Risk analysis of debris and non-debris flow in the Cisokan river flood event

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Abstract. Cisokan River is one of the main inflow rivers of Cirata Reservoir aside from Citarum River. Cisokan River is the second largest contributor to Cirata inflow after Citarum River. In May of 2023 Cisokan River experienced instances of flash flood disasters that submerged houses in Cianjur Regency, one of the affected villages is Ciranjang Village. Several news outlets reported that this flood also left debris and mud in the affected areas, which indicated that the flood was debris flow. This study conducts the risk analysis resulting from debris and non-debris flow with the changes in river cross-section due to sedimentation. In this study, modeling was carried out employing a Digital Elevation Model (DEM) map and utilizing the Hec-RAS software. One focus of the modeling was on simulating the Newtonian (non-debris) and non-Newtonian (debris), comparing the results and analyzing the risk from both. The result showed that the non-Newtonian flow’s flood inundated area is larger than the Newtonian flow’s, which means the high flood risk area of debris flow is 12.5% larger than the non-debris flow's high flood risk area.

1 Introduction

Cisokan River is part of the Citarum Watershed tributary, it spans from Gununghalu, West Bandung Regency, and empties into Cirata Reservoir. In May 2023, a flash flood occurred in two districts in Cianjur Regency, with one of the villages being Ciranjang Village, Ciranjang District. According to various news reports, the flood that occurred was a mixture of mud, and this was further reinforced by reports that when the flood receded, evacuees still had to remain displaced because their submerged homes were still filled with mud. This indicates that the flood was a debris flow that carried mud [1,2]. Debris flow occurs when the flow of a river or water channel is suddenly disrupted by materials such as mud, rocks, and debris carried by the water current [3]. This can be caused by heavy rainfall, landslides, or severe soil erosion [1]. Such floods are often very destructive and dangerous as they can destroy buildings, bury land, and threaten the safety of residents [1–4].

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Floods are one of the disasters that frequently occur in Indonesia, and this, of course, leads to significant losses for both the country and its people. Therefore, there is a need for flood disaster risk analysis. Flood risk analysis is typically conducted to determine the extent of the risk of a disaster event in a specific area [5–7]. For this study, the focus will be on Ciranjang Village, where this village is one of the villages with the most significant losses that have occurred.

Ciranjang Village is in Ciranjang District, Cianjur Regency, West Java. The coordinate for this village is 6°49'5.65"S 107°14'46.38"E, covering an area of 3.71 Km². According to the Department of Population and Civil Registration, Cianjur Regency, Ciranjang Village has a population of 19,802 people.

As seen in Fig. 1 is that Ciranjang Village is strategically located at the junction when the Cilaku River converges with the Cisokan River, which means that during high rain intensity, the village would not just receive water flow from the Cisokan River but also Cilaku River. This could potentially elevate the risk of flooding in Ciranjang Village.

![Fig. 1. Ciranjang village by Cisokan river and Cilaku river.](image)

In Indonesia typically flood risk hazard is simulated with the non-debris flow, as the debris or particles in the water are not counted for. As mentioned above debris flow is a river flow that carries debris particles such as mud. This could mean that the volume of water in a river flow would increase as it also carries solid particles with it. The increase in volume means the increase in flood volume [8], making the area flooded could be larger than a non-debris flood [8].

Hence, in this study, the flood discharge of debris flow and non-debris will be considered as a potential flood scenario, aiming to maximize the risk assessment to ensure the best possible outcomes for risk analysis.

## 2 Methodology

The concept for this study is to simulate both non-debris flow flood and debris flow flood, then use both results for the risk analysis. Fig. 2 below shows the concept diagram for this study. As the result of non-debris flow and debris flow simulations used to analyze flood risk, it would show two different map results. As debris flow simulations are usually not used for
flood risk analysis, it would show us the difference between risk analysis using debris flow simulations and non-debris flow simulations.

Fig. 2. Conceptual diagram of non-debris flow and debris flow on flood risk analysis.

2.1 Hydrology analysis

The data needed for hydrology analysis is daily rainfall. The rainfall data are from the Cisokan rainfall station, Cidadap Montaya rainfall station, and Cisondari rainfall station. Land cover refers to the physical characteristics and surface features of a piece of land [9]. Land cover data is collected and analyzed to calculate the Curve Number (CN). The Curve Number is a hydrological model parameter developed by the Soil Conservation Service, and it quantifies the physical conditions of a watershed [10], typically represented as a numerical value ranging from 1 to 100.

Frequency analysis was initially carried out at each rain station. Once the frequency analysis for each rain station was obtained, calculations for regional rainfall were performed using the Thiessen method [11].

For flood discharge analysis in this study, SCS Synthetic Unit Hydrograph (HSS) methods were utilized using HEC-HMS software [12]. Calibration was performed by adjusting the parameters of each method to ensure that the results closely matched the observed discharge [13]. The discharge used to calibrate the maximum discharge is from the Cisokan water level recorder.

2.2 Debris flow

The debris flow transformation process initiates with solid particles transitioning into a viscous state as they flow. This flow can be characterized as both liquid and viscous, with particle dispersion occurring during the flow. When the flow eventually comes to a stop, the particles reassemble and solidify [14]. There are several types of non-Newtonian flow characteristics, such as mudflows, debris flows, lahars, and snow avalanches. In non-Newtonian fluids, the relationship between shear rate and shear stress can be nonlinear and may not pass through the origin. Equations for mixtures and the properties of non-Newtonian flow can be described using a single-phase mathematical model [15]. However, to distinguish between the liquid and solid phases in non-Newtonian flow and to address conservation issues for each phase, a two-phase model can be employed [14, 16].

In 2010, JICA released a guidebook titled "Manual Sabo Works" which discusses the influence of sediment on the magnitude of flood discharge [17]. Qw (design flood discharge),
which is calculated based on the 100-year return period flood discharge considering the sediment influence, represented by sediment concentration \( C_d \).

\[
Q_s = Q_w (1 + C_d) \quad \text{(1)}
\]

\[
C_d = \frac{\rho_w \cdot (\sigma - \rho_w) \cdot (\tan \theta - \tan \beta)}{\sigma \cdot \rho_w} \quad \text{(2)}
\]

Where \( Q_s \) is discharge with the influence of sedimentation, \( Q_w \) is the flood discharge, and \( C_d \) is the sediment concentration. Sediment concentration could be calculated with Eq.2, wherein \( \rho_w \) is water mass density (1000 kg/m\(^3\)), \( \sigma \) is sediment mass density, \( \theta \) is the average riverbed, \( \beta \) and \( \theta \) are sediment shear angle (35\(^\circ\)).

### 2.3 Non-Newtonian equation

The depth-averaged Shallow Water Equations (SWE) model addresses volume and momentum conservation equations, encompassing temporal and spatial accelerations, along with horizontal mixing. In contrast, the DWE model simplifies matters by omitting these processes, resulting in greater computational efficiency [17]. As stated by Hergarten and Robl [15], the equation for mass conservation is described below:

\[
\frac{\partial \eta}{\partial t} + \nabla \cdot (hV) = q \quad \text{(3)}
\]

Incorporating both external and internal fluxes, changes in the elevation of the flow surface with respect to time \( t \) are related to variables such as depth \( \eta \), velocity vector \( hV \), and lateral flow rate per unit length \( q \).

The momentum of the average depth equation by Hergarten and Robl [15] is as follows:

\[
\frac{\partial V}{\partial t} + (V \cdot \nabla)V = -g \cos^2 \phi \nabla \eta + \frac{1}{h} \nabla \cdot (V h \nabla V) - \frac{\tau}{\rho_m R} \frac{\cos \phi}{\cos \psi} \frac{|V|}{V} \quad \text{(4)}
\]

Using the given definitions, where \( g \) represents the acceleration due to gravity (with a value of 9.81), \( \nu_t \) stands for turbulent flow viscosity, \( \tau \) represents the total basal stress, \( \rho_m \) denotes the bulk density of the water-solid mixture, \( R \) signifies the hydraulic radius, \( |V| \) indicates the magnitude of the velocity vector, \( \phi \) represents the slope of the water surface, and \( \psi \) represents the angle of inclination concerning the direction of the flow velocity.

The formula for fluid stress equation in a non-Newtonian model [15]:

\[
\tau = \tau_r + \tau_{MD} \quad \text{(5)}
\]

The choice of material for the stress-strain model (rheology) is determined by the basal stress, derived from \( \tau_r \) and \( \tau_{MD} \). When combined with channel bed roughness, it becomes a function of the friction slope \( S_f \).

\[
\tau_r = \gamma R S_f \quad \text{(6)}
\]

In this context, the unit of fluid weight is denoted as \( \tau_r \), hydraulic radius as \( \gamma R \), and friction slope, as per Manning’s equation, is represented as \( S_f \). The flow velocity is \( V \), and there is a unit conversion factor denoted as \( k \), which can be described by the following equation:

\[
S_f = \left( \frac{nV}{kR^{2/3}} \right)^2 \quad \text{(7)}
\]
2.4 Rheology

Rheology is the study of the mechanical characteristics and flow behavior of substances, particularly non-Newtonian fluids, mixtures, and plastic solids [18]. In this paper, we explored non-Newtonian rheological models, with a specific focus on the Bingham model [18].

![Fig. 3. Rheological model schematic [18].](image)

The Bingham model formula could be written as [17, 18]:

\[ \tau_{MD} = \tau_y + \tau_v \]  \hfill (8)
\[ \tau_v = \mu_m \dot{\gamma} \]  \hfill (9)

Wherein, \( \tau_y \) stands for the yield stress, \( \tau_v \) represents the viscous stress, \( \mu_m \) denotes the mixture dynamic viscosity, and \( \dot{\gamma} \) signifies the shear rate. This model exhibits a linear stress-strain relationship characterized by a non-zero intercept [17, 19]. Consequently, \( \tau_y \) and \( \tau_v \) correspond to the intercept and the slope, respectively, in the stress-strain relationship. The Bingham model proves valuable in simulating mudflows occurring at low shear rates, where both yield and viscous stresses are contingent upon the cohesion of fine sediments [17, 19-24].

2.5 Risk analysis

Disaster risk assessment primarily involves assessing the extent of three risk components (hazard, vulnerability, and capacity) and presenting them in both spatial and non-spatial formats for ease of comprehension. Disaster risk assessment serves as the foundation for implementing effective disaster management strategies within a specific region.

The Disaster Threat Index is composed of two main components, namely the likelihood of a threat occurring and the magnitude of the recorded impact of the disaster that occurred [25-27]. Usually, disaster risk could be calculated with the formula below:

\[ R = H \times \frac{V}{C} \]  \hfill (10)

Wherein, \( R \) is disaster risk, \( H \) is hazard, \( V \) is vulnerability, and \( C \) is capacity.
2.5.1 Hazard analysis

The categorization of flood hazard levels relies on both the depth of inundation and the speed of floodwater. The flood hazard index is divided into three classes: low, medium, and high [7, 26]. According to the National Board for Disaster Management (BNPB), flood depth categorized as "high" is defined as flood levels exceeding 1.5 meters, while flood depths ranging from 0.76 meters to 1.5 meters fall into the "medium" classification. Floods with depths below 0.76 meters are categorized as "low" [26, 27].

Hazard analysis, especially flood hazard analysis could be conducted with another method too, using Flood Hazard Index (FHI) [28, 29], where the hazard parameters used are flow velocity, flow duration, and flow depth. For this study, the FHI is not yet conducted as a comparison to the BNPB hazard index. However, the flow velocity parameter would be used to see the range of accepted velocity in flood areas, with the velocity hazard index divided as follows.

For this study hazard analysis was calculated by using both flood depth and velocity to calculate the hazard index with both depth and velocity used are fifty-fifty in the calculation.

Table 1. FHI Velocity Index.

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>Hazard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.1</td>
<td>Very Low</td>
</tr>
<tr>
<td>0.1 - 0.5</td>
<td>Low</td>
</tr>
<tr>
<td>0.5 - 0.6</td>
<td>Medium</td>
</tr>
<tr>
<td>0.6 - 0.7</td>
<td>High</td>
</tr>
<tr>
<td>&gt; 0.7</td>
<td>Very High</td>
</tr>
</tbody>
</table>

2.5.2 Vulnerability analysis

Social vulnerability indicators include population density, sex ratio, poverty ratio, the ratio of disabled individuals, and age group distribution. The Social Vulnerability Index is calculated by taking the weighted average of these indicators, with population density accounting for 60% of the weight, and vulnerable groups (comprising sex ratio, poverty ratio, disabled person ratio, and age group ratio) contributing the remaining 40%, with 10% each [6, 7, 25-27].

\[
Social\ vulnerability = 0.6 \times \frac{\log(\text{population density})}{\log(100)} + (0.1 \times \text{sex ratio}) + (0.1 \times \text{poverty ratio}) + (0.1 \times \text{ratio of disabled people}) + (0.1 \times \text{age gap ratio})
\] (11)

2.5.3 Capacity

Similar to vulnerability analysis, capacity analysis also involves multiple parameters, and these parameters are individually assigned weights based on their respective levels of importance [1, 6, 7, 25-27].

According to BNBP, the indicators used for the capacity map include HFA indicators, which consist of: a) disaster management regulations and institutions; b) early warning and disaster risk assessment; c) disaster education; d) reduction of underlying risk factors; and e) readiness development across all sectors [27]. This could be simplified in Table 2.
Table 2. Capacity Index

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weight (%)</th>
<th>Class</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Disaster management regulations and institutions</td>
<td>100%</td>
<td>&lt; 0.33</td>
<td>0.33 - 0.66</td>
</tr>
<tr>
<td>b. Early warning and disaster risk assessment;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Disaster education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Reduction of underlying risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Readiness development across all sectors</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Capacity Index = (0.1 x Capacity Score)

Meanwhile, according to the Technical Module for Flood Disaster Risk Assessment prepared by BNBP in 2019, capacity takes into account regional capacity. Regional capacity is defined as the ability of an area and its community to undertake structured, planned, and integrated actions to reduce threats and potential losses due to disasters [30].

Though the method above is widely used in Indonesia, in this study however the factor for capacity used is the safety factor for the river as the riverbed changes because of sedimentation. The bank of the river is determined by running 2 2-year return period discharge for the bank's full capacity [31] and using it as the riverbank. Safety factor is defined as the ratio or comparison between nominal resistance (Rn), which is the capacity of river to sustain flow, and its nominal load (Ln) which is the extreme discharge values determined through hydrological analysis, considering their return periods [32, 33]:

\[
SF = \frac{R_n}{L_n} \tag{12}
\]

Where, Rn is nominal resistance, Ln is nominal load, and SF is safety factor. The formula for Ln and Rn could be written as [32, 33]:

\[
L_n = \bar{L} + (WL \times L \times f^{-1}(1-aL)) \tag{13}
\]
\[
R_n = \bar{R} + (WR \times R \times f^{-1}(1-aR)) \tag{14}
\]

Where, \( \bar{L} \) = averaged load, \( \bar{R} \) = averaged resistance, \( W \) = coefficient of variation (St. Deviation/average), \( aL \) = designed load failure = 2\% - 50\%, \( aR \) = designed resistance failure = 5\% - 10\%.

As safety factor (SF) is the ratio between nominal resistance and nominal load, it can be safely assumed that the higher Rn the safer a river could be considered, as with higher resistance and lower load, the river would not be overtopped, which means no flooding. With this knowledge we could consider the capacity index classification by the safety factor result.
Table 3. Capacity index.

<table>
<thead>
<tr>
<th>Safety factor</th>
<th>Index</th>
<th>Index multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1.00</td>
<td>High</td>
<td>&gt; 0.66</td>
</tr>
<tr>
<td>1.00 - 0.85</td>
<td>Medium</td>
<td>0.33 - 0.66</td>
</tr>
<tr>
<td>&lt; 0.85</td>
<td>Low</td>
<td>&lt; 0.33</td>
</tr>
</tbody>
</table>

Table 3 indicates the capacity index according to river safety factors, where a safety factor greater than 1.00 is classified as high capacity. The higher the safety factor, the safer the river. This aligns with capacity index, where higher values indicate better conditions because capacity is the inverse of vulnerability. Safety factors between 1.00 and 0.85, fall into the medium index category, and safety factors below 0.85, it is classified as low index. The index multiplier values are divided according to regulations, where the high index is above 0.66, the medium index ranges from 0.33 to 0.66, and the low index is below 0.33.

3 Result and discussion

3.1 Hydrology analysis

The delineation of the Cisokan River and Cilaku River watersheds was conducted using DEMNAS data with the HEC-HMS GIS feature. In the case of the Cisokan River, the outlet was not located at the inlet of the Cirata Reservoir, as the required watershed area for this hydrological analysis is situated upstream of the inlet. Instead, the chosen outlet is near Ciranjang Village, resulting in a watershed area of 627.88 km$^2$ for the Cisokan River. Meanwhile, the delineated area for the Cilaku River watershed is 241.76 km$^2$.

![Watershed delineation](image)

For this research, the land cover within the watershed is sourced from the Ministry of Environment and Forestry's data for the year 2022. Additionally, the soil types within the watershed, classified under the Hydrologic Soil Group (HSG) categories, are obtained from...
data provided by the Food and Agriculture Organization (FAO). The analysis results in a Curve Number (CN) value of 82.38.

In this study, rainfall data is derived from three rain stations: the Cisokan Rain Station, Cidadap Montaya Rain Station, and Cisondari Rain Station. The impact of these three rainfall stations on the watershed can be observed in Table 4. Based on the outcomes of the analysis conducted, the Log Normal method has been selected for frequency analysis for the best outcome according to the Chi-Square test and Smirnov-Kolmogorov test.

Table 4. Planned rainfall for each station.

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Rain stations (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cisokan</td>
</tr>
<tr>
<td>100</td>
<td>141</td>
</tr>
<tr>
<td>50</td>
<td>136</td>
</tr>
<tr>
<td>25</td>
<td>131</td>
</tr>
<tr>
<td>20</td>
<td>129</td>
</tr>
<tr>
<td>10</td>
<td>122</td>
</tr>
<tr>
<td>5</td>
<td>114</td>
</tr>
<tr>
<td>2</td>
<td>98</td>
</tr>
<tr>
<td>Thiessen %</td>
<td>32%</td>
</tr>
</tbody>
</table>

From the table above it can be calculated the regional rainfall, aside from that the regional rainfall result also be multiplied by the area reduction factor (ARF) of 0.807 (IOH).

Table 5. Planned regional rainfall.

<table>
<thead>
<tr>
<th>Return Period</th>
<th>R (mm)</th>
<th>R x ARF</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>131</td>
<td>106</td>
</tr>
<tr>
<td>50</td>
<td>125</td>
<td>101</td>
</tr>
<tr>
<td>25</td>
<td>118</td>
<td>96</td>
</tr>
<tr>
<td>20</td>
<td>116</td>
<td>94</td>
</tr>
<tr>
<td>10</td>
<td>108</td>
<td>87</td>
</tr>
<tr>
<td>5</td>
<td>99</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>81</td>
<td>65</td>
</tr>
</tbody>
</table>

Using HEC-HMS 4.10 software, the flow discharge for both the Cisoka River and Cilaku River could be analyzed. But before the discharge result could be used, a calibration was conducted using Cisokan water lever recorder data as the observation data. From the data available, from 2007 to 2019, the highest recorded daily average discharge was 892.24 m³/s, with rainfall of 86 mm. The calibration result is that the simulated discharge using the SCS method results in a maximum flow of 900.7 m³/s. After the parameter is calibrated, the discharge flow could be used. The hydrograph result is as follows:
Fig. 5. Cisokan River flood hydrograph.

Fig. 6. Cilaku River flood hydrograph.

3.2 Newtonian flow result

The Newtonian analysis is done by HEC-RAS 6.2 with the parameter of the 2D flow area of Ciranjang Village, discharge inflow from Cisokan River and Cilaku River, with a maximum discharge of 1676.3 m$^3$/s for Cisokan River and 755.8 m$^3$/s for Cilaku River.

Fig. 7. (a) Flood model result for Newtonian flow, (b) Flood model result for non-Newtonian flow.
Figure 7. (a) shows the result of the Newtonian simulation. The depth closer to the river is deeper than the one further from the river. The flooding area with the Newtonian flow is calculated as 2.57 km² in total.

### 3.3 Non-Newtonian flow result

The non-Newtonian analysis is done by HEC-RAS 6.2 with the parameter of the 2D flow area of Ciranjang Village, discharge inflow from Cisokan River and Cilaku River, with a maximum discharge of 1676.3 m³/s for Cisokan River and 755.8 m³/s for Cilaku River. Additionally, the non-Newtonian parameter used was obtained from secondary data from PJB BPWC now known as PT PLN Nusantara Power UP Cirata. In 2017 they did a sedimentation survey in Cirata Reservoir which included a sediment survey of the reservoir river inflow.

From the available data, it is found that $\sigma$ is 2614.6 kg/m³, $\theta$ is 34 degrees, with $\rho_w$ being 1000 kg/m³, and $\phi$ is 35 degrees. Consequently, using Eq.2, the sediment concentration value is determined to be 0.35 or 35%.

Figure 7. (b) shows the result of the non-Newtonian simulation. Similar to Newtonian simulation, the depth closer to the river is deeper than the one further from the river. The difference is the flooding area which is calculated as 2.89 km² in total.

### 3.4 Result comparison

![Flood inundation comparison of Newtonian and non-Newtonian.](image)

From the Fig. 8 above it can be seen that the flooding model area using non-Newtonian parameters is larger than the Newtonian simulation. This could happen because non-Newtonian flow carries particles that increase its volume by 35%, as the result shows in the previous sub-chapter. This obviously will cause the rise of water.
Fig. 9. Comparison of Newtonian and non-Newtonian flow velocity.

Fig. 9 above shows that the Newtonian flow will have a higher velocity as it did not carry any solid, which will make the flow faster, while the Newtonian flow will have a slower velocity as it has to carry solid particles. But it also means that the debris flow would have a slight advantage in the sense that more areas are in the very low and low-velocity index than the non-debris counterpart.

Fig. 10 Comparison of Newtonian and non-Newtonian flood depth.

Fig. 10 shows the flood depth for debris and non-debris flow, where debris flow have a higher number of depth over 1.5 m than the non-debris flow.

3.5 Bed change

Riverbed changes were being modeled using Hec-RAS 6.2 with 1D modeling. The river that is being simulated is from the point of the water level recorder, PDA Cisokan, to downstream
of Cirata Reservoir. The total length of the river simulated is around 16 Km, from the Cisokan water lever recorder to its downstream before entering Cirata Reservoir.

**Fig. 11** shows the changes in bed elevation, where the black line is the existing bed elevation and the red line indicates the bed elevation changes. The simulation was run for one year using discharge data from the year 2018. The result shows that sediments will settle at various points where the water tends to be calmer, with the highest depth of sedimentation being 2.5 m. Even though it looked like in the graph that only sediment deposition happens, in reality, there are several cross-sections in which bed erosion happens, with the largest being 0.1 m. The bed changes then could be used to analyze the river safety factor.

![Riverbed changes of Cisokan River](image)

**Fig. 11.** Riverbed changes of Cisokan River.

### 3.6 Risk analysis

#### 3.6.1 Hazard

![Hazard index](image)

**Fig. 12.** Hazard index of (a) non-debris flow (Newtonian) (b) debris flow (non-Newtonian).
Fig. 12 (a) shows that almost all the inundated areas could be included in the high hazard index with a total area of 2.33 km², with 0.21 km² in the medium index, and 0.018 km² in the low hazard index. The hazard index is getting lower as the flood area moves further away from the river.

Fig. 12 (b) Similar thing happens in the debris flow hazard index as most of the flood area is categorized as a high hazard index with a total area of 1.99 km², and the medium hazard index covers 0.84 km² of the total inundated area, with only 0.045 km² is in low hazard index.

3.6.2 Vulnerability

According to data released by the Central Statistics Agency of Cianjur Regency in 2020 under the title "Kecamatan Ciranjang Dalam Angka," Ciranjang Village had a population of 19,802 people, with 51% being male and 49% female. The population density is 5,561 individuals/km². The ratio of those under 14 years of age was 26%, while the ratio of those over 55 years was 15%, meaning that 59% of the population falls within the productive age group. From the same source, it was also found that the disability ratio in Kelurahan Ciranjang was 38 individuals out of 19,802, which is 0.2%. In this study, the poverty ratio used is the result of a survey conducted in Kecamatan Ciranjang, where the percentage is 10%. With Eq.11 the vulnerability index could be calculated:

\[
V = 0.6 \times \log\left(\frac{5561}{0.01}\right) + (0.1 \times 0.98) + (0.1 \times 0.1) + (0.1 \times 0.002) + (0.1 \times 0.41) = 1.00
\]

So, the social vulnerability of Ciranjang Village is 1.00 or higher.

3.6.3 Capacity

As mentioned in the previous methodology Indonesia's capacity index is used to analyze the ability of an area and its community to undertake structured, planned, and integrated actions to reduce threats and potential losses due to disasters. However, this means that the parameter used could only be calculated based on the quality of a region’s ability to do so. It is a perfectly fine method which mainly used in Indonesia, but in this study, we would like to use an alternative of calculating capacity index with the parameter that could be calculated by quantity, which is why we use the Reliability Index Method’s Safety Factor (Level I) for river, and how river bed changes would affect it.

From sub-chapter 3.5, that the bed change was simulated for 16 Km, but this range is larger than the actual river length that intersects Ciranjang Village. From the 16 Km of river length, it was then divided into 46 cross-sections, with 19 of its cross-sections intersecting with Ciranjang Village. The SF analysis was conducted for every cross-section with different discharges to see the safety of the river per different flood discharges, with the discharges used 5, 10, 20, 25, 50, and 100-year return periods. Furthermore, the SF was also calculated as the riverbed changed, making the safety factor also change.
Fig. 13. River cross-sections for capacity analysis.

With all 46 cross-sections, the safety factor of the river average for each return period discharge is:

**Table 6. Average safety factor of the river (existing and with bed change).**

<table>
<thead>
<tr>
<th>Return period</th>
<th>Avg SF existing</th>
<th>Avg SF with bed change</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.89</td>
<td>0.88</td>
</tr>
<tr>
<td>10</td>
<td>0.84</td>
<td>0.81</td>
</tr>
<tr>
<td>20</td>
<td>0.81</td>
<td>0.80</td>
</tr>
<tr>
<td>25</td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td>50</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td>100</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

From Table 6 above it can be seen that as the river morphology changes, the safety factor of the river decreases. This could mean that as the river filled up with sedimentation, it would be without a doubt that the capacity index is decreasing, making the risk higher. As stated before, Ciranjang Village only amounts to 19 cross-sections of the total. The average safety factor is as follows:

**Table 7. Ciranjang Village part of Cisokan River safety factor.**

<table>
<thead>
<tr>
<th>Return period</th>
<th>Avg SF existing</th>
<th>Avg SF with bed change</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>10</td>
<td>0.82</td>
<td>0.80</td>
</tr>
<tr>
<td>20</td>
<td>0.79</td>
<td>0.78</td>
</tr>
<tr>
<td>25</td>
<td>0.78</td>
<td>0.77</td>
</tr>
<tr>
<td>50</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>100</td>
<td>0.73</td>
<td>0.72</td>
</tr>
</tbody>
</table>
From Table 7 above it can be concluded that the capacity index for this section of the river falls under the low index as the average safety factor is less than 0.85 except for a five-year return period. So, the capacity index used is low.

3.7 Risk map

Following that, from the above analyses, flood risk analysis can be conducted under two conditions, namely when debris flow occurs and when debris flow does not occur, with the results summarized in two risk maps as follows.

![Flood risk map with (a) non-debris flow, (b) debris flow.](image)

The flood risk map in Figure 14 (a) with non-debris flow shows that most of the non-debris flow inundated area is in the high-risk category which includes most of the residential area, with 2.33 km² is high risk, 0.21 km² is medium risk, and 0.018 km² is low risk. This means that Ciranjang Village is in the high-risk category for flood.

Once again, similar to the non-debris flow risk map (Figure 14 (b)), most of the inundated area is in the high-risk index category, with 1.99 km² is high risk, 0.84 km² is medium risk, and 0.045 km² is low risk, and considering that the area affected by debris flow flooding is larger than non-debris flow flooding, this will certainly be more detrimental.

4 Conclusion

After the analysis results are obtained, in the form of risk maps, several conclusions can be drawn from this study. Firstly, it's noted that floods may not always involve just water; sometimes, they also carry debris particles that increase the water volume and expand the flooded area. This aspect should be considered in flood analysis, especially in areas or rivers with a high sedimentation rate. Based on the results, it can be concluded that the inundated flood area is larger when we include debris flow or non-Newtonian flow parameters, 2.89 km², when the inundated area of non-debris flow is 2.57 km².

Even though the debris flow flooding area is larger than the non-debris flow flood area, the non-debris flow velocity is higher than the debris flow velocity. This could result in more
difficult access of evacuation as the higher velocity could endanger the people that try to flee their homes to safety.

Furthermore, risk analysis capacity indices usually use qualitative factors, but in this study, we utilized quantitative factors as an alternative to assess the influence of river morphology on the occurring floods.

References

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