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Simplified Methodology for Assessing River Carrying Capacity Based on Land-Use Types

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ABSTRACT

Land conversions or land use changes also become the main cause of the decline in Citarum River conditions. The relationship between river sustainability and its watershed carrying capacity plays a vital role in protecting watersheds to implement sustainable water resources management. Previous studies on river assessment for watershed management have predominantly focused on specific hydrological and/or technical results, rather than considering the process of the development of carrying capacity methodology due to land-use types. Motivated by this fact, the objective of this study is to develop a simplified carrying capacity methodology due to land-use types for sustainable river management by selecting the Upper Citarum Watershed (a main part of Citarum Watershed) located in West Java Province, Indonesia as an example of a study area. The conceptual framework development for watershed carrying capacity due to land-use types was designed the step-by-step methodology standard regarding the sustainable river management. The methodology of this study also used AHP method consisting of screening and selecting attributes, transforming and developing sub-indices, assigning weights, and formulating a runoff cumulative (Ccum) to examine standards and criteria for carrying capacity classification due to the changes of land-use types. The analysis revealed a significant change in the proportions of the various land use types of the study area. The conclusion is it integrates the measures of selected important land-use types to create a single dimensionless number of runoff cumulative and its classification, and a modified approach to communicate information on river status to the public and related policy makers. To advance future studies, it is necessary to develop a comprehensive

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evaluation and monitoring systems by using GIS-based spatial and temporal analysis.

Keywords: Land-use types; Carrying capacity methodology; Sustainable river

1. Introduction

Natural and anthropogenic process as well as changes in certain watershed are very diverse and complex. These complexity in watershed is not only the physical and hydrological variables, but also features such as land-use types and land-use pattern, and other variables including antrophogenic activities within. Many stakeholders from governments and experts might well have a similar expectation especially when it is recognized how diverse and complex a watershed through time and place [1]. Potential problems in watershed are mostly come from anthropogenic activities that related to the condition of waterbodies such as rivers. Some flood cases can be seen when the rainy season as well as drought cases when the dry season. The carrying capacity of a watershed refers to its potential to create sustainability and harmony in its ecosystem while also optimizing the advantages of natural resources for humans and other living creatures [2]. Moreover, vegetation significantly impacts global and regional ecosystems. Converting land-use types such as forest to agricultural land may result in loss of hydrological functions especially infiltration process [3]. These land-use changes will also affect the carrying capacity of a watershed combined with the increased of urbanization as the trigger or driving factor for the decline condition of watershed and rivers within. Therefore, it is still challenging to develop comprehensive methodology for watershed carrying capacity regarding sustainable river management [4].

Citarum Watershed that located in West Java Province, Indonesia is a very large watershed with an area of ±6080 km^2. It consisted on Citarum River as a main river includes 36 tributaries with a total length of 873 km. According to The National Medium Term Development Plan for 2020–2024 (RPJMN) from the Indonesia' government, Citarum Watershed is categorized as one of the critical watersheds in Indonesia due to its degradated condition [5]. The hydrology and hydraulic characteristics of Citarum River are vary and fluctuated between rainy and dry seasons. The environmental issues such as water pollution, flood during rainy season and water scarcity during dry season became priority problems in the Citarum Watershed that must be handled. Land conversions or land use changes also become the main cause of the decline in Citarum River conditions. The relationship between river sustainability and its watershed carrying capacity plays a vital role in protecting watersheds to implement sustainable water resources management. Previous studies on river assessment for watershed management have predominantly focused on specific hydrological and/or technical results, rather than considering the process of the development of carrying capacity methodology due to land-use types [6]. Motivated by this fact, the objective of this study is to develop a simplified carrying capacity methodology due to land-use types for sustainable river management by selecting the Upper Citarum Watershed (a main part of Citarum Watershed) located in West Java Province, Indonesia as an example of a study area.

2. Materials and methods

Study area

The upper Citarum Watershed (**Figure 1**) are located between 107°24'0"–107°48'0" East Longitude and 6°45'0"–7°12'0" South Latitude. It becomes a very important watershed since it has three large reservoirs i.e. Saguling Reservoir, Cirata Reservoir and Jatiluhur Reservoir with various water functions such as a source of fresh water, irrigation, fishing, water supply for industrial activities, and a source of hydroelectric power. The Citarum River itself stretches from a spring at Mount Wayang to the end of river at Tanjung Karawang by passing through 12 regencies such as Subang, Bandung and West Bandung Regencies with a high level of economic development and complex agricultural system within [7].

According to the jurisdiction region administrative perpective, the upstream Citarum watershed covers Bandung City, Bandung Regency, Cimahi Regency, and West Bandung Regency. These four regions are areas with a high level of economic development and a relatively well-established and complex agricultural system. Some of land use types are agricultural area that can contributed the environmental degradation condition of the upstream area of the Citarum watershed. Some agricultural-athropogenic activities have been actively monitored recently such as the cultivation forest areas, expansion of vegetable crops in steep and hilly areas, etc which may damage and reduce the upstream Citarum watershed[8].Meanwhile, this study also shown that the land use change in study area by using GIS-based approach in year 2018 and 2023 (**Figure 2**).

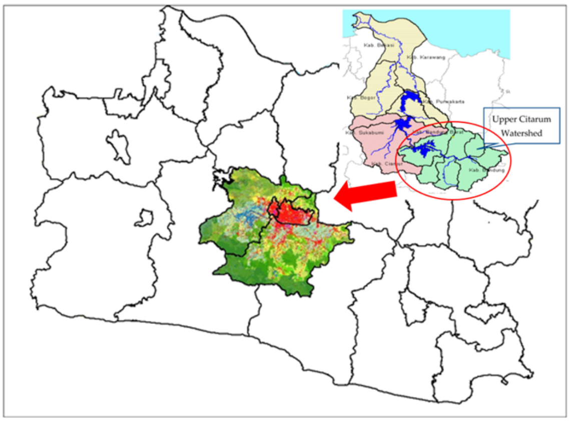

Figure 1. Location of upper citarum watershed.

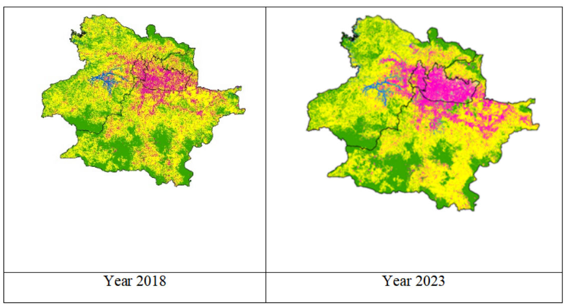

Figure 2. Land-use changes in study area.

3. Results and discussions

This study used data from satellite imagery which are freely available from sources like Landsat that can be used to classify land cover into categories like forest, agriculture, urban areas, and water bodies. Other tools like Google Earth Engine or open-source GIS software also can be used for analysis. Some of government agencies such as national or regional government agencies often have land-use maps available online or through data portals. Moreover, concerning the scoring, the process of this study was consulted with experts to assign scores to each land-use type based on their potential impact on water runoff. Variables like vegetation cover, infiltration rate, and soil type would be considered. Moreover, for the data acquisition process as follows: first stage, we has downloaded or acquired land-use data for the specific watershed of study area (Upper Citarum Watershed) for a chosen timeframe (2018 and 2020). Then, the study conducted with the experts to established scoring systems to assign values to each land-use type. These scores represent their relative contribution to water runoff. The accuracy of the Ccum index depends on the quality of the land-use data and the necessary information to calculate the Ccum index and assess the condition of a watershed.

3.1 A proposed methodology

The conceptual framework development for watershed carrying capacity due to land-use types was designed the step-by-step methodology standard regarding the sustainable river management. In general, the methodology of this study used AHP method consisting of screening and selecting land use types, transforming and developing sub-indices, assigning weights, and formulating a runoff cumulative (Ccum) to examine standards and criteria for watershed carrying capacity classification due to the land-use types (**Figure 3**).

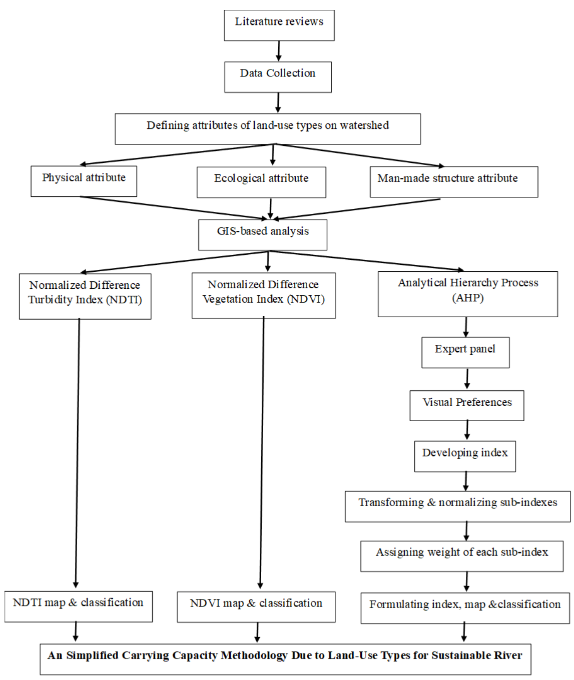

Figure 3. The step-by-step process of a simplified carrying capacity methodology due to land-use types for sustainable river.

In order to develop an index, first it is important to identify and select certain land use types should be included in the developing index. Spatial data should be performed by spatial analysis that reveal the geometric or geographic properties of data[9]. Spatial data could use a computational model such as Geographic Information System (GIS)-based model[1]. This study proposed the rapid advancement of ArcGIS combined with Google-Earth software in spatial analyses of land use types and if necessary validate the data by doing field survey measurements[10]. Next method is interviews with experts in order to assign scores to each land use types. The scores should be based on the relative importance of each land use types regarding the level or weight of importance[11]. Detail steps to create an index can be seen on **Table 1**. Numericaly, the runoff cumulative (Ccum) can be represented as:

$$\text{Ccum} = \sum_{i=1}^{n} w_i C_i \tag{1}$$

Where w_i was the average weight factor for the ith land use type, and C_i was the standardized sub-index for the ith land use type. Each quality value was then multiplied by an average weight factor, to take into account the relative contribution of each land use type to the overall index.

3.2 The formulation of harmonious land use types through the cumulative runoff (Ccum) index

The common definition of land-use is a state of land elements that can be measured and has land characteristics that will be able to determine and influence land behavior such as water availability, air circulation, root growth, erosion sensitivity, nutrient availability and so on so that land behavior determines the growth of vegetation commonly referred to as land quality[12]. Soil, land and water are natural resources and they are closely related from one place to another in relation to the continuity of ecosystem processes. This study identified four land use types (forest area, agricultural area, built-up area, and waterbody areas) from the interpretation results of satellite imagery by using spatial analysis embedded with a geographical information system (GIS)-based model to examine the pattern of land use changes on year 2018 and 2020. Harmonious land use patterns in a watershed can support the sustainability of watershed. The following result is a formulation of harmonious land use studied through the process methodology of cumulative runoff (Ccum) index in the upper watershed:

$$\begin{aligned} &\text{Ccum index} = 0.2F + 0.3A + 0.4B + 0.1W \\ &\text{For: } F + A + B + W = 1 \end{aligned} \tag{2}$$

Where :

F = Percentage of forest area

A = Percentage of agricultural area

B = Percentage of built-up area

W = Percentage of waterbody area

The analysis of land-use changes in the study area for 2018 and 2020 can be seen on **Table 2** and **Table 3**. The results indicated that the changes has increased significantly especially in several sub-watershed area due to its increased runoff cumulative.

4. Discussion

Table 2 presents the land-use types and their corresponding percentages (F, 0.1F, R, 0.3R, Gr, 0.35Gr, U, 0.7U) and the calculated runoff cumulative (Ccum) index for each sub-watershed within the study area in 2018. The table is organized by the three administrative areas: Bandung Regency, Bandung City, and West Bandung Regency. These land-use types of Citarurm Hulu sub-watershed are represented by their respective symbols and percentages such as forest (F) consisted of 43.4%, rice paddy fields (R) consisted of 26.7%, grassland (Gr) consisted 23.2% urban areas (U) consisted 6.7%. And so on for **Table 3** and **Table 4**. Meanwhile, the Ccum index is a dimensionless value that represents the overall runoff potential of the watershed, considering the different land-use types and their relative contributions to water runoff. Higher Ccum values indicate a higher potential for runoff.

The table reveals that the land-use composition varies across the sub-watersheds, with some having a higher proportion of forest cover (e.g., Citarum Hulu) and others having a higher proportion of urban areas (e.g., Cisangkuy). The Ccum index values range from 0.3 to 0.6, indicating that the runoff potential varies moderately among the sub-watersheds. The results from the table also provided valuable information for understanding the relationship between land-use patterns and runoff potential in the study area. This information can be used for watershed management and planning purposes. Comparing **Table 2** to **Table 3**, this study has detected the changes in land-use percentages for some sub-watersheds between 2018 and 2020. For instance, the percentage of

Table 1. Methods for developing runoff cumulative (Ccum).

No.	Stages	Spatial data analysis	Interviews with experts	Field survey measurements
1	Screening and selecting land use types	●	●	●
2	Transforming and developing sub-indices	●		●
3	Assignment of weights	●	●	
4	Formulating an index	●		

Table 2. Results of land-use types in study area for developing runoff cumulative (2018).

Sub-watershed	Area (km^2)	Land use types (2018)								
		F (%)	0.1 F	R (%)	0.3 R	Gr (%)	0.35 Gr	U (%)	0.7 U	Ckum
Bandung Regency										
Citarum Hulu	290.1	43.4	0	26.7	0.1	23.2	0.1	6.7	0	0.3
Cikeruh	183.2	17.4	0	17.7	0.1	17.8	0.1	46.9	0.3	0.5
Ciwidey-Cimahi	322.7	37.6	0	18.6	0.1	26.3	0.1	14.1	0.1	0.3
Citarum/Sapan	754.7	27.1	0	29.8	0.1	23.6	0.1	19.6	0.1	0.3
Citarum/Dayeuh Kolot	1332.1	28.8	0	23.5	0.1	24.4	0.1	23.1	0.2	0.3
Bandung City										
Cisangkuy	276.5	38.6	0	9.9	0	38.9	0.1	11.6	0.1	0.3
Cidurian-Cicadas	102.9	12.3	0	29.3	0.1	3.6	0	54.1	0.4	0.5
Cikapundung	144.3	40.7	0	6.7	0	6.3	0	46.2	0.3	0.4
Cimahi City										
Cibeureum	117.2	12.9	0	5.8	0	5.2	0	76	0.5	0.6
West Bandung Regency										
Citarik	281.4	16.4	0	40.8	0.1	27.8	0.1	14.9	0.1	0.3
Citarum/Nanjung	1718	28.6	0	21.8	0.1	23.6	0.1	25.1	0.2	0.3
Citarum/Curug Jompong	1772	29.4	0	21.4	0.1	23.5	0.1	24.9	0.2	0.4

urban areas in Citarum Hulu increased slightly from 6.7% to 6.718%. The Ccum index values in **Table 3** range from 0.3 to 0.6, similar to those in **Table 3**. This suggests that the overall runoff potential of the sub-watersheds remained relatively stable between 2018 and 2020. Meanwhile, **Table 4** compares the land-use types in each sub-watershed of the study area between 2018 and 2020. It presents the percentage cover of each land-use type (Forest (F), Rice paddy fields (R), Grassland (Gr), Urban areas (U)) for each sub-watershed in both years. This study reveals that the changes in land-use patterns within the sub-watersheds during 2018–2020. For instance, in Citarum Hulu, the percentage of Forest cover remained the same (43.4%), while the percentage of Urban areas increased slightly (from 6.7% to 6.72%). This results also highlighted the potential shifts in land-use practices and their implications for water runoff and watershed condition.

Added information based on GIS analysis of land use in 4 districts of West Java (Bandung Regency, Upper Citarum and Cikeruh Sub-watershed, Ciwidey-Cimahi Sub-watershed, Sapan and Dayeuh Kolot Sub-watershed, West Bandung Regency) during the period 2018–2020 (**Table 4**), it can be observed that the dynamics of waterbody area varies, it can be seen that for the bandung regency area there are fluctuations in land change, for the upper citarum and cikeruh sub-watershed areas there is an increase in waterbody area. This is due to the efforts of the government through the upstream citarum sediment dredging project in the dry season which took effect in 2018, but on the other hand, the sub-watersheds in Ciwidey-cimahi, Sapan and Dayeuh Kolot experienced a decrease in waterbody area, when viewed from the data this

Table 3. Results of land-use types in study area for developing runoff cumulative (2020).

Sub-watershed	Area (km^2)	Land use types (2020)								
		F (%)	0.1 F	R (%)	0.3 R	Gr (%)	0.35 Gr	U (%)	0.7 U	Ckum
Bandung Regency										
Citarum Hulu	290.1	43.4	0	26.7	0.1	23.2	0.1	6.718	0.1	0.3
Cikeruh	183.2	17.4	0	17.7	0.1	17.8	0.1	46.997	0.3	0.5
Ciwidey-Cimahi	322.7	37.7	0	18.6	0.1	26.4	0.1	14.069	0.1	0.3
Citarum/Sapan	754.7	27.1	0	29.8	0.1	23.6	0.1	19.571	0.1	0.3
Citarum/Dayeuh Kolot	1332.1	28.8	0	23.5	0.1	24.5	0.1	23.061	0.2	0.3
Bandung City										
Cisangkuy	276.5	38.6	0	9.9	0	38.9	0.1	11.681	0.1	0.3
Cidurian-Cicadas	102.9	12.3	0	29.3	0.1	3.6	0	54.13	0.4	0.5
Cikapundung	144.3	40.7	0	6.7	0	6.3	0	46.223	0.3	0.4
Cimahi City										
Cibeureum	117.2	12.9	0	5.8	0	5.2	0	76.024	0.5	0.6
West Bandung Regency										
Citarik	281.4	16.4	0	40.8	0.1	27.8	0.1	14.961	0.1	0.3
Citarum/Nanjung	1718	28.6	0	21.9	0.1	23.6	0.1	25.116	0.2	0.4
Citarum/Curug Jompong	1772	29.4	0	21.5	0.1	23.5	0.1	24.927	0.2	0.4

reduction in area occurred due to an increase in the area of build-up area in these areas [1]. The decrease in waterbody area is also influenced by the increase in forest area [13]. In sub-watersheds of urban areas such as Bandung and Cimahi, there is an increase in waterbody area, the increase in waterbody area is associated with government projects in the dredging efforts of the Citarum River [14].Meanwhile, land use change in the sub-watershed of the west Bandung regency area has increased the area of agricultural land, which needs to be further examined regarding its implications for the waterbody [2]. This study also showed the trends in Land-Use Change from 2018 to 2020. Based on the results of tables, it is indicated that an increased urbanization in a specific sub-watershed reflected by an increase in the urban area percentage. Moreover, the Ccum index and land-use changes. It shows that a decrease in forest cover and an increase in urban areas (which likely have higher runoff scores) drive the potential for increased runoff based on the Ccum index. Therefore, the formula of Ccum index assigns higher scores to land-use types with a higher impact on runoff. The results is reflect this understanding. However, this study also considered the timeframe of the data analysis. Changes observed in a two-year period (**Table 2** and **Table 3**) might not represent long-term trends.

5. Conclusions

A simplified carrying capacity methodology is indispensable for ensuring sustainable river management practices since the significant land use changes have been remarked recently due to unplanned land use patterns in watershed and rapid urbanization. In general, this methodology should consider important land use types to to create a comprehensive framework for effectively managing watershed systems and balancing anthropogenic activities within. Watershed carrying capacity methodology integrates the measures of selected important land use types to create a single dimensionless number of runoff cumulative and its classification, and a modified approach to communicate information on watershed status to the public and related policy makers. By carefully analyzing this methodology and implementing the appropriate management strategies, it will be possible to maintain the long-term viability of watershed systems. Additionally, this methodology can serve as a valuable tool for decision-makers and policymakers in developing effective policies and regulations that protect and sustain watershed systems while also promoting economic growth and social development.

Further studies, some potential variables such as num-

Table 4. The comparation results of land-use types in study area.

Sub-watershed	Area (km^2)	Land use types (%)							
		F (2018)	F (2020)	R (2018)	R (2020)	Gr (2018)	Gr (2020)	U (2018)	U (2018)
Bandung Regency									
Citarum Hulu	290.1	43.4	43.4	26.7	26.7	23.2	23.2	6.7	6.72
Cikeruh	183.2	17.4	17.4	17.7	17.7	17.8	17.8	46.9	47.00
Ciwidey-Cimahi	322.7	37.6	37.7	18.6	18.6	26.3	26.4	14.1	14.07
Citarum/Sapan	754.7	27.1	27.1	29.8	29.8	23.6	23.6	19.6	19.57
Citarum/Dayeuh Kolot	1332.1	28.8	28.8	23.5	23.5	24.4	24.5	23.1	23.06
Bandung City									
Cisangkuy	276.5	38.6	38.6	9.9	9.9	38.9	38.9	11.6	11.68
Cidurian-Cicadas	102.9	12.3	12.3	29.3	29.3	3.6	3.6	54.1	54.13
Cikapundung	144.3	40.7	40.7	6.7	6.7	6.3	6.3	46.2	46.22
Cimahi City									
Cibeureum	117.2	12.9	12.9	5.8	5.8	5.2	5.2	76	76.02
West Bandung Regency									
Citarik	281.4	16.4	16.4	40.8	40.8	27.8	27.8	14.96	14.96
Citarum/Nanjung	1718	28.6	28.6	21.8	21.9	23.6	23.6	25.12	25.12
Citarum/Curug Jompong	1772	29.4	29.4	21.4	21.5	23.5	23.5	24.93	24.93

bers, size, distribution and location of watersheds and some other land use type could be considered into the index. However, it may be beneficial to develop regional-specific templates within the watershed carrying capacity methodology framework. These regional-specific templates would take into account the unique characteristics and dynamics of different geographic regions.

Conflict of Interest

The author declares no conflict of interest.

Data Availability Statement

The author confirms that the data supporting the findings of this study are available within the article.

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