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Analysis of environmental carrying capacity for the development of sustainable settlement in Yogyakarta urban area

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Abstract

The growth of urbanization in Yogyakarta area has a significant impact on environmental degradation. One of the indications is the environmental carrying capacity and environmental settlement quality that tend to decrease. The research was aimed to analyze the environmental carrying capacity of the settlement land resources and water resources as the development base of sustainable settlement in Yogyakarta Urban Area (YUA). The research method used a studio analysis based on primary and secondary data and available mathematical formulas. The results showed that the carrying capacity of settlement land resources in YUA reached 2.89 or conditionally-save. In addition, the analysis of water resources carrying capacity in YUA indicated a conditionally-save result with the value of 2.44. Land resources carrying capacity is considered as save when reaching 22.73%, conditionally save when the value is 60.60%, and overshoot when it reaches 16.67%. Meanwhile, water resources carrying capacity is entitled save if the value is 15.15%, conditionally-save if it reaches 74.24%, and overshoot if reaching 10.61%.

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1. Introduction

The United Nations predicts that 3 out of 5 people in the world will live in urban areas in year 2030¹. As an urban area, Yogyakarta has a significant urbanization level. The extent of its available land has been extremely limited, and this has caused urbanization in Yogyakarta to spread out to Sleman Regency and Bantul Regency. Sleman has the highest urbanization rate because there are more supporting factors. The consequence of such condition is that the demand for houses and other supporting facilities becomes very high, making settlement areas wide and dense.

The large number of settlement areas in Sleman cannot be separated from the image of Yogyakarta as a study destination along with the developments of various business units supporting it. Around 60% of university campuses are located in Sleman, and it is assumed that more than 63% of their students come from other cities. Consequently, the need for houses/settlement areas increases significantly. Developments of property to support settlement areas reach the highest percentage in Yogyakarta Special Region, *i.e.*, 71%, followed by commercial properties with 26%, while the rest is for industries and conferences².

The growth of settlement areas has caused a lot of problems. Relating to land use, some of the emerging problems are: the domination of strategically located lands resold for higher price, the long list of land brokers, the land ownership problems, etc. Widodo predicted that rice fields in Sleman, Yogyakarta and Bantul would disappear and change into settlement areas by 2030s if these problems were not well controlled³.

The control and management of settlement buildings as well as the construction of housings should focus on the ecosystem approach by combining all environmental aspects fairly. Similar to living things, settlement areas should have a healthy condition physically, spiritually, and environmentally (*men sana in corpore sano in vicinia sana*). The development of housing areas and/or settlement areas must comply with the development regulations in a responsible and sustainable way.

The development trend of YUA has been continuously spreading to its surrounding areas, and one major phenomenon of this is the development of settlement areas. A significant problem related to the growth of YUA indicates that the environmental carrying capacity is likely to decline. This research tries to describe the condition of environmental carrying capacity of the settlement land resources and water resources as the base for the construction and management of settlement areas that adhere to the sustainable settlement concept. In other words, this research is aimed to analyze the environmental carrying capacity of either the settlement land resources and/or water resources to be the base of sustainable settlement development in Yogyakarta Urban Area.

2. Literature Review

Land-use development represents the increasing human needs, particularly the primary need for building houses. Today, housing provision has been a potential business project. In *DIY* (Yogyakarta Special Region), property developments for housing complexes reach 71 %, while 26% develops commercial properties, and the rest is for industries and conferences². The highest settlement growth occurs in Sleman Regency⁴ with about 1,500 houses per year⁵. The housing business in Sleman Regency is mostly run by developers; yet, according to^{4, 5}, this business remains prospective and conducive. As a result, the housing business keeps increasing and makes an impact on land conversion occurring frequently in Sleman. If no suitable control efforts are taken, it is forecasted that by 2030s the rice fields in Sleman will vanish because they are used as settlement areas³.

The market of housing business and properties remains a ‘booming’ trend in *DIY*, especially in Sleman and Bantul. A research stated⁵ that the factors influencing the housing growth in Sleman Regency are land locations, credit accessibility from banks, and land prices. The research recommended that the issues of building permits should consider the land availability and land mapping in order to maintain the balance between land sustainability and settlement areas. It is therefore important to analyze how far that aspect has been fulfilled by housing business developers.

The development of settlement areas should not only fulfill the need for places to live in but also consider all facilities or infrastructures that either support or influence the surrounding environment. One of the important impacts caused by land conversion into buildings is environmental problems^{6, 7}. Some of the emerging problems are floods, droughts, ground water contaminations, environmental diseases, wastes, increasing local temperatures, etc. Therefore, the settlement development planning should consider environmental conservation aspects as an act of

responsibility as well as ethics towards the environment⁸. The existing housing areas cannot be regarded as ‘free’ from conservation demands. The developers and inhabitants of housing areas can revitalize the settlement’s surroundings to achieve the function of environmentally-friendly area⁹. The revitalization acts can be established by providing green open space, planting trees, as well as building catchment wells, *IPAL* (Waste Water Treatment Plant), and other environmental infrastructures. The efforts of revitalization towards sustainable settlements, however, need to be examined based on the condition of environmental carrying capacity.

The essence of environmental carrying capacity is the comparison between supply and demand. Supply is usually limited, while demand is unlimited. The many factors influencing demand and supply make the calculation of environmental carrying capacity difficult; consequently, environmental carrying capacity is usually determined for a closed system without considering the interaction among areas/locations. The concept of environmental carrying capacity is usually developed based on sectors (agriculture, tourism, physical, social, etc.). Meanwhile, the application of environmental carrying capacity to people/human beings should be appropriately positioned on the condition it is meant for^{10, 11}.

Some people no longer live from nature recently, so it also causes pressure on their environments. The population pressure towards the environment, according to¹⁰, is the problem of the most critical environmental degradation. This problem keeps increasing as the population growth and economic activities escalate.

The environmental carrying capacity and its influencing factors vary according to areas due to the differences in such aspects as population, environment, natural resources, and local management. Therefore, it is extremely important for the policy making and priority of development programs to consider the existing situation, condition, characters, and local potentials that are reflected from their environmental carrying capacity. As a matter of fact, many researches on environmental carrying capacity as well as the available concepts have not yet explicitly considered the factors of physical land and water resources carrying capacity. This research is therefore conducted to analyze specifically the environmental carrying capacity by relating the existing condition evaluation, the future condition projection, and their strengthening strategies.

3. Methods

The data were collected from primary and secondary sources found in relevant institutions, journals, and others. Then, the data analysis was conducted by applying a quantitative and descriptive analysis method. The quantitative method was used to analyze the environmental carrying capacity involving mathematical formulas. Meanwhile, the descriptive method was utilized to analyze the recommendations resulted from the calculation of environmental carrying capacity. The formulas used for calculating the environmental carrying capacity are as follows:

3.1. Settlement land resources carrying capacity:

$$DDLb = \frac{\alpha * LW}{LTb} \quad (1)$$

$$LTb = LB + LTp \quad (2)$$

Note:

DDLb : Settlement land carrying capacity for buildings

LW : Extent of Land (Ha)

α : Coefficient of maximum extent of built-land:

- For cities, use 70%, according to Law No. 26/2007 stating that 30% must be used for green open space (*RTH*)
- For villages, use 50% (assumed value) because the rest is for agricultural lands and preservation/conservation function

LTb : Extent of Built-Land (Ha)

LB : Extent of Buildings (Ha)

LTp : Extent of land for infrastructures, such as roads, rivers, drainages, and others (Ha). If they cannot be identified, then it is assumed to use 10% of the building extent.

3.2. Water resources carrying capacity:

- Water Availability (SA)

$$C = \frac{\sum(C_i \times A_i)}{\sum A_i} \quad (3)$$

$$R = \frac{\sum R_i}{m} \quad (4)$$

$$SA = 10 \times C \times R \times A \quad (5)$$

Note:

- SA = water availability (m³/year)
- C = coefficient of weighted runoff
- C_i = coefficient of land use runoff i as shown on the following table
- A_i = extent of land use i (Ha)
- R = average of annual rainfall of the area (mm/year)
- R_i = annual rainfall on i station
- m = number of rainfall observation stations
- A = extent of the area (Ha)
- 10 = conversion factor

Table 1. Coefficient of Land Use Runoff

No	Land Cover	C _i
1.	City, asphalted road, roof tile	0.7 – 0.9
2.	Industrial area	0.5 – 0.9
3.	Multi-unit settlement area, shopping centre	0.6 – 0.7
4.	Housing complex	0.4 – 0.6
5.	Villa	0.3 – 0.5
6.	Park, cemetery	0.1 – 0.3
7.	Yard of heavy land:	
	a. > 7 %	0.25 – 0.35
	b. 2 – 7 %	0.18 – 0.22
	c. < 2 %	0.13 – 0.17
8.	Yard of lightweight land:	
	a. > 7 %	0.15 – 0.2
	b. 2 – 7 %	0.10 – 0.15
	c. < 2 %	0.05 – 0.10
9.	Heavy land	0.40
10.	Meadow	0.35
11.	Land for agricultural cultivation	0.30
12.	Production forest	0.18

Source: Regulation of Environmental State Minister No. 17/ 2009

- Water Demand (DA)

$$DA = DAD + DAND \quad (6)$$

- a. Demand for Domestic Water (*DAD*)

- village (rural): 80 liters/day/capita
- city (urban): small city: 100 liters/day/capita, and average-big city: 150 liters/day/capita

- b. Demand for Non-Domestic Water (*DAND*)

- livestock: 40 liters/day/lives for cows/buffalos/horses, 5 liters/day/lives for goats/sheep, 6 liters/day/lives for pigs, and 0.6 liters/day/lives for poultry
- fishery: 7 liters/day/lives for ponds with the depth < 70 cm
- agriculture: 1 liter/second/hectare for paddy, and 0.3 liters/second/hectare for dry-crops, dry-land paddy, and moorland plants/garden
- industry, based on the number of employees, assumed: 500 liters/day/employee

- Water Resources Carrying Capacity (DDA)

$$DDA = SA/DA \quad (7)$$

Note:

DDA = Water Resources Carrying Capacity

SA = Water Availability

DA = Water Demand

Output analysis:

DDA < 1 = The Water Resources Carrying Capacity is overshoot.

DDA 1-3 = The Water Resources Carrying Capacity is conditionally-save.

DDA >3 = The Water Resources Carrying Capacity is save.

4. Results and Discussions

Yogyakarta Urban Area (YUA) is a fast growing area that covers all administrative areas of Yogyakarta City, and some of them are located in Sleman Regency as well as in Bantul Regency. Geographically, the position of YUA is in the middle of Yogyakarta Special Region with the coordinates of latitude 7° 42' 5.3786" South Latitude – 7° 52' 2.0603" South Latitude and longitude of 110° 18' 9.7310" East Longitude – 110° 26' 57.0212" East Longitude. YUA consists of 3 (three) regencies/cities, covering 23 sub-districts and 67 villages with the total extent of 15.535,21 Ha.

The area of built-land use dominates the extent by 57%, while the rest is non-built land. The built-land is dominantly used for settlement areas, which keeps expanding as the population grows. In addition, new asphalted-road access, hotels, and campuses in the sub-urban areas of Yogyakarta City contribute to the growth of settlement areas and the decreasing number of rice fields. The growth of settlement areas itself, according to the Report of Spatial Plan of YUA in 2007, was 4.47% per year.

4.1 Settlement Land Resources Carrying Capacity

The analysis of the settlement land resources carrying capacity in YUA showed that the area was conditionally-safe with the grade of 2.89 (Table 2). This result was gained as the extent of built-land (3767.83 Ha) did not go beyond the extent of land permitted to build (15535.21 Ha). However, the grade indicates a worrying condition for

the next few years because the extent of land permitted to build is static, whereas the extent of built-land will keep increasing.

Table 2. Value of Settlement Land Resources Carrying Capacity in YUA in 2013

No	Aspect	Value
1	Extent of Building (Ha)	3425.30
2	Extent of Settlement Infrastructure Area (Ha)	342.53
3	Extent of Built-Area (1+2) (Ha)	3767.83
4	Extent of Permitted to Build Area (Ha)	15535.21
5	Settlement Land Resources Carrying Capacity	2.89 (Conditionally-Save)

The above value of settlement land resources carrying capacity varies according to villages. The settlement land resources carrying capacity that is considered save is found in 15 villages (22.73%), while the one regarded as conditionally-save is found in 41 villages (60.60%), and what is beyond save level is found in 11 villages (16.67%). The details of settlement land resources carrying capacity per village are presented in Table 3.

Table 3. Distribution of Settlement Land Resources Carrying Capacity in YUA in 2013

No	Status	Number of Villages	(%)
1	Save	15	22.73
2	Conditionally-Save	40	60.60
3	Overshoot	11	16.67
	Total	66	100

The projection of settlement land resources carrying capacity for the upcoming years can be conducted based on the prediction of land availability and land need. The availability of land permitted to build is static; meanwhile, the need for land as settlement areas is assumed based on the population growth. The analysis result indicated that the settlement land resources carrying capacity in YUA would be reached in 250.58 years, or it would start exactly in the year 2262 (Figure 1) assuming that the efforts to strengthen the settlement land resources carrying capacity are not conducted.

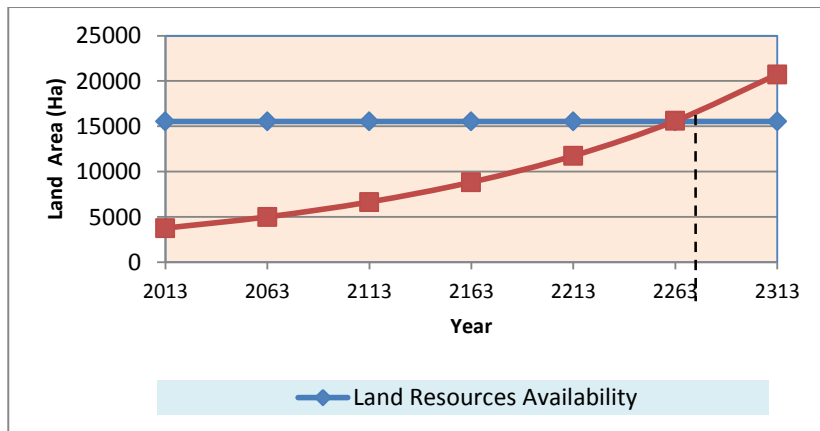


Fig. 1. Projection of Settlement Land Resources Carrying Capacity in YUA

4.2 Water Resources Carrying Capacity

The analysis of water resources carrying capacity in YUA confirmed that it was conditionally-save with the value of 2.44 (Table 4). This result was achieved because the total amount of water availability ($155,449,579 \text{ m}^3$) did not go beyond the total amount of water demand ($63,698,431 \text{ m}^3$). The value indicates a worrying condition because the

water demand will certainly increase in accordance with the rapid population growth and development activities. If the water availability remains stagnant, its water resources carrying capacity will be overshoot at certain time.

Table 4. Value of Water Resources Carrying Capacity in YUA in 2013

No	Aspect	Grade
1	Water Availability (m ³)	155,449,579
2	Water Demand (m ³)	63,698,431
3	Water Resources Carrying Capacity	2.44 (Conditionally-Save)

The value of water resources carrying capacity also has various projections based on villages. The water resources carrying capacity that is still safe found in 10 villages (15.15%), the conditionally-safe one is found in 49 villages (74.24%), while the one with overshoot condition is found in 7 villages (10.61%). The details of water resources carrying capacity of each village are described in Table 5.

Table 5. Distribution of Water Resources Carrying Capacity in YUA in 2013

No	Status	Numbers of Villages	(%)
1	Save	10	15.15
2	Conditionally-Save	49	74.24
3	Overshoot	7	10.61
	Total	66	100

Similar to the settlement land resources carrying capacity, the water resources carrying capacity can also be projected. The projection is conducted based on the prediction of water availability and water demand. The water availability is assumed as static and experiencing the worst condition. Meanwhile, the water demand is predicted based on the population growth. The analysis result showed that the water resources carrying capacity of YUA would become overshoot in 157.98 years or beginning exactly in the year 2161 (Figure 2). It is foreseen that the water resources carrying capacity will decrease faster than the land resources carrying capacity if there are no efforts made to strengthen it.

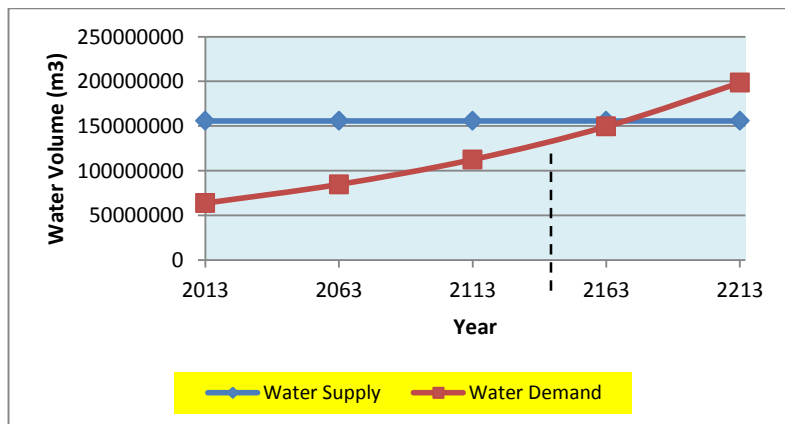


Fig.2. Projection of Water Resources Carrying Capacity in YUA

The environmental carrying capacity should be strengthened for the sake of the establishment of sustainable settlement. The area that is found overshoot becomes the first priority to be strengthened. The strengthening of the land resources carrying capacity can be conducted by optimization of land use. In addition, the urban settlement must be developed and managed based on the following intensity criteria.

Table 6. Criteria of Urban Settlement Area Intensity

Aspects of Criteria	Value
Plan of Maximum <i>KDB</i> (Coefficient of Building Area)	50
Maximum Height of Building (m)	12
Minimum Green Open Space Coefficient (<i>KDH</i>) (%)	30

Managing settlement areas can also be conducted using building range. The building range is determined based on building heights. Table 7 illustrates the criteria of ideal range for buildings.

Table 7. Terms of Height and Building Range

Building Height (m)	Building Distance (m)
0 to 8	3
8 to 14	3-6
14 to 40	6-8
>40	>8

5. Conclusion and Recommendation

Strengthening land and water resources carrying capacity altogether can be conducted through the development of green open space (*RTH*). Based on Law No. 26/2007 on Spatial Planning, *RTH* of Urban Area must be at least 30% of the total urban area, which comprises 10% private *RTH* as the responsibility of inhabitants and 30% public *RTH* as the responsibility of the local government. The following alternatives to achieve the targeted *RTH* are: 1) Determining rice fields as *RTH* by managing timeless rice fields or encouraging the government to buy rice fields to be used as *RTH*; 2) Managing and suggesting private spaces (private yards, office buildings, and settlement areas) to have at least 30% of its extent as *RTH* with a suitable canopy density; 3) Optimizing state lands and buildings to be the model of *RTH*; 4) Customizing private *RTH* of high buildings in dense areas, such as establishing roof gardens, pots, arbors, etc.

Several effective strategies for water resources carrying capacity include the containment of land conversion rates, the management of rainwater harvesting, and the control of water use. The models of rainwater harvesting that are appropriate for urban settlement areas are, for example, rainwater storage, catchment wells, bio-pore holes, retention ponds and open space lands.

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