Carrying capacity of transit-oriented development (TOD) area in Jakarta

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Abstract. Transit-Oriented Development (TOD) is an urban development concept that is carried out in Jakarta. The development of urban areas with the TOD concept needs to consider land and water as a support system called the environmental carrying capacity concept. Therefore, this research is conducted to analyze the environmental carrying capacity in the TOD area based on land capability and water availability. The land capability is analyzed based on the elevation, slope, and subsidence, while water availability is analyzed based on groundwater quality and water supply. This research is conducted in the Dukuh Atas TOD area as part of the Jakarta MRT track phase 1. The GIS overlay analysis is used to determine the environmental carrying capacity of the TOD area. The results show that the TOD area is in excellent land capability but inadequate water availability due to its low groundwater quality. Nevertheless, water availability is still in good condition due to the local water company's supply. Therefore, the environmental carrying capacity of the TOD areas has not exceeded.

1. Introduction

The Capital City of Jakarta is one of the urban areas in Indonesia that is increasing the integration of the public transportation system more intensively, such as integrating Bus-Rapid Transit (BRT), Mass-Rapid Transit (MRT), and Light-Rapid (LRT) systems. One positive impact on developing integration is urban development, namely Transit-Oriented Development (TOD). The TOD concept developed in Jakarta is expected to reduce environmental stress due to high population growth and urbanization flows [1]. It is also expected to be a solution for urban land-use planning, which is currently experiencing changes due to existing environmental pressures [2].

The TOD area is developed by integrating transportation systems with land uses containing three characteristics: density, diversity, and design [3]. Nowadays, the main characteristics of TOD have been developed more broadly into "5D": density, diversity, design, destination, and distance [4]. The TOD area has a high-intensity building that consists of residential, office, and shopping integrated with a functional road network and pedestrian-friendly [5-6]. Essential things that can be achieved by applying the TOD concept are improving the urban community's welfare in economic such as increasing economic activity, social such as reducing the potential distribution of the population, and environmental such as reducing air pollution [7]. In several countries worldwide, TOD becomes an essential way to do land conservation, keep local environmental values, and reduce car dependency [6,8-9].

Using the TOD concept to develop urban areas requires considering the physical and geographical conditions, namely environmental carrying capacity [10]. The environmental carrying capacity can accommodate the maximum amount of life during a specific period [11]. In the scope of urban areas, environmental carrying capacity is the basic principle to assess sustainable urban development due to
its function to determine urban areas' ability to conduct existing human activities [12]. It is also an inventory of natural resources and environmental conditions and a basis for comparing availability with natural resource needs [13-14]. Urban areas in Indonesia can be developed with the TOD concept, especially Jakarta [15]. TOD concept has a critical role in achieving a sustainable urban environment and reducing air pollution in urban areas [16-17]. The purpose and roles of the TOD area prove that the development of the area with the TOD concept is an effort to achieve sustainable development even if only within the scope of urban areas [18].

The TOD area provides various purposes, one of which is landscaping [19]. The urban landscape arises due to spatial planning based on environmental carrying capacity [20]. Urban landscape proves that environmental carrying capacity has a critical role in achieving sustainable development, one of which is in the TOD area [21]. Research has shown the importance of assessing environmental carrying capacity in Jakarta's TOD, although it is limited in land capability with altitude and slope [22]. Therefore, this research was carried out by expanding land capability with land subsidence parameters and using water availability with groundwater quality and water supply parameters of clean water companies.

Dukuh Atas selected as research locations due to their development officially regulated in Presidential Regulation No. 55 of 2018 concerning the Jabodetabek Transportation Master Plan for 2018-2029. Besides, the Dukuh Atas TOD area is integrated with the MRT transportation system development in Jakarta. This study aims to analyze and determine the TOD area's environmental carrying capacity based on land capability and water availability. The land capability in this study has parameters such as the elevation, slope, and land subsidence. The variable water availability has parameters, namely groundwater quality and water supply of clean water companies.

2. Method
This research is conducted in Jakarta's TOD area; namely, Dukuh Atas regulated in Presidential Regulation No. 55 of 2018 concerning the Jabodetabek Transportation Master Plan for 2018-2029 as City TOD (regional service scale). The TOD of Dukuh Atas is part of the Jakarta MRT development phase 1. TOD of Dukuh Atas integrated with MRT Station, and it has a buffer area of 800 m. This study uses GIS methods to determine the carrying capacity of the TOD area [13].

This study analyzes land capability and water availability as selected variables to determine the environmental carrying capacity in TOD of Dukuh Atas [23-24]. For land capability, selected parameters are elevation, slope, and land subsidence. Whereas in water availability, selected parameters are groundwater quality and water supply of water companies. This study uses a spatial analysis unit, 800 m circumference of the TOD area [25].

Research data is secondary data obtained through the literature study from other research and institutional study reports related to the variables. The data obtained are spatial and non-spatial. The data also processed using GIS methods, starting from administrating, processing, classifying, weighting, and modelling [13]. The processed data is then analyzed based on each variable and presented in tables and figures. The overlay technique is used to analyze spatial and non-spatial data. The analysis results are then mapped using GIS software.

The overlay analysis aims to get the value of environmental carrying capacity based on selected variables. For land capability and water availability, each parameter classified and weighted in the previous process is then overlayed using GIS software to obtain the value of land capability and water availability from each analysis unit [23-24]. The value of land capability and water availability is then overlaid to obtain environmental carrying capacity (see Figure 1). The descriptive analysis was used to explain the results to strengthen this study's argument—Furthermore, the results presented in the form of a map for each analysis unit.
3. Results and discussion

3.1. TOD area profile

There are 19 TOD areas in Jakarta, which have been officially regulated in Governor Regulation No. 1 of 2014 concerning Spatial Planning Details and Zoning Regulations and Presidential Regulation No. 55 of 2018 concerning Jabodetabek Transportation Master Plans for 2018-2029. The regulations also divide the TOD area into three categories: the city TOD (regional service scale), the sub-city TOD, and the environmental TOD. Dukuh Atas classified as city TOD (regional service scale). All of the TOD areas are distributed in almost all Jakarta regions, but more located in central Jakarta (see Figure 2).

TOD of Dukuh Atas integrated with transit point, namely the MRT (Mass-Rapid Transit) station. Besides integrated with the MRT, Dukuh Atas also integrated with various other modes such as BRT (Bus-Rapid Transit), Airport Train (Airport Rail Link), and Electric Rail (Commuter Line). Besides integrated with transportation modes, Dukuh Atas has various supporting facilities for urban activities.
such as river parks, transit plazas, park bridges, civic plazas, proper streets, urban parks, landmark towers, and renewed river corridors.

Office, Trade, and Services Zone (29.82%) are dominating the planning directions of Dukuh Atas (see Figure 3). It is in line with the existing conditions, located in the Sudirman-Thamrin corridor, Jakarta's leading economic and business area. Other zones that dominated are Medium-High Housing (21.60%), Mixed (14.12%), and Veritative Housing (11.91%). Other zones that also with large composition is similar to the most dominant. Mixed Zone is a combination of Office, Trade, and Services Zone and Vertical Housing Zone. Vertical Housing Zone is directed to support human activities that carry out business activities in Dukuh Atas in the residential perspective.
The housing of 35.5% dominates land use in TOD of Dukuh Atas (see Figure 4). Other land uses that dominate are offices and trade (18.6%). These things show that the existing land use of Dukuh Atas does not differ much with the planning director. TOD of Dukuh Atas located at Sudirman-Thamrin corridor influencing the existing land use. High accessibility and adequate modes of transportation caused TOD of Dukuh Atas ideal for office and trade. Residential domination is the impact of existing business and economic activities in Dukuh Atas. Housing appears as a support for business and economic activities.

3.2. Land Capability

Table 1. Land Capability Parameters of Dukuh Atas.

| Elevation (Meter Above Sea Level) | Slope (%) | Subsidence (Cm/Year) |
|----------------------------------|-----------|----------------------|
| 0-15                             | 0-3       | <4                   |
| 15-30                            | 3-8       | <4                   |
| 8-15                             |           |                      |

Table 1. shows the values of the parameter in the TOD of Dukuh Atas. Value is determined based on the conditions of elevation, slope, and land subsidence. The elevation is 0-30 meters above sea level due to the location of the TOD area in central Jakarta. Administratively, TOD of Dukuh Atas is part of the Central Jakarta. Based on the slope parameters, the TOD of Dukuh Atas is at the level of 0-15%. It is due to the Ciliwung River that runs through the area from the east to the west. The Ciliwung River, classified as an old river, causes a more varied slope in this area. The location of Dukuh Atas is far from big rivers with old morphological conditions make no slope variation steeper than 8%.

The parameter of land subsidence is crucial in determining the value of land capability. Within the scope of urban areas, land subsidence is one of the environmental degradations caused by groundwater's high use through pump wells. The level of land subsidence in urban areas can reach 50 cm in less than 25 years [26]. In TOD of Dukuh Atas, the value obtained is <4 cm/year, whereas the value obtained is also <4 cm/year in TOD of Dukuh Atas. It proves that the TOD of Dukuh Atas is at low land subsidence. The locations of the TOD area that is not in the coastal area make it not exposed to the danger of land subsidence [27].

Figure 5. Land capability of TOD of Dukuh Atas.
The overlay analysis results on each land capability parameter based on its (see Figure 5). The results of land capability defined into two classes, namely "Class 1 - Very Good (3-4)" and "Class 2 - Good (5-6)". The value of land capability in the TOD of Dukuh Atas is dominated by "Class 1 - Very Good" with an area coverage of 1.95 km² or 97.5%, while the land capability of "Class 2 - Good" only has an area of 0.05 km² or 2.5%.

The condition of land capability in the TOD of Dukuh Atas, which is still in excellent condition, causes this area ideal for more intensive development of urban areas. It is based on the definition of land capability that functions as a substantial asset in the development through land-use activities to avoid various environmental impacts [28]. On the other hand, determining the value of land capability is very important and needs to consider the land's ability to be a crucial part of sustainable land-use [29]. It is also in line with the TOD principle, which also provides conditions for sustainable land use.

3.3. Water availability

| Groundwater Quality | Water Supply from Company |
|---------------------|--------------------------|
| Lightly Polluted    | Well-Serviced            |

Table 2. shows the values of the water availability parameter in the TOD of Dukuh Atas. The value is determined based on groundwater quality and the water supply of clean water companies. Groundwater quality is measured by several indicators, such as TDS (Total Dissolved Solids), Ferro (Fe), Manganese (Mn), and Coli Bacteria [30]. Obtained quality values in TOD of Dukuh Atas are 0.579 and 3.363. Based on the Groundwater Pollution Index in the Decree of the Minister of Environment No. 115 of 2003 concerning the Guidelines for Determination of Water Quality Status, the quality status in the TOD of Dukuh Atas are Good (0 ≤ 0.579 ≤ 1) around 22% and Lightly Polluted (1 < 3,363 ≤ 5) around 78%.

Figure 6-7 shows the concentration value of groundwater quality. In the TDS and Ferro (Fe), the TOD of Dukuh Atas is below the standard (see Figure 6a and Figure 6b). Fe concentrations that exceed can be categorized as unfit if intended as drinking water. Excess concentration of Fe potentially causes health problems, namely hemochromatosis that triggers cancer, heart attacks, and lung disorders [31-32]. In the Manganese (Mn), the TOD Dukuh Atas is above the standard (see Figure 7a). Groundwater
conditions in the TOD of Dukuh Atas polluted by Manganese (Mn) cause drinking water to be neurotoxic, which will cause interference with the human nerve [30]. Besides, excess manganese in the human body can cause emotional and memory disorders [33]. In the Coli Bacteria, the TOD of Dukuh Atas is above the standard (see Figure 7b). The indicator of Coli bacteria is that most polluting groundwater, and it is due to various types of human activity [34]. Coli bacteria is the best indicator in testing the biological water quality, where the excess amount of Coli bacteria in the human body can cause health problems, disrupting the digestive system.

![Figure 7. Concentration Value of Manganese (a) and Coli Bacteria (b) of Dukuh Atas.](image)

The TOD of Dukuh Atas is in good condition based on the clean water company's water supply. The area is under the local clean water company's service zone, The Service Zone I. The service area coverage has a positive impact on supplying water for people living in the TOD area and its surroundings. Water companies' existence is essential for the community due to the low access to clean water as a sustainable development challenge [35].

![Figure 8. Water Availability of TOD of Dukuh Atas.](image)
Figure 8 shows each parameter's results by entering the water availability based on its weight. The result is defined into only one class, namely "Class 2 - Good (3). The TOD of Dukuh Atas has water conditions for "Class 2 - Good". Its condition of "Class 2 - Good" has an area of 2 km² or 100%, which indicates that the water availability in the TOD of Dukuh Atas is relatively good. Although their quality is quite low, the availability is still overcome due to the water supply from local water companies. The privatization of water supply needs plays an essential role in meeting urban communities [35]. Due to the high pollution of rivers and other water sources, the declining quality causes disease vulnerability in groundwater [36]. Therefore, the emergence of alternative clean water sources has become an essential part of meeting the community's needs, namely clean water companies.

3.4. Carrying capacity

| Land Capability | Water Availability |
|-----------------|--------------------|
| Very Good       | Good               |

The main focus of this study is identifying the environmental carrying capacity in the TOD of Dukuh Atas. Table 3. shows each variable's values in the analysis, namely land capability and water availability of the Dukuh Atas. The land capability of the TOD area is "Very Good" and "Good", while the water availability is "Good". It is based on the results from variables in the previous discussions. The value of the carrying capacity will be the primary reference in the process of concluding.

The carrying capacity analysis results indicate that the TOD area has conditions of "Very Good" to "Good". The environmental carrying capacity in the TOD of Dukuh Atas is "Very Good" and "Good" (see Figure 9). It is based on a combination of land capability and water availability, which are relatively good conditions. These conditions prove that the environmental carrying capacity in the TOD of Dukuh Atas has not exceeded and ideal to use for urban development activities. The construction of high-rise buildings can be done intensively in the TOD of Dukuh Atas. On the other hand, this area's actual land and water conditions can support all human activities above.

Figure 9. Carrying Capacity of TOD of Dukuh Atas.
This study's result is strengthened by another research that states that environmental carrying capacity that has not exceeded in an area can increase environmental benefits, especially in the social and economic aspects [37]. The next finding is the importance of identifying land capability from other research that states that an area's land capability can benefit and reduce the risk of permanent damage to the land [38]. Besides, land capability can be a crucial instrument in managing a given land and mitigating land degradation [28]. This study also finds the importance of groundwater quality for human life, which states that groundwater contaminated with hazardous materials potentially cause many diseases. Besides, the low quality of groundwater can reduce the water supply for human needs [39]. The low groundwater quality raises the demand for new supply schemes managed by a private like a water company [40]. More broadly, groundwater quality and water supply are some examples that indicate water availability related to environmental sustainability [41].

4. Conclusion
The TOD of Dukuh Atas's environmental carrying capacity is excellent and serviceable, indicating that it has not exceeded. Variables that drive the environmental carrying capacity, such as land capability and water availability, show good value and status. The land capability of the Dukuh Atas is excellent and serviceable, which indicates that there is availability in terms of land to receive more rapid and intensive development in the future. On the other hand, the water availability of the Dukuh Atas is relatively good, which is classified as safe and sufficient to accommodate the water needs of people who are active in the TOD area.

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