

The Carrying Capacity Assessment of Two MRT Stations Transit-Oriented Development Areas in Jakarta

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Abstract. Many studies have investigated the effects of transit-oriented development (TOD) on density, design, diversity development, and transit ridership. However, fewer studies address the issue of carrying capacity of TOD. This paper aims to assess TOD areas' carrying capacity using four criteria (land capability, water availability, socio-economic, and green infrastructure) and 14 indicators on Jakarta's two TOD areas. These results show that even though both of the TOD area, Dukuh Atas and Lebak Bulus, are in the good of carrying capacity in land capability, there are some issues to address the possibility of water availability. For TOD's success, the socio-economic criteria should be promoted in the fringe-urban TOD area like Lebak Bulus. We identified the green infrastructure, such as pedestrian, cycling route, and green open space, still in low development and should be pursued to extend the TOD carrying capacity for the future.

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1. Introduction

Transit-Oriented Development (TOD) has "3D" characteristics based on the combination of the transportation system and land-use, namely density, diversity, and design (Furlan et al., 2019). It has developed further in recent years as "5D", added with destination, and distance (Jeffrey et al., 2019). Transit-Oriented Development (TOD) consists of high-intensity building integrating with the road network and pedestrian-friendly (Kamruzzaman et al., 2018; Nasri & Zhang, 2014). Transit-Oriented Development (TOD) concept can increase economic welfare, control the population, reduce environmental stress (Curtis et al., 2009). TOD has used all those characteristics and benefits as an appropriate sustainable planning strategy (Su et al., 2021). It also becomes an important strategy to conduct spatial effectiveness, keeps green urban areas, and improve public transport ridership in urban cities (Akbari et al., 2018; Nasri & Zhang, 2014; van Lierop et al., 2017).

Jakarta is an urban area in Indonesia that is intensively improving the public transportation system's quality, especially in intermodal integration. The integrated model of transportation is TransJakarta (BRT), MRT, LRT, and commuter electric line. The method of integrating transportation modes in Jakarta is by implementing the TOD concept. This implemented concept is expected to solve the uncontrolled high population growth and urbanization flows, improper land-use planning, and less interest in environmentally friendly behavior. High population growth and urbanization flow become the leading cause of environmental problems (Chen et al., 2017). Improper land-use planning becomes the leading cause of land-use

degradation (Ma et al., 2018). Less interest in environmentally friendly behavior becomes the leading cause of car dependency and air pollution (Huang et al., 2021). Nevertheless, there are some diversities of TOD implementation based on local context (Su et al., 2021a).

Study on TOD has been carried out in various countries in the world. In Dubai, accessibility and network connectivity around TOD examined through the alleys' role (Alawadi et al., 2021). An improper land-use pattern was identified based on residents' incompatibility in Australia (Kamruzzaman et al., 2021). In Greece, the most potential TOD model was determined in Southern European cities (Papagiannakis et al., 2021). Social engagement in public transportation is identified from the TOD environment in Vietnam (Chen et al., 2021). In Seoul, the bike-sharing track with bus and subway became the TOD performance indicator (Tamakloe et al., 2021). TOD implementation is raised due to an approach to urban land-use planning in Beijing (Ruan et al., 2021). TOD also proves that it has a significant role in controlling California's household transportation expenditure (Dong, 2021). TOD in Thailand shows the differences of "home to work" travel behavior between social group of residents (Matsuyuki et al., 2020).

The carrying capacity focused not only on the physical environment but also the socio-economic and the infrastructure (Sun et al., 2018). Liu & Borthwick (2011) assessing the environment carrying capacity of Ningbo (China) based on land capability, water availability, and environmental protection investment. Another study conducted by Cheng et al. (2019) assessing the environment

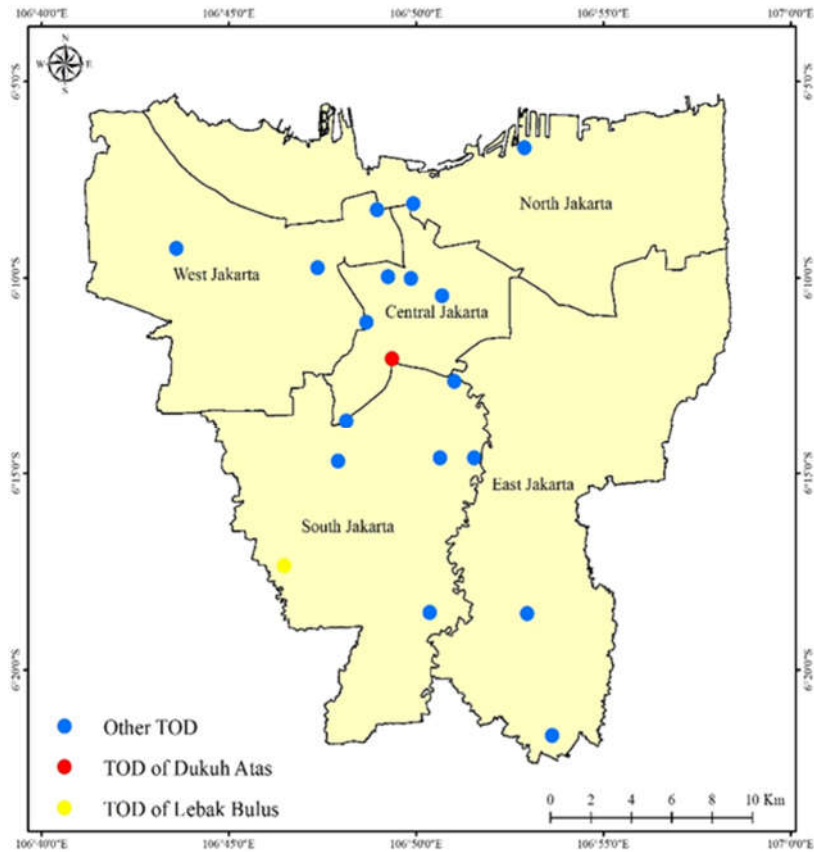


Figure 1. TOD Areas in Jakarta

carrying capacity of Zhaoshu Island (China) based on land capability, water availability, population distribution, economic improvement, and life quality. The previous study assessed it from land capability, water availability, public utility, and public facility (Wei et al., 2015; Wei et al., 2016). From TOD's perspective, the previous study conducted by Strong et al. (2017) shows the critical factors for implementing the TOD concept focusing on walkability and cycling network, mixed land-use, and green open space. On the other hand, the previous TOD study is dominated by developed countries, while cities in developing countries such as Jakarta have recently focused on adopting the TOD concept (Ibraeva et al., 2020).

The studies of TOD in Jakarta are relatively new. Some scholars have done TOD studies, with the scopes of research on identifying categories of TOD (Siburian et al., 2020), maximum ridership by allocating land-use (Berawi et al., 2020), optimizing property income in TOD (Gunawan et al., 2020), and institutionalization process of TOD (Permana et al., 2018) and still limited research on carrying capacity of TOD. However, the previous study on TOD carrying capacity was conducted merely focus on environmental carrying capacity with the indicators of ecological footprint, carbon emission, and green open space (Hasibuan et al., 2014). This study aims to assess 'TOD areas' carrying capacity using four criteria (land capability, water availability, socio-economic, and green infrastructure) and 14 indicators on Jakarta's two TOD areas. Previous studies on land capability showed that the right conditions could be an essential asset for environmental conservation through land-use (Araújo Costa et al., 2019). In terms of water availability, the previous study showed the essential role of water availability in environmental management and spatial planning in a given area (Liu & Borthwick, 2011). From the socio-economic

point, the previous study showed the importance of developing economic activities in the TOD area to increase local economic value and trigger social concentration in the community (Peek & Van Hagen, 2002). On the other hand, the previous study about green infrastructure showed that the importance of improving the quality of pedestrian paths, bicycle routes, land-use, and green open spaces to improve the quality of the local environment (Griffiths & Curtis, 2017; Kamruzzaman et al., 2014; Lyu et al., 2016; Monajem & Ekram Nosratan, 2015).

2. Method

Study Area

Jakarta has 19 TOD areas with several types of TOD in scale and function. This study selects TOD Dukuh Atas and TOD Lebak Bulus, based on the MRT station, as the study areas (see Figure. 1). TOD Dukuh Atas is integrated with several transits system, namely, TransJakarta (BRT), commuter electric line, MRT, Airport Rail-Link, and Electric LRT. TOD Dukuh Atas located in the central city of Jakarta, surrounded by high density business centers. On the other hand, TOD Lebak Bulus, which located in the fringe area of Jakarta, is a new area developed for TOD from the intercity bus terminal as the end-station of MRT. The selection background of Dukuh Atas and Lebak Bulus is the connection of each area with Jakarta MRT Line phase 1.

Data and Analysis

Data collected both from primary sources and secondary sources. The data sources come from literature studies and government agency reports. The data collected is also divided into two, namely spatial data and non-spatial data. Data on people mobility and economic activity, land-use diversity,

Table 1. Research Criteria and Indicators

Criteria	Indicators	Range of value
Land Capability	Elevation	1 = very good
	Slope	2 = good
	Subsidence level	3 = fair
	Land-use diversity	4 = poor
	Density	5 = very poor
Water availability	Groundwater quality	
Socio-economic	Water supply	
	Inhabitant	
Green Infrastructure	Density	
	People mobility	
	Economic activity	
	Walking-pedestrian	
	Cycling-route	
	Green Open Space	

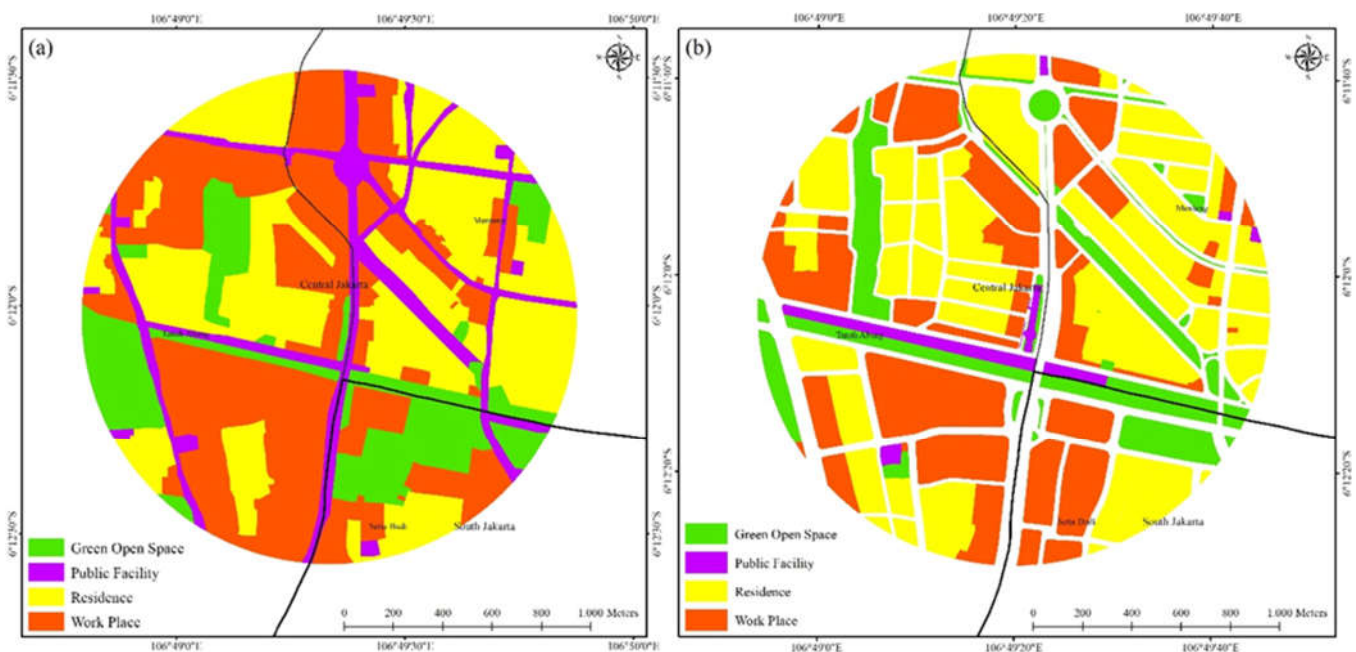


Figure 2 . Land-use of TOD Dukuh Atas (a) and Spatial Planning of TOD Dukuh Atas (b)

density, cycling route, and pedestrian infrastructure are collected from the observation at the two study areas. In contrast, data on groundwater quality, water supply, elevation, slope, and subsidence level are obtained from the secondary data. This study's analysis unit is the TOD circumference zone, 800 meters (Higgins & Kanaroglou, 2016). The GIS method is used to determine each TOD's carrying capacity (Świąder, 2018). Carrying capacity is analyzed based on several variables such as land capability, water availability, socio-economic conditions, and green infrastructure (Cheng et al., 2019; Liu & Borthwick, 2011; Strong et al., 2017), with indicators as follows; For land capability, water availability, socio-economic, and green infrastructure, each parameter classified and weighted in the five categories:

1= very good; 2 = good; 3 = fair; 4 = poor; 5 = very poor

The concept of land-use diversity uses the formula as follows:

$$\text{Landuse diversity} = - \sum_{i=1}^n li \cdot \frac{\ln(i)}{\ln(4)} \dots\dots\dots(1)$$

A particular land-use category's ratio area is to all land-use categories in the TOD area. Here we use four categories of land-use: (1) residence area, (2) workplaces, (3) public facility, and (4) Green Open Space. The carrying capacity concept adopted the Cheng et al. (2019); Liu & Borthwick (2011); Strong et al. (2017), which aggregates environment, social economics, and green infrastructure. This study uses descriptive analysis in providing data analysis, explaining the results found, exploring the relationship between TOD's variables, and summarizing the results. This study uses maps to help explain the findings on spatial bases.

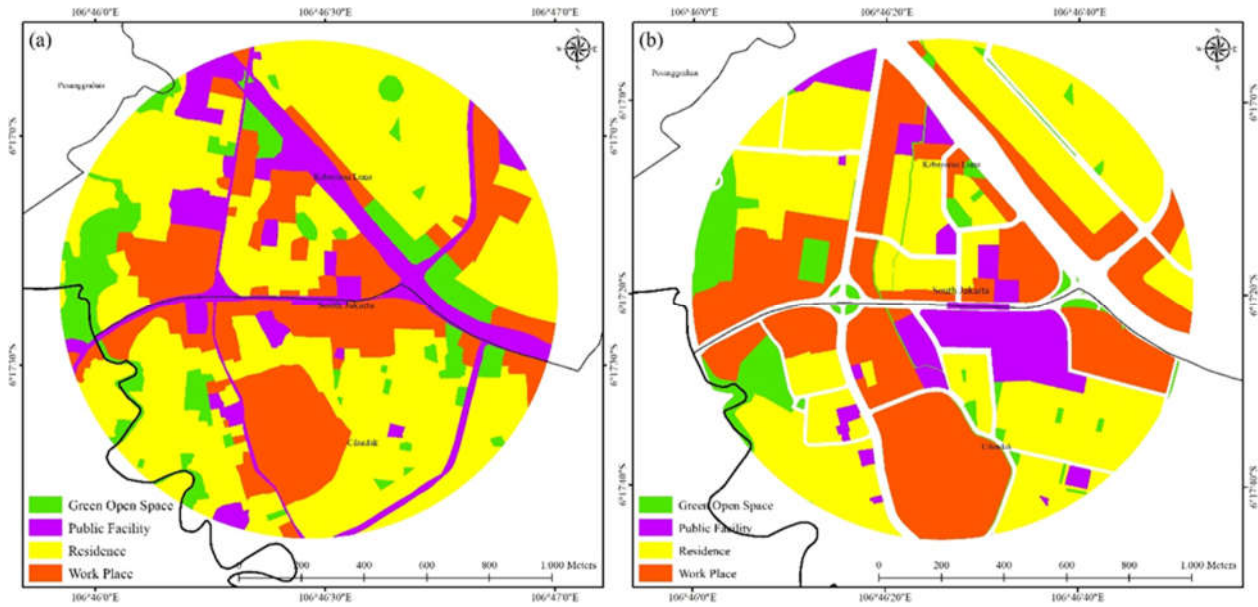


Figure 3. Land-use of TOD Lebak Bulus (a) and Spatial Planning of TOD Lebak Bulus (b)

Table 2. Land-use and Spatial Planning of TOD Dukuh Atas and TOD Lebak Bulus

Function	Dukuh Atas		Lebak Bulus	
	2020	2030	2020	2030
Residence	111.46	70.41	168.01	77.84
Work Place	115.95	54.06	73.77	62.13
Public Facility	36.26	4.96	40.99	16.96
Green Open Space	50.50	24.65	31.26	12.87
Diversity Index	0.92	0.55	0.84	0.84

3.Results and Discussion

Land-Use Diversity

Dukuh Atas and Lebak Bulus TOD areas have different land-use diversities. Using four land-use categories: (1) residence, (2) workplace, (3) public facility, and (4) green open space, we identify the diversity of the land-uses in each TOD area. We also investigate the actual land-use and the spatial planning in each TOD area.

TOD Dukuh Atas serves as an international transit hub and business and economic center in Jakarta. As an economic and business center area, TOD Dukuh Atas is dominated by workplaces of 36.91%. The workplace is scattered throughout the Sudirman-Thamrin corridor to the Bundaran Hotel Indonesia. This area also has high transportation integration as an international transit hub, namely the MRT, LRT, BRT, and electric trains. Other land-uses that exist in Dukuh Atas TOD are residence (35.48%), public facility (11.54%), and green open spaces (16.08%). The residence is scattered outside of TOD Dukuh Atas, away from the access corridors for economic and business activities (see Figure. 2).

Based on its spatial planning, TOD Dukuh Atas is not dominated by workplaces but by residence. The TOD Dukuh Atas residence is 45.69%, while the workplace is 35.08%. It shows a match between spatial planning and existing

conditions in the TOD Dukuh Atas in terms of the workplace. Other spatial planning at Dukuh Atas TOD is the public facility of 3.21% and green open spaces of 15.99%. The workplace is scattered throughout the Sudirman-Thamrin corridor to the Bundaran Hotel Indonesia. On the other side, the residence is also scattered outside of TOD Dukuh Atas, away from the access corridors for economic and business activities (See Figure. 2).

TOD Lebak Bulus serves as the terminal gate from outside Jakarta. TOD Lebak Bulus connects people's movement from the suburbs to the city center. The TOD's location, which is also close to small cities outside Jakarta, impacts land-use distribution. The low distribution of workplaces proves it compared to the residence. It is evidenced by the domination of residence in this area, 53.50%. The other land-use is the workplace of 23.49%, public facilities of 13.05%, and green open spaces of 9.93% (see Figure. 3).

Value Indicator

Assessment to the 14 indicators of four criteria (land capability, water availability, socio-economic, and green infrastructure) in each TOD area found out those values as presented in Table 3.

Table 3. shows the value of each indicator. The land capability is determined based on the elevation, slope, land subsidence, land-use density, and density. The parameter of land subsidence is crucial in determining land capability value. 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 (Giao et al., 2018). Both in TOD of Dukuh Atas and Lebak Bulus, the value obtained is <4 cm/year, it considered low land subsidence. The TOD area locations that are not in the coastal area make it not exposed to the danger of land subsidence (Yastika et al., 2019).

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 (Araújo Costa et al., 2019). 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 (Atalay, 2016). It is also in line with the TOD principle, which also provides conditions for sustainable land-use.

Table 3. also shows the water availability parameter values in the TOD of Dukuh Atas and Lebak Bulus. The value is determined based on groundwater quality and clean water companies' water supply. Groundwater quality is measured by several indicators, such as TDS (Total Dissolved Solids), Ferro (Fe), Manganese (Mn), and Coli Bacteria (Hasan et al., 2019). 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 of TOD Dukuh Atas is moderately polluted ($-11 \leq -12,3 \leq -31$), and Lebak Bulus is moderately polluted ($-11 \leq -15 \leq -31$).

Both TOD of Dukuh Atas and Lebak Bulus 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 (Sala-Garrido et al., 2019).

Dukuh Atas TOD is superior to Lebak Bulus TOD from a socio-economic perspective. The population level in the TOD Dukuh Atas has a higher number than the TOD Lebak Bulus. The TOD Dukuh Atas' density level was ten times greater than that at the TOD Lebak Bulus. Due to a large amount of economic activity in the TOD Dukuh Atas as the central business district, the TOD Lebak Bulus is only a service area. This condition was also reinforced by the more significant number of people moving towards Dukuh Atas TOD than Lebak Bulus TOD.

From an infrastructure perspective, there is a striking difference between the TOD Dukuh Atas and the TOD Lebak Bulus. The first thing that becomes clear is comparing the walking paths in the two TOD areas. The TOD Dukuh Atas has a pedestrian lane nine times longer than the TOD Lebak Bulus. The second is the TOD Dukuh Atas has a bicycle lane, while the TOD Lebak Bulus does not have a bicycle lane. Finally, the TOD Dukuh Atas's green open space is almost twice as large as the TOD Lebak Bulus.

This study's primary focus is comparing the carrying capacity in the TOD of Dukuh Atas and Lebak Bulus. Table 4. shows each variable's values in the analysis, namely land capability, water availability, socio-economic, and green infrastructure of the Dukuh Atas and Lebak Bulus. As for the Dukuh Atas TOD area, the land capability is "Very Good" and "Good" from the morphological aspect, while the Lebak Bulus TOD area is in "Good" condition. The TOD component, namely land-use diversity and density, Dukuh Atas is better than the Lebak Bulus at current condition. In contrast, the water availability is "Good" both in Dukuh Atas and Lebak Bulus. For socio-economic criteria, Dukuh Atas, as the TOD in downtown Jakarta has very high mobility and economic activity.

Meanwhile, Lebak Bulus, as a new potential TOD as the MRT station, still has low socio-economic activity. TOD's critical criteria are green infrastructure that comprises

Table 3. Value Indicators

Criteria	Indicators	Dukuh Atas	Lebak Bulus
Land Capability	Elevation (m asl)	0-15, 15-30	15-30, 30-50
	Slope (%)	0-3, 3-8, 8-15	0-3, 3-8
	Subsidence level (cm/year)	<4	<4
	Land-use diversity	0.922	0.844
	Density (building/ha):	51.75%	33.33%
	>1000/ha	41.14%	57.45%
	100-1000/ha	5.67%	7.09%
	10-40/ha	1.42%	2.13%
Water availability	Groundwater quality	moderately Polluted	moderately Polluted
	Water supply	Well-Serviced	Well-serviced
Socio-economic	Inhabitant (people)	34,388	20,057
	Density (people/100m2)	10	1
	People mobility (trip/day)	660,690	96,000
	Economic activity	CBD	Services
Green Infrastructure	Walking-pedestrian (m)	18,247	2,200
	Cycling-route (m)	24,300	0
	Green Open Space (ha)	50.45	31.26

Table 4. Carrying Capacity Parameters of Dukuh Atas and Lebak Bulus

Criteria	Indicators	Dukuh Atas	Lebak Bulus
Land Capability	Elevation (m asl)	1 = very good	2 = good
		2 = good	3 = fair
	Slope (%)	1 = very good	1 = very good
		2 = good	2 = good
		3 = fair	
Subsidence level (cm/year)	1 = very good	1 = very good	
Land-use diversity	1 = very high	2 = high	
Water availability	Density	1 = very high	2 = high
	Ground water quality	3 = fair	3 = fair
Socio-economic	Water supply	1 = very good	1 = very good
	People mobility	1 = very high	4 = low
Green Infrastructure	Economic activity	1 = very high	4 = low
	Walking-pedestrian	1 = very good	2 = good
	Cycling-route	1 = very good	5 = very poor
	Green Open Space	1 = very good	2 = good

walking pedestrians, cycling routes, and green open space. Dukuh Atas, as the main-hub TOD area, has been prepared with a broad and friendly walking pedestrian and cycling route and green open space. Meanwhile, Lebak Bulus is still preparing to provide the TOD area's three basic designs to improve the green infrastructure.

The carrying capacity analysis results indicate that the TOD area of Lebak Bulus has conditions of "Very Good" to "Good". The TOD of Dukuh Atas's carrying capacity is "Very Good" and "Good". It is based on a combination of land capability and water availability, which are relatively good conditions. These conditions prove that the carrying capacity in the TOD of Dukuh Atas and Lebak Bulus has not exceeded and still in ideal condition to using intensively 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.

The different results between Dukuh Atas dan Lebak Bulus TOD areas argued the importance of classifying TOD's typology. The classification offers a benchmark, thus enabling planners and governors to maximize the long-term benefit and reinforce TOD success (Su et al., 2021).

This study's result is in line with the previous research that states that carrying capacity that has not exceeded in an area can increase environmental benefits, especially in the social and economic aspects (Zhang et al., 2019). 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 (Gad, 2015). Besides, land capability can be a crucial instrument in managing a given land and mitigating land degradation (Araújo Costa et al., 2019). 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, groundwater's low quality can reduce the water supply for human needs (Nayan et al., 2019). The low groundwater quality raises the demand for new supply schemes managed by a private like a water company (Das et al., 2019). More

broadly, groundwater quality and water supply are some examples that indicate water availability related to environmental sustainability (Wang et al., 2019).

In socio-economic criteria, there is a gap in the intensity of activity and people density between TOD Dukuh Atas, which is located in the inner circle city, with TOD Lebak Bulus, which is located in a fringe-urban area. As the CBD, Dukuh Atas become the essential destination of working places. Meanwhile, Lebak Bulus now the origin place, but it is planned as the future economic center. TOD's integrative systems in central Jakarta and TOD areas in the fringe-area needed to build in the future. Those findings align with the concept that TOD is indeed defined as integrating local and regional planning processes on a range of environmental, social, and economic (Zhou & Zolnik, 2013).

The green infrastructures as keys for TOD success are in different stages between TOD Dukuh Atas and Lebak Bulus. Walking-pedestrian, which is one of the critical characteristics of TOD (Renne, 2009), has been "very good" provided in Dukuh Atas and "good" in Lebak Bulus. The cycling route has been excellent in Dukuh Atas, but very poor di Lebak Bulus. However, the green open space areas are excellent in Dukuh Atas dan good in Lebak Bulus.

4. Conclusion

The Dukuh Atas and Lebak Bulus TOD areas' environmental carrying capacity is in a condition that has not been exceeded. Variables that drive the environmental carrying capacity, such as land capability and water availability, show good condition. The condition of the Dukuh Atas and Lebak Bulus TOD area's land capability indicates that these two regions can receive more rapid and intensive development in the future. On the other hand, the Dukuh Atas TOD and Lebak Bulus TOD area's water availability is classified as safe and sufficient to accommodate active people's water needs in the two TOD areas. However, there is a potential water availability problem in the future. The socio-economic criteria should be promoted in the fringe-urban TOD area like Lebak Bulus. We identified the green

infrastructure, such as pedestrian, cycling route, and green open space, still in low development and should be pursued to extend the TOD carrying capacity. Future research suggestions to estimate and predict the people's mobility and the potential impact of TOD areas in the Metropolitan region with the scenario planning for 2030.

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