of streams (km) per square kilometer of the watershed area. The greater value of Dd indicates better drainage, which results in higher water runoff (less infiltration) and smaller groundwater storage in the area. River density value can be determined as follows:

$$Dd = \frac{\Sigma L_n}{A} \quad (2)$$

Where:
L_n = River Length
A = Watershed area

The Ciliwung river data were obtained based on field observations along the Ciliwung river in the upstream, middle and downstream parts, and included various flooding indicators, as well as river morphometry and morphology characteristics, which were then used to determine the type of floods in the Ciliwung basin.

RESULTS

Types of Floods and their Criteria

Based on the type, floods can be divided into three categories, namely Fluvial Floods (Fig. 3), Coastal Floods (Fig. 4), and Flash Floods (Fig. 5). Fluvial Floods are usually caused by excessive rainfall occurring over a long period and a large area, which can cause large rivers to overflow and inundate the surrounding land. Precipitation in the upstream area will affect the downstream area, even when the downstream area does not receive much rain (Asdak et al. 2018). Coastal Floods in Indonesia include tidal floods, which is a phenomenon of increasing sea level that results in the inundation of tidal areas. Coastal flooding can also be caused by large storms that increase the water level and create high waves (Hanif et al. 2021). Increased flooding in coastal areas will affect both urban and traditional settlements not only due to rising sea levels and climatic factors of the island but also due to population increase in coastal areas (Esteban et al. 2011). Flash floods usually occur on steep slopes due to heavy rainfall, which can cause riverbeds that initially had no water to suddenly overflow. The rainwater that fell on a slope then rushes down the hill with high velocity and gathers in a river at the bottom. Flash floods can be also caused by infrastructure failures such as a broken embankment along the sea or a river, which can also cause water to flow suddenly and with high velocity. (Zanchetta dan Coulibaly 2020).

Contributing Factors to Each Flood Type

Fluvial floods, often called river floods, occur when the flow in a stream exceeds the channel capacity. These fluvial floods are usually observed in areas around rivers and lakes due to high rainfall or melted snow during the rainy season. They are stagnant and can recede after several hours. High rainfall intensity upstream can also cause flooding downstream. Specific indicators of Fluvial Floods are (a) high rainfall (Miftahuljannah dan Ibrahim 2019), (b)

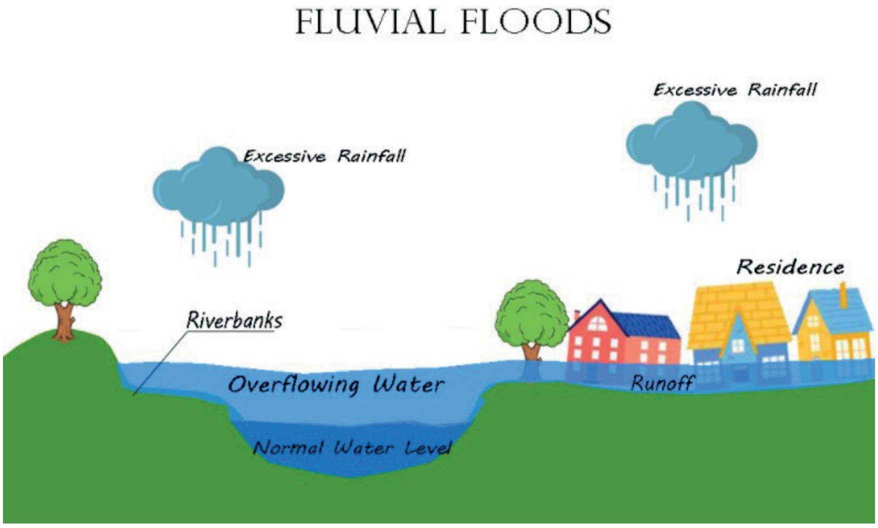

Fig. 3. Illustration of Fluvial Floods

Fig. 4. Illustration of Coastal Floods

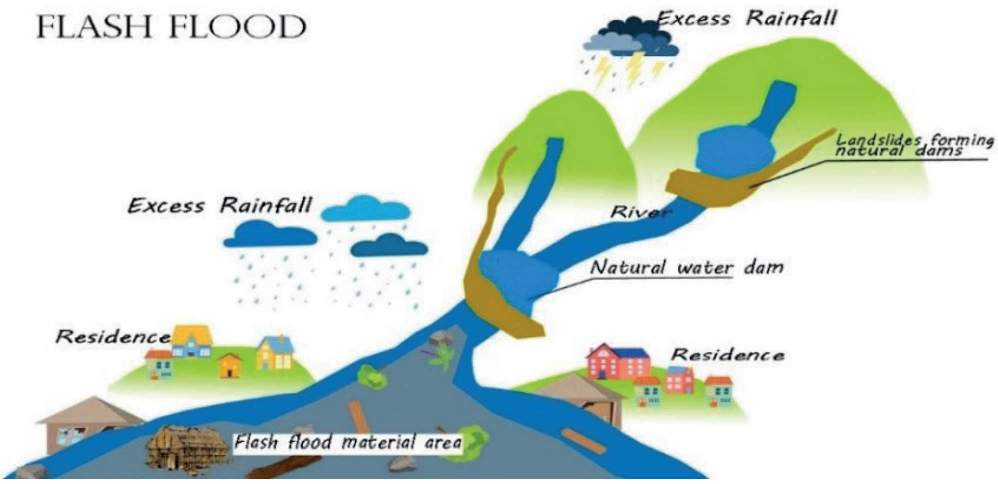

Fig. 5. Illustration of Flash Floods

rainfall intensity in a particular area, (c) channel capacity to accommodate rainfall, (d) watershed characteristics as downstream flooding may occur after a period of time from upstream, (e) type of land cover, which affects the occurrence of flooding, (f) river elevation, which affects the speed of downstream flooding. Examples of fluvial flood events include the Solok floods in 2019, which affected the rivers Sapan Aia Angek, Batang Pagu, Batang Bangko, Batang, and Batang Pulakek, as well as coal irrigation, and were caused by improper functioning of the waterways due to garbage (Miftahuljannah dan Ibrahim 2019). Floods caused by land cover changes also frequently occur in Baleendah Bandung, especially during high rainfall (Barus et al. 2019).

Coastal Floods occur in coastal areas due to rising seawater along with the melting of the north/south poles (Raditya et al. 2020). Specific Indicators of coastal floods also correspond to coastal areas. Floods are higher during the period of high tide, for example, around a full moon, and events are not directly affected by high rainfall. In Indonesia, Modukoro area is affected by both coastal floods and rain floods (Jatmiko 2018).

Flash Floods, or pluvial floods, occur when extreme rainfall events create floods that are not dependent on overflowing water bodies. Pluvial floods can occur in any location, urban or rural, even in areas without surrounding water bodies, and are characterized by a short duration with a relatively high peak discharge (Zain et al. 2021), generally occurs in areas of steep elevation (Kurniawan 2013). Flash floods generally occur due to landslides in the upstream part of the river. Debris consisting of water, rock, and tree trunks can stem river flow and form natural dams. Landslides are influenced by physical factors such as slope, vegetation density, soil texture, soil permeability, soil solum thickness, and weathering of rock (selvena). Specific Indicators of Flash Floods are the following: (a) occur suddenly, in a short time, (b) large volume of water (peak discharge) (Kurniawan 2013), (c) can be associated with river dam damage due to erosion (Hidayatulloh et al. 2018), (d) travel time from trigger to flood is less than 1 hour (Hidayatulloh et al. 2018), (e) high rainfall (Azmeri et al. 2015, Tewal et al. 2018). (f) the size of the catchment area, which affects the peak discharge, (g) vegetation density, (h) watershed slope, (i) the shape of the watershed (oval, round), a round watershed will be more prone to flooding because more water is accommodated (Savitri dan Pramono 2017), (j) soil permeability.

An example of a Flash Flood incident in Indonesia was observed on 1 Jan 2006, when a disaster occurred in the Kaliputih River, Jember, causing 80 deaths and hundreds of injuries. It was caused by extreme rain damaging a natural dam, which triggered a landslide with a distance of 12.8 km, flood arrival time was 1.7 hours, the speed varied depending on elevation, and the peak discharge was estimated at 891.53 m3/s (Kurniawan 2013, Hidayatulloh et al. 2018). In 2003, a flash flood in the Bahorok Catchment killed 200 people and destroyed nearby buildings. It was caused by heavy rainfall (200-300 mm for the three days before the incident), topographic conditions, soil, and rock structure characteristics. The slope there is more than 40 degrees (Zain et al. 2021). Flash Flood also occurred in Wasior Catchment, in Wasior District, Wondama Bay Regency, West Papua Province, where rainfall reached 179 mm in 10 hours, and with the slope ranging from 5 to 75 degrees, the peak discharge reached 152 m^3/hour. The watershed of Krueng Teungku was flooded three times, in 1987, 2000, and 2013. On 2 January 2013, there was an extreme daily rainfall of 125 mm, leading to a flood with a peak discharge of 34.83 m^3/s and a travel time of about 4 hours (Azmeri et al. 2015). Landslides that triggered flash floods in the Kali river along Manado-Tomohon in North Sulawesi on 15 January 2014 were also caused by very high rainfall of 215 mm in Tondano and 41 mm/day in Tumpaan, the erosion was also strongly influenced by physical factors, such as slope and vegetation density (Tewal et al. 2018). The flash flood in Garut, in the upstream part of the Cimanuk watershed, on 20 September 2016 was very high due to heavy rainfall (110 to 255 mm/day), high soil moisture before the flood (35 to 44 mm), and the forest area covering only 17.9% of the watershed (Savitri dan Pramono 2017). The flash flood in Batu city on 4 November 2021 occurred upstream of Brantas due to the break of the Brantas river bank, while the rainfall in Pasuruan was recorded at 99 mm over the last 24 hours (Davies 2021).

Based on general indicators and specific indicators for each flood type, it can be seen that there are several components that cause flooding, including various indicator variables and sub-indicators, which have a different impact. These indicators, as well as data sources from which they can be obtained, are presented in Table 1 below. Dynamic factor means that the variable can change, while static factor means that the variable either cannot change, or a strong intervention and a long time is needed for changing the variable.

Table 1. Variables/Indicators affecting floods and their data sources

Component	Variable/ Indicator/ sub indicator	Factor	Potential Data	Impact on Flood	Data Source
Hazard (Climate Factor)	Rainfall	Dynamic factor	Design rainfall, rainfall intensity, river discharge, flood return period	Historical changes in rainfall have contributed to approximately one third of cumulative flood damage from 1988 to 2017 with rainfall changes of 20% to 46%, leading to a 36% increase in flood damage (Davenport et al. 2021). Rainfall intensity greater than 70 mm/hour with a return period of 20 years can increase the amount of surface runoff and cause flooding (Yilmaz et al. 2014)	BMKG, BBWS Ciliwung Cisadane
Hazard (non climate factor/ physical factor)	Elevation/Topography	Static factor	Elevation height	The topographic contribution level reaches 96.14% for flood inundation areas, quantitatively it can be stated that lower elevation and smaller topographical variability, can make an area more vulnerable to flooding (Xie dan Zhao 2013)	DEMNAS, USGS
	Slope	Static factor	Percentage of the average slope in the site including sloping or steep areas	Time of concentration (Tc) is influenced by the slope of the land, in areas with a gentle slope, the Tc value and the runoff volume will be smaller, while in areas with a larger slope, the Tc value and the volume of flood runoff will be greater. A slope of 86% will cause an increase in runoff volume of 98% (Elmoustafa 2012)	DEMNAS, USGS
	Soil Type	Static factor	Type of soil on site	A soil erodibility value between 0.02 to 0.04 means that liquid can be absorbed by the porous medium relatively fast before it reaches a saturated state (high permeability), while soil types with an erodibility value between 0.11 and 0.3 have very low permeability (Giatman et al. 2019). Soil types associated with certain land uses in the watershed have a runoff coefficient >0.5, which tends to cause high surface runoff (Basri et al. 2022, Alaoui et al. 2017)	BBWS

Hazard (non climate factor/ social factor)	Land Cover	Dynamic factor	The area of land used for each land cover	Increased change in residential land use by 2.278% can cause an increase in flood discharge of 35% over five years (Wirosoedarmo et al. 2020, Marizan dan Syarifudin 2022, Ariyanto dan Irawan 2020)	BPS, RTRW, Landsat 4, 5 dan 8
	Distance from the river	Dynamic factor	Safe distance from the river	Areas close to rivers are more prone to flooding in the case of fluvial and flash floods (Pham et al. 2020). River borders are determined based on the characteristics of the river and the depth of the riverbed (Presiden Republik Indonesia 2011).	River border regulations
Vulnerability (non-climate factors/ social factor)	Garbage in the river	Dynamic factor	The condition of the garbage in the river during the dry and rainy seasons	Garbage that is thrown carelessly into the river will hinder the flow of water from upstream and result in negative impacts on the environment and humans (Qomariyatus sholihah et al. 2020)	Field Observations
	Population density	Dynamic factor	Total Population, Residential Area	An increase in population can lead to climate change, which causes the intensity and frequency of rainfall to increase (Swain et al. 2020)	BPS
Capacity	Infrastruc-ture	Dynamic factor	Availability of infrastructure for flood management	Infrastructure is one solution in dealing with floods, but infrastructure has an environmental impact and increases the risk of flooding elsewhere. The development of green infrastructure for risk reduction is required for achieving large-scale ecological benefits, social justice, and fiscally functioning local government (Shi 2020)	BPS, BBWS, Provincial SDA Office
	Early warning system	Dynamic factor	Is there an early warning system?	Flood Early Warning Systems (FEWS) are implemented in many parts of the world, but an early warning does not always translate to emergency response for all individuals at risk. In addition to FEWS, warning communication and community response capabilities are also needed (Perera et al. 2020).	Regional Disaster Management Agency
	Institution	Dynamic factor	The relationship between stakeholders in dealing with floods	In handling floods, it is necessary to have a collaborative mechanism in the decision-making process related to efforts to reduce flood risk (Sunarharum 2021, Samaddar et al. 2015)	Relevant agencies/ institutions

History of Flood Disasters in the Ciliwung Watershed

Human civilization is surrounded by various natural hazards that have the potential to cause disasters which are classified according to the type of triggering event (Titley et al. 2021, Bian et al. 2020, Perera et al. 2020). Due to their potential impact on several sectors of society, disasters have been the subject of scientific study in various fields. The development of human civilization over the environment creates the conditions for disasters (Alca´ntara-Ayala 2002). The concept of human-nature relations in the study of natural disasters is associated with the contribution of the geographer Gilbert F. White. His publication "Human adaptation to floods" (Nawaz 2017) studies flooding, risk and risk management, the environment, and climate change (Macdonald et al. 2011). In this context, natural disasters can and should be understood as "non-natural disasters" (Birkmann 2006, Staupe-delgado 2019, Cutter et al. 2008). Flood disasters are caused by natural factors such as extreme rainfall, topography, etc., while non-natural factors significantly influence the change in land use.

In the Ciliwung watershed, flood events continue to increase and occur almost every year, while the most severe floods occurred in 2022, 2007, 2015, and 2020. The history of flood disasters in the Ciliwung watershed and their consequences can be seen in Fig. 6. Floods generally occur due to high rainfall, with the increase in flood discharge directly proportional to the increase in rainfall. Based on the rainfall data for ten years, from 2011 to 2020, the maximum daily rainfall in each year was taken to calculate the design rainfall using various methods for specific return periods, the results of these calculations are presented in Table 2. It can be seen that the flood event in 2020 was caused by a rainfall of 377 mm (Fig. 6), which has a return period of approximately 50 years (design rainfall of 345.92 mm, Table 2).

From Fig. 6 it can be seen that floods are usually caused by rainfall events of more than 100 mm. In addition to extreme rainfall and other natural factors (geographical and physical characteristics), floods can also be caused by man-made factors (Fig. 8). Increased vulnerability to flooding cannot only be attributed to climate as it is also affected by population growth, rapid urbanization, and urban sprawl (Pornasdoro et al. 2014). Land use changes in the Ciliwung watershed from 1990 to 2020 are shown in Fig. 7. The type of land cover significantly affects runoff that causes flooding in an area (Table 1), the results of the land cover analysis in the Ciliwung watershed for 30 years showed a significant change in residential land cover (Fig. 7), which increased from 91,927 km^2 in 1990 to 204,335 km^2 in 2020 and greatly affected surface runoff. In addition, although cities are densely populated and have a high economic value, disasters caused by floods can cause development delays for several years (Tingsanchali 2012). Flood damage

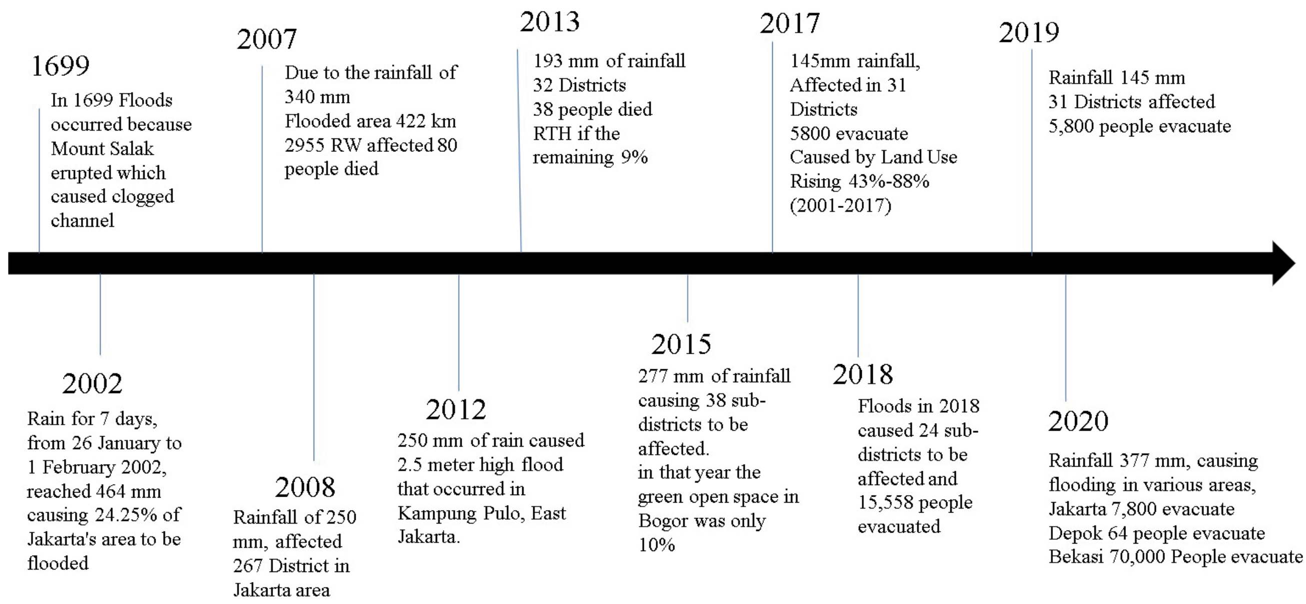

Fig. 6. Flood History in the Ciliwung

Table 2. Design rainfall with return periods of 2, 5, 10, 25, 50, and 100 years

Return Period	Design Rainfall (mm)			
(Year)	Log Pearson Type III	Gumbel	Normal	Log-Normal
2	181.298	180.034	187.748	181.625
5	228.166	233.218	230.770	228.187
10	257.577	268.430	253.305	257.164
25	293.327	312.921	275.242	288.903
50	319.139	345.927	292.741	317.005
100	344.383	378.689	307.082	342.063

depends on the type of flood, flow velocity, and duration of the flood. An increase in population density coupled with the presence of flood-affected infrastructure and assets in a city increases the likelihood of urban flood damage, while the uncontrolled growth of urban settlements reduces their drainage capacity (Tingsanchali 2012).

As shown in Fig. 8, the increase in population can cause land use and land cover changes which put pressure on river areas and change their characteristics such as river width, flow patterns, flow density, and river gradient. In addition, the government carries out various actions to reduce the pressure on river areas by setting zoning, performing flood control, developing infrastructure for river normalization, and providing counseling so that people are aware and do not throw garbage in rivers. Besides that, the increasing population can also lead to air temperature increase in the area, resulting in climate change if not handled properly.

Morphological Characteristics of the Ciliwung River

Based on its morphology, the Ciliwung river can be divided into three zones, the first zone is a sediment supply zone located in the upstream part of the watershed which has a v-shaped valley and is directly connected to the river banks. This zone has a long and steep slope with large sediment grains. The water flows at high speed, resulting in significant erosion from cliffs and the riverbed (Fig. 9). The second zone is the sediment transport zone which is located in the middle part of the watershed, where the river begins to form a floodplain. In this zone, upstream sediment originating from the erosion of cliffs and the riverbed is distributed downstream, thus forming river meanders and filling the floodplain with fine sediments (Fig. 10). And the third zone is the depositional zone, which is located in the downstream part, close to the estuary, and accumulates the sediments originating from zones 1 and 2. In natural conditions, this zone is usually an area of very high potential for wildlife, but in the estuary zone of the Ciliwung river there are many residential areas, and river normalization is carried out by making embankments to prevent flooding (Fig. 11).

Morphometry Characteristics of the Ciliwung Watershed

River morphometry characteristics include watershed area, shape, river network, flow density, flow pattern (Fig. 12), and river steepness gradient. The combination of watershed morphometry factors with other factors that can be changed by humans such as land cover, slope, and slope length will give a different response from the watershed to rainfall, absorption of flow into the soil (infiltration, runoff, groundwater content), and river flow behavior, for example, morphometric characteristics combined with land use will be used to evaluate the occurrence of flooding in the area.

Based on the drainage map of the Ciliwung watershed (Fig. 12), river order according to Strahler was determined, and the obtained results are presented in Table 3.

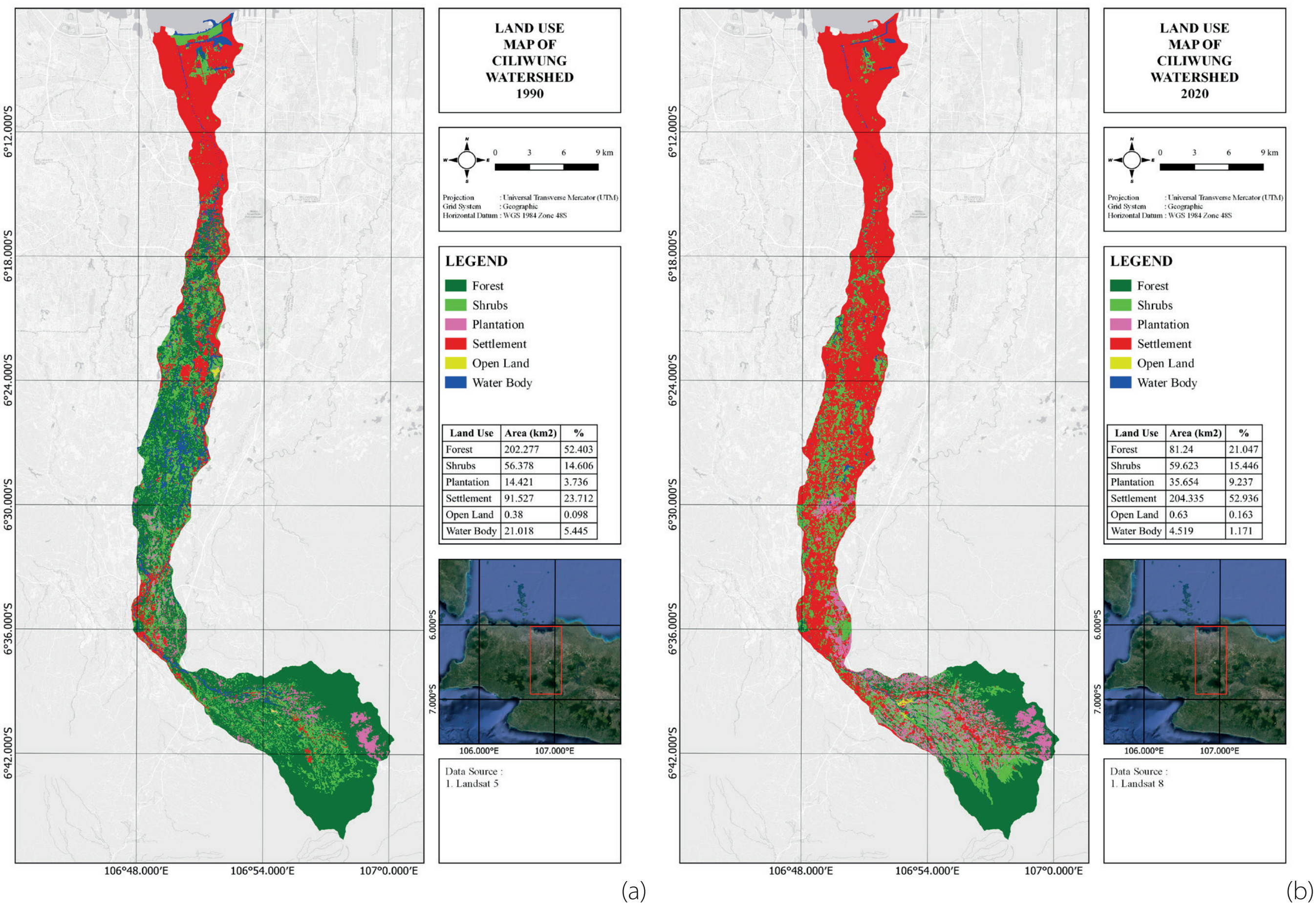

Fig. 7. Land Cover Map (a) 1990 (b) 2020

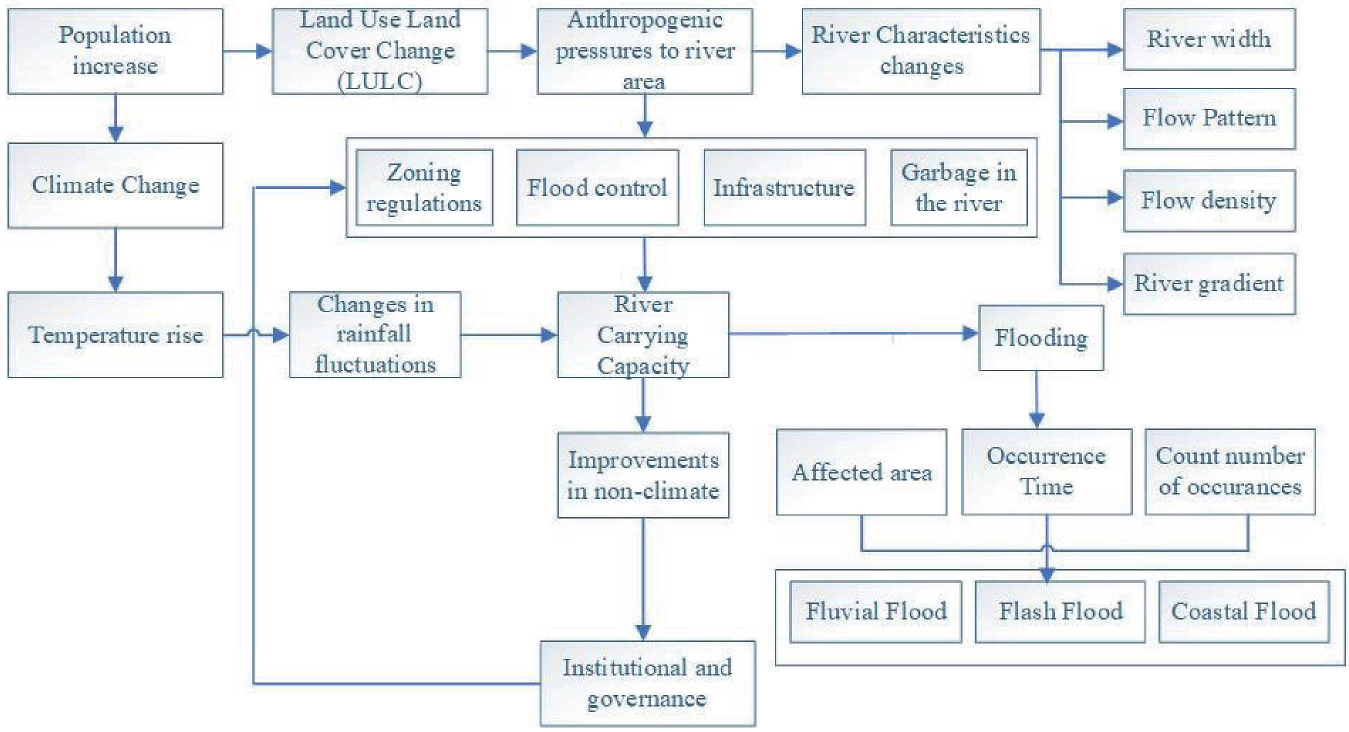

Fig. 8. Identification of factors causing flooding (Mathanraj et al. 2021, Perdinan dan Julie Winkler 2013, Akter et al. 2018, Elmoustafa 2012)

Fig. 9. Sediment Supply Zone/Zone 1 (coordinate '-6.62598, 106.82485)

(a) (b) (c)

Fig. 10. Sediment Transport Zone/Zone 2 (a) coordinate -6.58617, 106.79825, (b) coordinate -6.53742, 106.80347 (c) coordinate -6.50385, 106.79723

Fig. 11. Sediment Deposition Zone/Zona 3 (a) coordinate -6.11865, 106.82867, (b) coordinate -6.15389, 106.83573

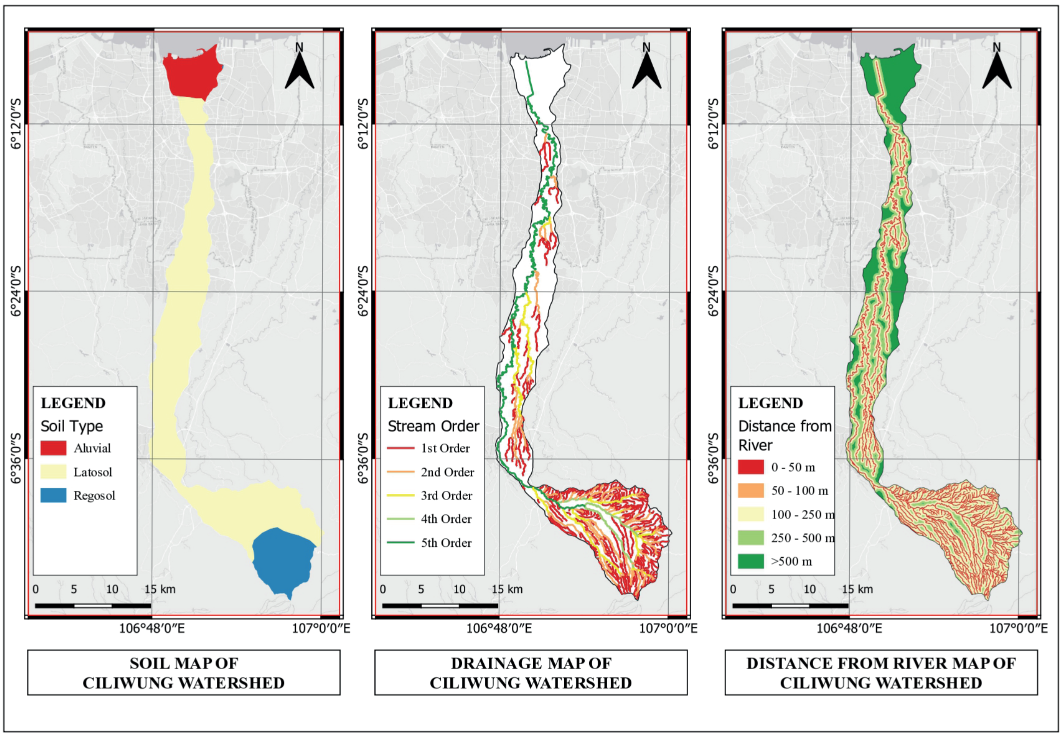

Fig. 12. The Ciliwung Watershed Characteristics, Soil Type, Drainage, and Distance from the River

Table 3. The Ciliwung River Network Order

River Order	River Length (km)	Stream Number	River Branch Index
			Rb = Un/Un+1
1	340.62	325	4.392
2	136.73	74	3.895
3	75.76	19	6.333
4	27.13	3	3.000
5	112.33	1	-
Total	692.57	422	

Based on the obtained values and formula (1), the bifurcation ratio was calculated for each river order. Also, the weighted average branching index (WRb) was calculated, which was equal to 5.392 for order 1, 4.895 for order 2, 7.333 for order 3, and 4 for order 4. These WRb values for each river order result in the weighted average branching index value (WRb average) of 5.05. The length of the river network in the Ciliwung watershed is 692.57 km and the area is 386 km^2, which results in a Drainage density (Dd) of 1.794 km/km^2. The Dd value is calculated based on formula (2) and describes the distance between rivers in the area (Kelaiya et al. 2019, Ali et al. 2018, Dragicevic et al. 2019).

DISCUSSION

Flood events in river areas are influenced by river characteristics. Based on the results of research and field observations, the conditions in the Ciliwung watershed were identified. In terms of morphometric characteristics, the Ciliwung watershed has an area of 386 km^2. According to the guidelines for identifying watershed characteristics issued by the Ministry of Forestry (Ministry of Forestry, Directorate General of Watershed Management and Social Affairs 2013), the Ciliwung watershed belongs to the category of moderate watersheds with an area between 100,000 and 500,000 ha. The Ciliwung watershed has an elongated shape with a rapidly increasing or decreasing peak discharge. The shape of the watershed is determined based on the Rc value, which in this case is 0.122, less than 0.5. Based on the Dd value of 1,794 km/km^2, the density in the Ciliwung watershed can be characterized as good according to the Smith 1950 classification in Raj dan Azeez (2012). According to other classifications, the density of the river network in the Ciliwung watershed is classified as low or medium ($1.24 < Dd < 2.49$), which also indicates the low infiltration capacity of the watershed. The slope of the watershed is also low, with an average value of 8% it belongs to the category of watersheds with a gentle slope. According to the studies of Lynsley in 1975, if the flow density value is below 1 mile/mile2 (0.62 km/km^2), the watershed will be prone to inundation, and if it is greater than 5 miles/mile2 (3.10 km/km^2), the watershed will often experience drought.

To develop action plans and flood mitigation measures in the Ciliwung watershed, it is necessary to know its characteristics including the river morphometry and morphology, as well as the factors that affect flooding. From the Rb value, it is known that the Ciliwung river is characterized by a rapidly increasing and decreasing flood water level. In this study, it was found that the Ciliwung watershed is dominated by fluvial flooding, which is affected by many factors including the distance of settlements to the river, and the lack of public awareness, which results in a lot of garbage in the river and clogging of the river flow. In addition, the lack of operation and maintenance of infrastructure built by the government in the Ciliwung tributaries, such as the new Situ Weir which is supposed to be used for flood control, has resulted in sedimentation and suboptimal functioning of the lake. As a result, floods continue to occur in the downstream area during the rainy season.

The first recorded case of flooding in the Ciliwung dates back to 1699, or about 323 years ago (Fig. 6), when a flood was caused by the eruption of Mount Salak which blocked the flow of the Ciliwung River and its drainage network. Around that time there was also a flood due to heavy rainfall in January and February which resulted in the inundation of the Old City which used to be the capital of the Dutch colony under the government of Verenigde Oostindische Compagnie (VOC). The next largest flood according to the WHO Emergency Situation Report (2007), occurred in 1714 when the Ciliwung River overflowed due to the clearing of forests in Bogor (Peak Area). Another major flood was recorded in 1996 and led to the inundation of the capital city and ten casualties. From Table 1 it can be seen that flooding in the Ciliwung Watershed (DAS) is usually caused by high rainfall above 100 mm (Fig. 6). Based on the character of events and indicators from Table 1, the floods in the Ciliwung watershed can be classified as Fluvial, which occur due to high rainfall (Fig. 6 and Table 2). The rainfall in certain areas that discharge into the main river through tributaries may result in the cumulative increase of river discharge, which can cause flooding if the carrying capacity of the river decreases. Because of this, rainfall in the upstream area will have an impact on the downstream area as well, while the type of land cover and river elevation will affect the velocity of water that triggers flooding. It was also found that the Ciliwung watershed experienced significant land cover changes from 1990 to 2020 (Fig. 7), as residential land cover increased from 91,527 km^2 to 204,335 km^2, or by 123% over the last 30 years.

However, flood problems do not only come from upstream but also from the middle and downstream, while flood control often does not include certain watersheds or sub-watersheds in flood management units. The novelty of this research is that it describes various factors of flooding that flood management must take into account, it can not include only upstream or downstream, but should be conducted on a watershed level and include comprehensive interventions covering the entire area. This research can be used as a foundation to further explore the factors that form floods in order to develop a more integrated flood management strategy in watershed areas.

In addition, the coordination between different institutions in the Cliwung watershed is also not optimal. Having too many institutions and regional autonomy results in the decentralization of authority, lack of law enforcement in the transition of land use into housing, and difficulties in developing the existing infrastructure in accordance with regional spatial planning. Besides that, infrastructure development is usually not followed by an increase in the capacity of drainage

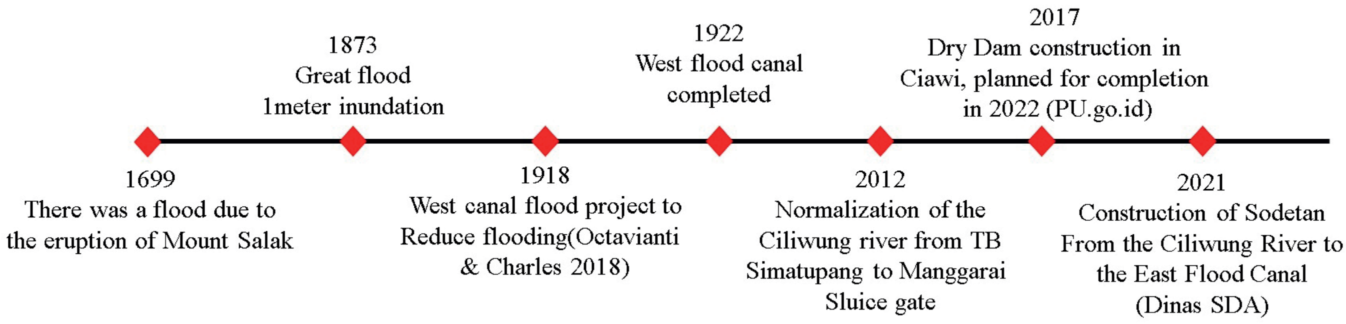

Fig. 13. Mitigation Efforts from the government

channels (especially in the downstream area), which hampers the flow of rainwater and causes inundation.

Based on Fig. 13, what the government has done to reduce the river discharge due to rainfall in the upstream area is building a Dry Dam in Ciawi, according to the PU Dry Dam planning it can reduce flood discharge before the Manggarai sluice gate by 2 to 10% (Prakoso et al. 2020). To reduce flooding in the downstream part, a Flood Sode and the east canal were built by the DKI Jakarta Provincial Natural Resources Service. However, the handling is not maximal in the middle part, where an extended Dam can be constructed along the Cliwung river to include the floodplain and reduce flood discharge downstream. In addition, it is necessary to know the relationship between infrastructure, the economic system, and the role of human factors in assessing and managing risk. In flood management, uncertainty about future conditions is the most important challenge to be faced, which means that strong and resilient measures with good performance in the future should be developed (Jonkman dan Dawson 2012).

Based on the factors causing flooding (Table 1), the government has introduced certain mitigation measures (Fig. 13). To reduce the risk due to the distance of residential areas from the river, the channel was normalized and several pumping stations were built in the downstream area to facilitate faster discharge of water into the sea. The pumping stations pump water in the river at high discharges reducing inundation in the upstream area. To reduce waste in rivers, counseling and assistance were provided to the community in order to change their mindset toward protecting the environment. Another measure was to build the Ciawi weir to reduce runoff in the upstream area of the Ciliwung, which is planned to operate in 2022. However, watershed management to reduce flood risk will not run optimally without the coordination and cooperation between various stakeholders. Stakeholders, whether from the government, the private sector, or the community, in the case of the Ciliwung river management include the Directorate General of Natural Resources, the Ciliwung-Cisadane River Basin Center (BBWS), the DKI Jakarta Provincial Government's Natural Resources Service, the Blood Disaster Management Agency (BPPD), NGOs, river care groups and community leaders. Cooperation and coordination are required to achieve the sustainability of the watershed functions and services. To accommodate the interests of all parties, the government must coordinate and cooperate with them during the planning, implementation, and evaluation process, for example, the improvement of river borders can involve people living near the river banks. The government collaboration with NGOs must be more intense in providing counseling to the community and improving their understanding of the importance of maintaining the sustainability of riverbanks and the proper functioning of rivers as natural drainage. In terms of normalizing riverbanks, it can also be done with an environmental approach, for example, by strengthening riverbanks with plants, which has more economic value and provides additional benefits to the community. However, this can only be applied in the middle part of the Ciliwung area, for the downstream part of the river effective normalization can only be done by building embankments and pumping stations so that water can be quickly discharged into the sea. So, in the case of flood control, maintaining optimal watershed functions and services from upstream to downstream is the responsibility of all relevant stakeholders including the community.

CONCLUSIONS

Based on the discussion above, it can be concluded that to carry out flood management in an area, it is necessary to determine the contributing factors (Table 1). These contributing factors can be used to develop intervention measures and carry out flood risk management. Also, for proper flood management, one must look at the entire watershed unit, not a city or province area. The Ciliwung watershed covers two provinces, namely West Java province, and DKI Jakarta province, where the capital city of Indonesia is located, and because the Ciliwung river is a major cause of flood events in the capital city, most of the government measures for flood control include building infrastructure downstream (Fig. 13). For sustainable flood management in the Ciliwung watershed, it is necessary to know the dominant type of floods in the area, as well as to study the characteristics and nature of the river flow. For example, because the slope of the Ciliwung watershed is not very high, only 8%, the water does not flow downstream quickly, causing inundation in the middle of the Ciliwung river. Mitigation efforts that the government has carried out include diverting the flow of the Ciliwung river to the west and east canal for reducing the flow of water in the central part of the Ciliwung and implementing other flood infrastructure measures such as building the embankments and raising riverbanks so that water can be quickly discharged into the river. In addition, there are also efforts to reduce flood discharge in the upstream area by constructing a dry dam in Ciawi, which is planned to be completed in 2021. However, infrastructure efforts must also be supported by stakeholder participation (Aung dan Lim 2021, Sunarharum 2021, Isa et al. 2019). An example of cooperation between the government and the community showing concern for maintaining and managing the environment could be in preventing people from throwing garbage in the river, especially in the middle Ciliwung area. The results of surveys and research showed that there is a narrowing of the river channel in the middle of the Ciliwung area caused by residential settlements. Due to the proximity of residential areas to the river, garbage is accumulated in the channel, which acts as a flow barrier during rainfall and causes river water to run off to settlements located near the riverbanks.

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