Rapid assessment of river watershed health and vulnerability level for restoration strategy: a study of river systems in Indramayu, West Java, Indonesia

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Abstract. Climate change triggers a vulnerable level of a watershed. The assessment of watershed was conducted in rivers in Indramayu. Indramayu has terrible water quality due to several factors. The research aims to state the vulnerability level of Indramayu sub-watershed. The research analyzed several locations: Cimanuk sub-river and Muara Kali Prajagumiwang. The river health and vulnerability were assessed according to physical, land use, and water quality indicators in rivers. The other indicators are proposed according to the previous studies to enrich the future study result. The study finds out the possible future indicators: watershed landscape, hydrology, stream geomorphology, aquatic habitat, and biological conditions. The research uses a watershed vulnerability sequential analysis to obtain the result. The study analyzes the parameter, problems, and triggering factors from the sites. The assessment of stream corridor involves the rare species, sensitive fishes, macro-invertebrates availability, fish movement, normalization, water quality, river-land interaction, water spring, and geomorphology. The research concludes that rivers in Indramayu indicate fair and restorable impacted sub-watershed characteristics. This condition indicates that the streams have bad water quality, but they still could support a sustainable environment if it restored.

1. Introduction
Climate change affects the watershed ecosystem process, for example river systems [1]. River systems are a compulsory thing because they have a function as a natural buffer balance and support human life [2]. As a buffer for the balance of nature, rivers are water quality restoration, flood suppliers, and primary plants of flora and fauna ecosystems [3]. Besides, as a support for human life, river water is often used for cooking, washing, bathing, defecating to dispose of waste or rubbish. The use of rivers for washing, urinating, and disposing of waste and garbage is an activity that can damage the river [4]. The activity of river utilization by humans is very influential on river conditions [2]. Based on data from the Directorate General of Pollution and Environmental Damage and Forest Damage Control [5] in 2015, the condition of rivers in Indonesia, which is classified as heavily polluted has reached 68%. As a result, the majority of river water quality in 33 provinces in Indonesia is unsafe [6]. This fact is undoubtedly worrying, considering that river water is the primary source of water consumed by most of the population in Indonesia.

Based on research conducted by Cesarin [7], in general, the most dominant problem related to rivers is rubbish. This problem is relevant to the use of rivers to meet human needs. The most dominant form of watershed utilization according to the results of a questionnaire is conducted by Cesarin [7], in the form of landfills (36.8%) followed by washing dishes and defecating (22.4%) and cooking and bathing...
(17.1%). In addition to activities that harm river sustainability, river utilization is also a recreational area (14.5%) and river transportation routes (9.2%).

Indramayu Regency is one area that uses rivers as the primary source of water to support the living needs of its inhabitants. This phenomenon is not surprising considering that Indramayu is a district that is crossed by the Cimanuk River in almost all areas. The Cimanuk River is used as the primary source of irrigation water for agriculture, raw water, and drinking water, to meet industrial needs in Indramayu Regency. Figure 1 [8] depicts the potential agricultural area in Indramayu that utilizes water from the Cimanuk River.

![Figure 1. Irrigation system of Cimanuk Cisanggarung River Basin [8]](image)

To fulfill the raw water supply for drinking water in Indramayu Regency, through the Regional Water Supply Company (PDAM) Tirta Darma Ayu relies on Cimanuk River water. Based on data obtained from the official website of PDAM Indramayu, there were 1055 liters / second of water treatment plants out of a total capacity of 1285 liters / second of water treatment plants to serve the needs of clean water in Indramayu Regency. In addition, Cimanuk River water was not spared from utilization for industrial activities in Indramayu Regency. Table 1 is the projection of Indramayu Regency RKI water needs from 2005-2030 according to the Cimanuk-Cisanggarung River Basin Pattern in m³/sec.

**Table 1. Projection of Indramayu water needs**

| Year | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|------|------|------|------|------|------|------|
| Regency/ City | City | 0.135 | 0.142 | 0.147 | 0.150 | 0.148 | 0.150 |
| | Village | 0.339 | 0.428 | 0.456 | 0.474 | 0.474 | 0.479 |
| Indramayu | Industry | - | 0.500 | 1.000 | 1.000 | 1.500 | 1.500 |
| | Total | 0.474 | 1.070 | 1.604 | 1.625 | 2.122 | 2.130 |

Seeing the conditions above, the Cimanuk River is very closely related to meeting the needs of the people of the Indramayu Regency. The water used must naturally meet both the quantity and quantity requirements so as not to create new problems. Based on data obtained from the Indramayu Regency Environmental Agency (BLH), there are several rivers in Indramayu whose conditions are of poor quality. The rivers are a tributary of the Cimanuk river in Kenanga Village, Cimanuk River in the Bojongsari Reservoir area, Cimanuk River after the Bojongsari reservoir, Cimanuk River in the Paoman village and the Kali Prajagumiwang estuary. Therefore, the research aims to assess the vulnerability level of sub-watershed system.
2. Research method

Figure 2 is a flowchart of the research stages to be carried out by the author. Because this research is a watershed vulnerability analysis based on Zielinski \[9\], the research flow chart in this study refers to the stages of watershed vulnerability analysis.

![Flowchart of Research Method](image)

**Figure 2. Research method of vulnerability analysis [9]**

The primary outcome A is the initial classification. The research uses secondary data to obtain this result. Next, to get the primary outcome B, an analysis of river corridor assessment and land use conditions was carried out based on field assessments when surveying the area. Each assessment, both in the river corridor and land use, has ten criteria to be analyzed.

The assessment criteria above are used to assess whether the sub-watershed boundaries can be classified in the categories: sensitive, impacted, or non-supporting. Sub-watersheds will enter the Sensitive criteria if they meet the five assessment criteria or more, even though the impervious cover in sub-watersheds is more than 10%. Similarly, when a sub-watershed only meets one of the criteria or more, it can be classified as Restorable Sensitive even though the sub-watershed has an impervious cover of less than 10 percent. Sub-watersheds has five categories: Sensitive, sensitive estuary, impacted, impacted estuary, and non-supporting sub-watershed. The final sub-watershed categories include Restorable Sensitive, Restorable Impacted, or Restorable Non-Supporting, according to the assessment result. After analyzing the assessment of river corridors and land use, the research could produce outcome B or final classification of the catchment.

The next step is to obtain primary outcome C results by calculating the extent of water-resistant land cover in the future of Indramayu regency. The analysis produces a ranking of the most vulnerable sub-
watersheds. After that, the outcome of primary outcome D is in the form of evaluation of the ability of watershed restoration based on several criteria.

Finally, the research recommends a sequence of recommended sub-watersheds for planning and implementation in watershed management. The next step is providing appropriate mitigation measures in the sub-watershed area — for example, green infrastructure, stormwater management, and LID (low impact development) application.

### 3. Result and discussion

#### 3.1. Primary outcome A

The result decision for the first primary outcome is according to the impervious cover area in Indramayu regency. The research uses secondary data to analyze the result.

According to the Figure 3, rice field dominates Indramayu regency by 63.54% with 132,095 hectares, fishponds cover 3.33% of Indramayu with 6,930 hectares, and housing settles in Indramayu by 18,677 hectares (8.98%). The other land uses in Indramayu are forest, farmland, vegetated land and other land use with 10,766 hectares (5.18%), 15,203 hectares (7.31%), 6,930 hectares (3.33%), and 1,948 hectares (0.94%), respectively. The result of the primary outcome based on Zielinski [9] is Sensitive Estuary. It means Indramayu has less than 10% of imperviousness draining to an estuary. The detailed category of vulnerability level could be seen at Table 2 according to Zielinski [9].

**Figure 3.** Land use of Indramayu Regency in 2008 – 2015 [10]

| Vulnerability category     | Condition                                                                 |
|----------------------------|---------------------------------------------------------------------------|
| Sensitive                  | Sub-watershed with less that 10% imperviousness                           |
| Sensitive estuary          | Sub-watershed with less than 10% imperviousness draining to an estuary    |
| Impacted                   | Sub-watershed with 11 to 25% imperviousness                              |
| Impacted estuary           | Sub-watershed with 11 to 25% imperviousness draining to an estuary        |
| Non-supporting             | Sub-watershed with greater than 25% imperviousness                       |
3.2. Primary outcome B

The final classification of the watershed is obtained by field analysis. The study area is selected according to the imperviousness area coverage. Five locations would be analyzed to obtain the final classification. There are 1) Cimanuk Sub-river in Kenanga village, 2) Cimanuk River in Paoman village, 3) Prajagumiwang Estuary, 4) Cimanuk River in Bojongsari Reservoir, and 5) Cimanuk River after Bojongsari Reservoir. Figure 4 depict the sampling location, and Figure 5 and Table 4 show all locations of sampling activities. Table 3 explains the result of field assessment in the sampling sites. Table 5 and Table 6 show the detailed stream corridor and land uses assessment, respectively.

Figure 4. Field condition in Cimanuk Sub-river in Kenanga village (a, b), Cimanuk River in Paoman village (c), Prajagumiwang Estuary (d, e), and Cimanuk River in Bojongsari Reservoir (f, g, h)
### Table 3. Field assessment

| No. | Location                        | Physical Condition Parameter                                      | Problems                                                                                                                                                                                                 |
|-----|---------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Cimanuk Sub-river in Kenanga     | a. Greenish-brown water                                          | Sedimentation causes narrowing of river bodies With houses facing the river, the likelihood of disposal of household waste into the river is very high, which has an impact on river pollution.       |
|     | village                          | b. The smell is still normal                                     |                                                                                                                                                                                                          |
|     |                                 | c. There is sedimentation on the right and left sides of the river|                                                                                                                                                                                                          |
|     |                                 | d. There are at some points houses of people who are facing the river|                                                                                                                                                                                                          |
| 2   | Cimanuk River in Bojongsari      | a. Riverbanks are visible and organized                          | None                                                                                                                                                                                                     |
|     | Reservoir                       | b. River water is greenish-brown                                 |                                                                                                                                                                                                          |
|     |                                 | c. There is no water hyacinth plant                             |                                                                                                                                                                                                          |
| 3   | Cimanuk River after Bojongsari   | a. River water is greenish-brown                                 | Direct drainage has a high potential to cause river pollution Fish livestock can cause high levels of nitrogen in the water                                                                                   |
|     | Reservoir                       | b. There are drainage channels into the river body               |                                                                                                                                                                                                          |
|     |                                 | c. At some point, river bodies are used for fish farming         |                                                                                                                                                                                                          |
|     |                                 | d. There is no water hyacinth plant                             |                                                                                                                                                                                                          |
| 4   | Cimanuk River in Paoman village  | a. Greenish-brown water (darker to green)                        | Rivers used for fish farming have the potential to increase nitrogen levels in the river The number of water hyacinth plants can accelerate the process of siltation/sedimentation of the river The existence of settlements on the riverside causes the potential disposal of household waste into the river |
|     |                                 | b. There are non-permanent buildings in the middle of the river  |                                                                                                                                                                                                          |
|     |                                 | (fish farm)                                                     |                                                                                                                                                                                                          |
|     |                                 | c. There are many water hyacinth plants                         |                                                                                                                                                                                                          |
|     |                                 | d. There are settlements on the side of the river that are facing the river |                                                                                                                                                                                                          |
| 5   | Prajagumiwang Estuary           | a. River water is black                                          | Human waste will pollute the river The river's color is black, indicating that the river is polluted Rivers used for the fish-based food industry have the potential to pollute rivers |
|     |                                 | b. The river is used to wash fish catches by fishermen          |                                                                                                                                                                                                          |
|     |                                 | c. There are still human waste disposal sites (although not too many) |                                                                                                                                                                                                          |
|     |                                 | d. There are many water hyacinth plants                         |                                                                                                                                                                                                          |
|     |                                 | e. Settlements on the upstream side have been arranged to face the river |                                                                                                                                                                                                          |
Figure 5. Research sampling areas

Table 4. Research sampling areas

| Site | Location                        | Coordinate       |
|------|---------------------------------|------------------|
| 1    | Cimanuk Sub-river in Kenanga village | 6°21'23.65"S 108°18'55.48"T |
| 2    | Cimanuk River in Bojongsari Reservoir | 6°20'52.89"S 108°18'59.27"T |
| 3    | Cimanuk River after Bojongsari Reservoir | 6°20'13.32"S 108°19'24.73"T |
| 4    | Cimanuk River in Paoman village      | 6°19'10.21"S 108°20'5.64"T |
| 5    | Prajagumiwang Estuary               | 6°18'59.08"S 108°20'5.64"T |
### Table 5. Stream corridor assessment

| Research criteria                                                                 | Information                                                                                   | Checklist |
|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------|
| The presence of rare, threatened, or endangered species in aquatic communities   | Fish and amphibian species are still found in fish species                                    | √         |
| (for example freshwater shellfish, fish, crayfish or amphibians)                  |                                                                                               |           |
| Confirm the presence of sensitive fish species.                                   | Not found                                                                                     | -         |
| Rating of invertebrates in the range of pretty-good, good, and very good.        | Good condition of invertebrates                                                               | √         |
| More than 65% of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) species are| Not found or not up to 65%                                                                    | -         |
| present in invertebrate assessments.                                              |                                                                                               |           |
| There is no obstacle blocking the movement of fish between the sub-watershed and  | Yes                                                                                           | √         |
| the main river.                                                                   |                                                                                               |           |
| The lack of efforts to change the river (normalization and canalization).         | There are not many changes to the river like normalization                                     | √         |
| Water quality monitoring does not show any standards that are violated during the | Bad water quality                                                                             | -         |
| dry season.                                                                       |                                                                                               |           |
| Rivers and land remain connected and interact regularly.                          | Yes                                                                                           | √         |
| The flow of water in the sub-watershed leads to the downstream surface of the    | Yes                                                                                           | √         |
| water source.                                                                     |                                                                                               |           |
| River flows are generally stable, as determined by Rosgen Level III analysis or  | Good condition                                                                               | √         |
| on other geomorphological analysis standards; assessment of river habitat is at  |                                                                                               |           |
| least good enough.                                                                |                                                                                               |           |

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![Figure 6. Sub-watershed vulnerability assessment](image-url)
Table 6. Land use assessment

| Research criteria                                                                 | Information                        | Checklist |
|----------------------------------------------------------------------------------|------------------------------------|-----------|
| There are populations of plants or animals in the rare, threatened and endangered | Not found                          | -         |
| threatened and endangered categories in the sub-watershed.                       |                                    |           |
| More than 10% of the sub-watershed area consists of wetlands, floodplains, and / | Wetlands still have > 10% of the  | √         |
| / or beaver complexes.                                                           | catchment area                      |           |
| More than 10% of the sub-watershed area is dedicated to conservation.            | Still surrounded by large trees    | √         |
| around the housing as a conservation effort.                                     |                                    |           |
| More than 50% of the riparian corridors have forest cover, and are public or     | Found                              | √         |
| regulated.                                                                       |                                    |           |
| There are forests in the sub-watershed, and more than 40% of the watershed area  | Not found                          | -         |
| is forest.                                                                       |                                    |           |
| There is a section / party responsible for watershed management.                 | There is, but does not manage the  | -         |
| The river border forms a continuous flow along the sub-watershed.                | watershed properly                  |           |
| The sub-watershed is connected to the watershed through a large, untouched      | Yes                                | √         |
| corridor where wildlife can live there.                                          |                                    |           |
| Application of BMP in agriculture, animal husbandry and plantation activities.   | Not found                          | -         |
| Before the development was carried out in the sub-watershed, the sub-watershed   | Not found                          | -         |
| itself had managed rain runoff both in quality and quantity.                     |                                    |           |

In this final classification, Indramayu sub-watershed could be classified into Restorable Impacted sub-watershed. It still has a fair condition of stream corridor and land use quality but a sensitive condition in the initial classification.

3.3. Primary outcome C

The next stage of the vulnerability analysis of sub-watershed is predicting the future impervious cover percentage in the Indramayu region. The prediction could be achieved by secondary data from Murdaningsih [10]. Table 7 shows the land use percentage in 2031.

Table 7. Land use of Indramayu in 2031 [10]

| Land use      | 2015 Area (ha) | 2015 % | 2031 Scenario I Area (ha) | 2031 % | 2031 Scenario II Area (ha) | 2031 % |
|---------------|----------------|--------|---------------------------|--------|-----------------------------|--------|
| Fishponds     | 22,258         | 10.71  | 23,837                    | 11.47  | 23,638                      | 11.37  |
| Forest        | 10,766         | 5.18   | 9,235                     | 4.44   | 9,436                       | 4.54   |
| Vegetated land| 6,930          | 3.33   | 6,842                     | 3.29   | 6,793                       | 3.27   |
| Farmland      | 15,203         | 7.31   | 15,479                    | 7.45   | 15,352                      | 7.39   |
| Housing       | 18,677         | 8.98   | 20,443                    | 9.83   | 20,187                      | 9.71   |
| Rice field    | 132,095        | 63.54  | 130,495                   | 62.78  | 130,925                     | 62.98  |
| Others        | 1,948          | 0.94   | 1,546                     | 0.74   | 1,546                       | 0.74   |
According to the data, it is predicted that in 2013, Indramayu still has the same category as in recent years. The percentage of settlements in Indramayu is still less than 10% or approximately 10%. There is no significant change in housing purposes in Indramayu. Based on Figure 6, Indramayu sub-watershed is still classified as Restorable Impacted sub-watershed.

3.4. Restoration technology
This research proposes a technology to improve the quality of the stream in Indramayu sub-watershed. According to the field study, the problem of water quality is complicated due to no waste-water treatment for society's disposal. Many nutrients like nitrate or phosphorus flow freely into the river without any treatment. The advanced technology in this sub-watershed is installing a much-vegetated wetland to improve the water quality of a river or sub-watershed. On the other side, climate change should be considered. The water quality becomes worse if the rainy season comes. Analysis of SWAT (The Soil and Water Assessment Tool) and SWMM (Storm Water Management Model) should be conducted to obtain better results and comprehensive discussion.

4. Conclusion and recommendation
The research concludes that the vulnerability level of Indramayu sub-watershed is classified as Restorable Impacted sub-watershed. Climate change makes compulsory effects of water resources in a certain region. The information about climate change effects at regional scale is still limited, but the assessment of watershed vulnerability is compulsory to observe changes in hydrology and is important for watershed management. Technology to develop the water quality should be installed like green technology along with the research result supports. Furthermore, the SWAT analysis is recommended to conduct to perform better results and understanding to tackle Indramayu sub-watershed problems. So does SWMM model to simulate various climate change condition effect to the watershed.

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