RESEARCH PAPER

SETTLEMENT DEVELOPMENT BASED ON ENVIRONMENTAL CARRYING CAPACITY IN BATU CITY, INDONESIA

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ABSTRACT. The increase in population and demand for settlement facilities and infrastructure affects the attractiveness of Batu city (Indonesia) and has a significant impact on the environmentWe perform spatial mapping of the environmental carrying capacity in developing settlements using the overlay-geoprocessing method. This method is based on unit indicators such as slope, morthology, soil type, elevation, and potential for disasters for obtaining the data on land capability, land suitability, and settlement development plans. Land capability analysis shows that slope, morthology and altitude are the main factors for attributing moderate, low, and poor development capability. The land capability unit shows the areas with slope steepness and land morthology that are not appropriate for intensively developing areas. Batu City areas of moderate, low, and poor development capacity cover 13,365.14 ha, 3193.04 ha, and 2858.07 ha. We also demonstrate that there is about 2,363 ha of unsuitable land use with poor land capability and 3,784.28 ha of land can be developed for settlement. Using this approach we determine saturation point in the residential area plan, because the environmental impact will increase if no threshold is given for residential development.

KEYWORDS: settlement development, carrying capacity, tourism, geoprocessing, GIS

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INTRODUCTION

Tourism is one of the drivers of sustainability, that recognized as a viable method of developing a region with abundant resources (jeong et al. 2014). Sustainable tourism indicators provide essential guidance for decision-making in developing priority strategies that are necessary for resource allocation with medium and long-term planning (Ristić et al. 2019). The guidance is essential because tourism development assists the local economy and puts more pressure on natural resources, local culture and ecological conditions, affecting the sustainability of tourism areas (Świąder et al. 2020; Wang et al. 2020). Furthermore, cities demonstrate less impressive spatial and physical characteristics as well as social sustainability, which is an important factor in the community's livability (Eizenberg & Jabareen 2017; Neamțu 2012).

The habitability of a community is unachievable when environmental problems such as floods, droughts, groundwater pollution, ecological diseases, and waste occur (Widodo et al. 2015). Furthermore, deteriorating water quality, possible epidemics, and urban disturbances can pose policy threats to sustainable urban growth (Roy et al. 2021). Hence, environmental carrying capacity is essential to support the development and improve the quality of life. Settlements development is related to the land's carrying capacity, which contains two main components: the availability of natural resource potential and environmental bearing capacity. It is essential because humans must be placed in safe residential spaces (Andersen et al. 2020). Other research proved that unlimited population and settlement growth would cause environmental damage. So it is necessary to improve the quality of human settlements in the future (Świąder et al. 2020).

One factor requiring improvement is water resources. It is a determinant that must be considered for sustainable development, especially in the housing business due to the increasing population. It is also imperative to consider this issue in implementing tourism because water is one of the components of environmental carrying capacity in the tourism and social sectors.

A development plan should be based on the carrying capacity of both land and water as water carrying capacity includes land locations that can potentially maintain water reserves in the soil. In previous studies, there has been little discussion about the carrying capacity of water (Widodo et al. 2015) and a paradigm shift is needed to explain modern urban-related changes (Zgheib et al. 2020). In addition, a theoretical foundation will allow to accommodate the environmental carrying capacity paradigm in the form of regional policies (Fan et al. 2017; Su & Yu 2020).

Batu City is a mountainous area flanked by several mountains, such as Panderman, Anjasmoro, and Arjuno.

It has an area of 19,908.72 ha, divided into three sub-districts (Batu, Junrejo, Bumiaji) and 24 villages. The total population in Batu Sub-district is 213,046 people, with a growth rate of 1.14 from 2010 to 2020[1]. As a tourism city, Batu experienced an increase in the number of tourists by 30.4% in 2019. This also promoted the growth of tourism objects, lodging, and restaurant facilities. As a result, the number of hotels in Batu City in 2020 increased by 45.27%[2]. Tourism development will lead to the increasing number of residents of Batu City on productive land, which can cause various impacts due to land changes, including an increase in the risk of flooding and landslides that cause a decrease in the land carrying capacity.

Most Batu City is located on sloping terrain with a land slope of 25-40%. Geographically, it is placed in the uppermost part of the Brantas River, where water resources are abundant. However, the spring water discharge is decreasing due to encroachment on the protected forest with an area of ± 5,900 ha used for plantations and settlements. In addition, the reduced area becomes congested by roads, causing longer water seepage. It was also proven that dense settlements cause longer runoff absorption time (Kumar et al. 2021). As a result, Batu City is easily flooded because the sustainability of environmental functions and the environmental carrying capacity were not considered in development planning, especially in settlement areas.

The increasing tourism activities in Batu City impact housing needs, relying heavily on natural resources. To ensure that its development continues to maintain the natural cycle, consideration of the location and natural conditions of the city is highly suggested. Research on the carrying capacity of resources and the environment has shifted from theory to practice and from single-factor studies to multi-factor analysis. The sustainability criteria on a regional scale provide an evaluation of the carrying capacity, which can be used as a scientific basis for planning (Zhou et al. 2020). This study aims to map the settlement development plan based on the land's carrying capacity with the main component being the carrying capacity of water.

MATERIAL AND METHODS

This research used mosaics of high-resolution space images (QuickBird, Landsat) available on map services. Through global measurements from satellites, mapping can include the dynamical aspects of the Earth's surface. Synoptic and long-term satellite monitoring of the Earth provides time series data sets made in a highly consistent manner facilitating surface analysis for change detection. Image interpretation is the process of studying images by recognizing and assessing objects. The operation phases needed for the object recognition seen in the image are as follows: detection is object recognition with essential characteristics of the sensor; identification is to characterize objects using reference data; interpretation is to collect more accurate details. Object recognition is an integral part of image interpretation. For this purpose, the image identity and object type are essential during the problem-solving analysis (Saing et al. 2021).

Object characteristics in the image can be used to recognize objects referred to by interpretation elements. satellite image analysis can be done using several approaches, one of which is a GIS program that has been commonly used. The present use of GIS is restricted to geographic and computational areas but has expanded to other fields (Maguire 1991), including agriculture, economics, mathematics, regional, and urban spatial planning. Several analytical methods and tools have been implemented using GIS. The classification application (Wijaya 2015) is the most widely used. Some GIS definitions; each manual or analytical method is used to store and modify the geographically referenced data (Aronoff 1989); the institution component represents the infrastructure organizational framework integrated with the database assistance, experience, and financing continuously over time. Also, a comprehensive framework geographically model (Koshkariov et al. 1989); a decision support system that requires the integration of spatial reference data in the handling of problems; a management information system type that enables general information to appear on maps (Saing et al. 2021).

To support environmental carrying capacity analysis, the overlay-geoprocessing method was applied using GIS software. The analysis requires more than one layer to be physically stacked to be analyzed visually. These layers are analyzed using the intersect feature to obtain spatial data slices that will form new map information.

This research has two outputs. First, it shows the suitability of the land's carrying capacity for the settlement plan in the city planning document. Second, it shows the direction of settlement development based on the carrying capacity related to water resources, building cover ratio, and building height from the city planning document.

Land carrying capacity is an important component because a mismatch between land use and land capability accelerates productivity (Tscharntke et al. 2012). Other research shows that land capability can be estimated by calculating the area's carrying capacity (D'Amour et al. 2017; Hixon 2008).

There were three stages of overlay-geoprocessing analysis (Fig.1). First, the maps of layers, like slope, morthology, elevation, soil type, and disaster vulnerability were used as unit indicators to analyze the land capability. Second, an analysis of conformity with the settlement plan in Batu City was carried out using the results of the land carrying capacity study and the settlement development plan based on the city planning document as unit indicators. Third, research on the indicators of the carrying capacity of water resources, land cover ratio, and building height was carried out. The land cover ratio and building height indicators were obtained from urban planning documents. Meanwhile, the carrying capacity of water resources was acquired from environmental feasibility documents.

RESULTS

In this study, the results of the analysis are divided into three parts: land capability analysis, land suitability analysis, and analysis of settlement development plans.

Land Capability Analysis

Calculation of the settlement land capability was carried out by analyzing carrying capacity through the following units:

• Slope. The land slope analysis based on the decree of the Indonesian minister of forestry in 1980 (Qibthia et al. 2019). The land slope factor affects the land capability analysis by determining the land function as shown in Table 1.

[1] *Batu City Population Development in 2021*
[2] *Batu City Tourism Development in 2021*

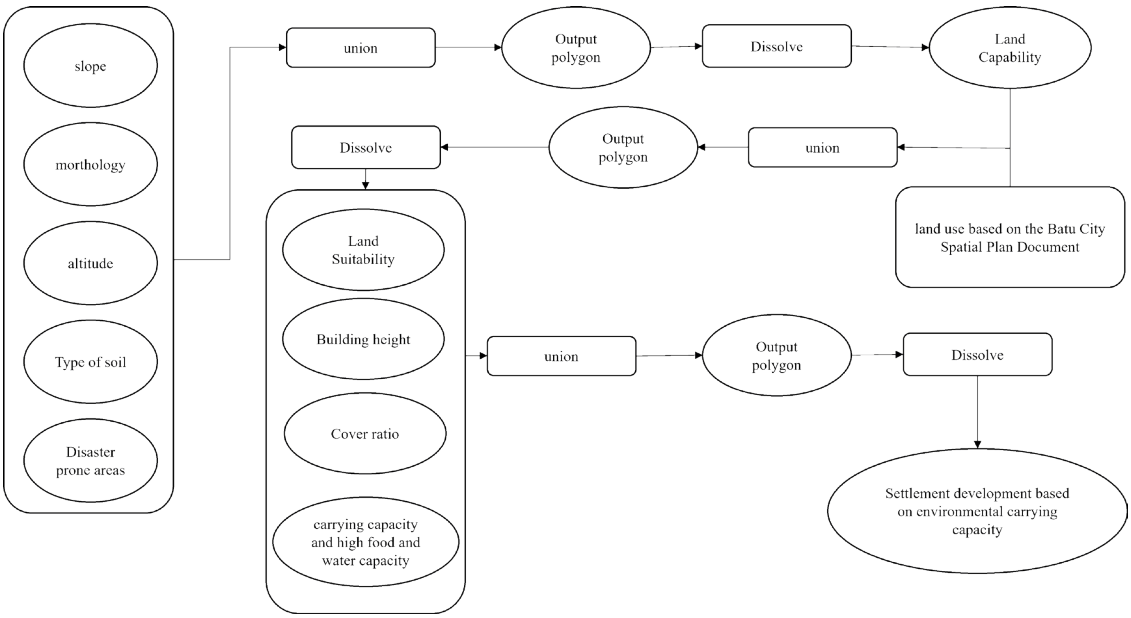

Fig. 1. Flowchart on the overlay layers

Table 1. Types of Land Use and Land Area of Batu City Land Use Plans that are not suitable with Land Capability

Slopes (%)	Classification	Area (ha)
0-8	Flat	2,207.21
8-15	Gentle	2,223.73
15-25	Sloping	1,799.37
25-40	Steep	4,529.85
>40	Very Steep	4,493.33

• MorthologyMorthology.
Morthological characteristics are sorting out the shape of the landscape nature/morthology of the region and/or area planning that can be developed according to its function. The geographical landscape is represented by hills and mountains, with an altitude of + 800 meters above sea level.
• Altitude
Based on the altitude, Batu City is classified into 6 (six) classes that the geomorthological mapping presented below refers to to the system developed by Verstappen (1967, 1968) and Van Zuidam (1968, 1975) based on experiences in tropical regions such as Indonesia and Latin America. The classification includes the following classes:
– 1. 600-1000 meters ASL with an area of 6,019.21 ha .
– This area covers three sub-districts: firstly, Batu Sub-District, which includes Sidomulyo Village, Temas, Sisir, Malik, and Sumberejo Village, and a small part of Oro-Oro Ombo, Pesanggrahan, and Songgokerto Village, Junrejo Sub-district, which includes Junrejo, Torongrejo, Pendem, Beji, Mojorejo, Dadaprejo, and parts of Tlekung village, and Bumiaji Sub-District, which includes a small number of villages.
– 2. 1000-1500 meters ASL with an area of 6.493,64 ha
The area at this altitude covers most of the villages in Bumiaji and Batu Sub-Districts, including the Songgokerto, Oro-Oro Ombo, and Pesanggrahan Villages and a small part of Tlekung Village in the Junrejo Sub-District area.
– 3. 1500-2000 meters ASL with an area of 4.820,40 ha
The area at this altitude includes small parts of Tlekung Village, Junrejo Sub-District, and Oro-Oro Ombo and Pesanggarahan Villages, especially around Mount Panderman, Mount Bokong, and Mount Punukwari. Meanwhile, in Bumiaji Sub-District, almost all villages are located at this altitude, especially the ones near Mount Rawung, Mount Tunggangan, and Mount Pusungkutuk.
– 4. 2000-2.500 meters ASL with an area of 1789,81 ha
The area at this altitude is relatively small and covers the territory around Mount Srandil and at the end of Oro Oro Ombo Village in Batu Sub-District, which borders Wagir Sub-District. For Bumiaji Sub-District, this altitude includes Mount Anjasamoro and a small part of the Giripurno, Bumiaji, Sumbergondo, and Torongrejo Villages.
– 5. 2.500-3000 meters ASL with an area of 707,32 ha
The area at this altitude covers a small number of villages located in the Bumiaji Sub-District regions bordering the Prigen Sub-District.
– 6. 3000 meters ASL with an area of 78.29 ha.
The area at this altitude includes several villages in Bumiaji Sub-District, around Mount Arjuno (Sourgondo Village), Mount Kembar, and Welirang (Tulungrejo Village).
• Type of soil
Land capability analysis is based on soil type factors according to different erosion sensitivity depending on the criteria and classification . It based on the decree of the Indonesian minister of forestry in 1980 (Qibthia et al. 2019) (Table 2).
• Disaster-prone areas
Batu City is flanked by several mountains, including Panderman, Anjasmoro, and Arjuno. Therefore, there is a volcanic disaster-prone area in Bumiaji Sub-District. Based on the results of the land capability assessment based on the units of slope, morthology, elevation, soil type, and disaster-prone areas, we obtained the following result . Slope, morthology, and altitude influence moderate, low, and poor development capability. The land capability unit

Table 2. Type of Soils Classification

Type of Soil	Classification	Area (ha)
Alluvial	not vulnerable	239.86 ha in Batu Sub-District, 199.93 ha in Junrejo, and 376.48 ha in Bumiaji Sub-District
Latosol/Inceptisols	less vulnerable	covers an area of 889.31 ha in Batu Sub-District, 741.25 ha in Junrejo Sub-District, and 1395.81 ha in Bumiaji Sub-District
Brown forest soil/ultisols	a bit vulnerable	covers an area of 260.34 ha, 217.00 ha, and 408.61 ha in Batu, Junrejo, and Bumiaji Sub-District
Androsol, Laterit, Grumusol, Podsol, Podsolic	vulnerable	1,831.04 ha in Batu Sub-District, 1,526.19 ha in Junrejo Sub-District, and 2,873.89 ha in Bumiaji Sub-District
Regosol, Litosol, Organosol, Rensina	very vulnerable	-

shows the areas with slope steepness and land morthology that are not appropriate for intensively developing areas. The areas of moderate, low, and poor development capacity cover 13,365.14 ha, 3193.04 ha, and 2858.07 ha, respectively.Existing land use in areas with moderate development capability consists of built-up land uses, such as industry, offices, trade and services, public facilities, tourism, urban forests, fisheries, permanent production forests, and horticulture. Land use types corresponding to low development capacity include horticultural areas, protected forests, permanent production forests, tourism, trade and services, housing, and urban forests. Finally, land use at poor development capacity consists of public facilities, horticulture, protected forest, permanent production forest, tourism, trade and housing services, and urban forest.

Based on the results of land capability analysis and the existing use, it is necessary to adjust the land use based on the Batu City Spatial Plan, especially the areas corresponding to tourism, housing, and trade in regions with insufficient land capacity.

Land Suitability Analysis

In this section, a suitability analysis is carried out based on the results of the land capability analysis (Fig.2) and the map of the Batu City land use plan. This analysis aims to show how well the land use plan matches the land's capability. Based on the results of the GIS overlay, some land use types were found to be unsuitable for the land capability in Batu City. Types and areas that are not suitable are shown in Table 3.

Table 3. Types of Land Use and Land Area of Batu City Land Use Plans that are not suitable with Land Capability

Land Capability	Land Use	Land area (ha)
Moderate	Public and Social Facilities	185.15
	Tourism	440.73
	Trade and Services	550.29
	Offices	34.44
	Defense and security	65.85
	Housing area	2,924.97
	Industry	13.15
	Farm	43.04
	Transportation	0.95
Low	Tourism	16.74
	Trade and Services	0.03
	Housing area	3.53
Poor	Public Facilities and Social Facilities	1.30
	Tourism	0.10
	Trade and services	0.003
	Housing area	0.96
Total		4,281.233

Based on the results of the suitability analysis (Fig.3), unsuitable land use types covered 4258.57 ha of land characterized by moderate capability. That is because the available land in Batu City is only of average capability, and all urban activity centers, offices, trade, and settlements, are located there. Also, there is 20.3 ha of unsuitable land use at low land capability and 2,363 ha of unsuitable land use at poor land capability. It is due to the development of tourism areas accompanied by the need for trade and settlements around them. Residential areas that exist on land with low land capability generally function as hotels, guest houses, or homestays for tourists.

Sustainable Development Analysis

This section presents the analysis of unit indicators from the results of land suitability assessment, land cover ratio plans, building height plans, and directions for carrying capacity and high food and water capacity in Batu City. This analysis aims to show a plan based on the unit indicators from the previous section (Fig.3 and develop a plan that considers the carrying capacity of water. The plans of the cover ratio and building height (Fig. a and b) were obtained from the city planning document, while the direction of carrying capacity and high food and water capacity in Batu City (Fig.c) was based on environmental city documents.

The land cover ratio (Fig.a) shows the recommended land cover for each house plot based on land slope, morthology, and soil type indicators. The recommended building height (Fig.b) shows the maximum building height in the area based on land slope and soil type indicators. The carrying capacity and high food and water capacity (Fig.c) indicate the areas with the potential to have high food and water reserves. The recommendations are based on areas with increased productivity and the maximum amount of sustainable water extraction per year.

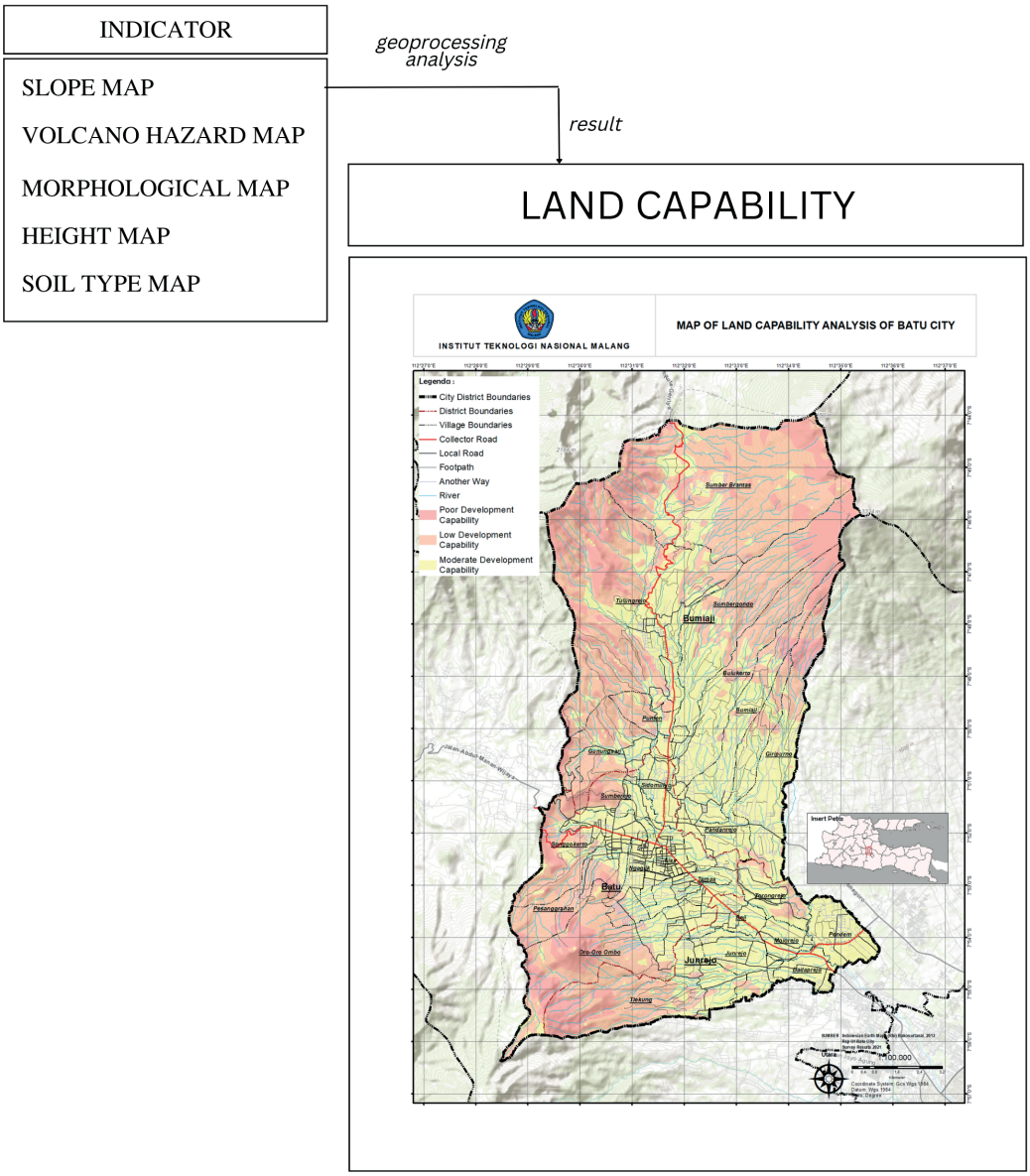

Fig. 2. Land Capability Analysis Using 5 Indicators (Slope, Morthology, Soil Type, Height, Volcano Hazard) in Batu City

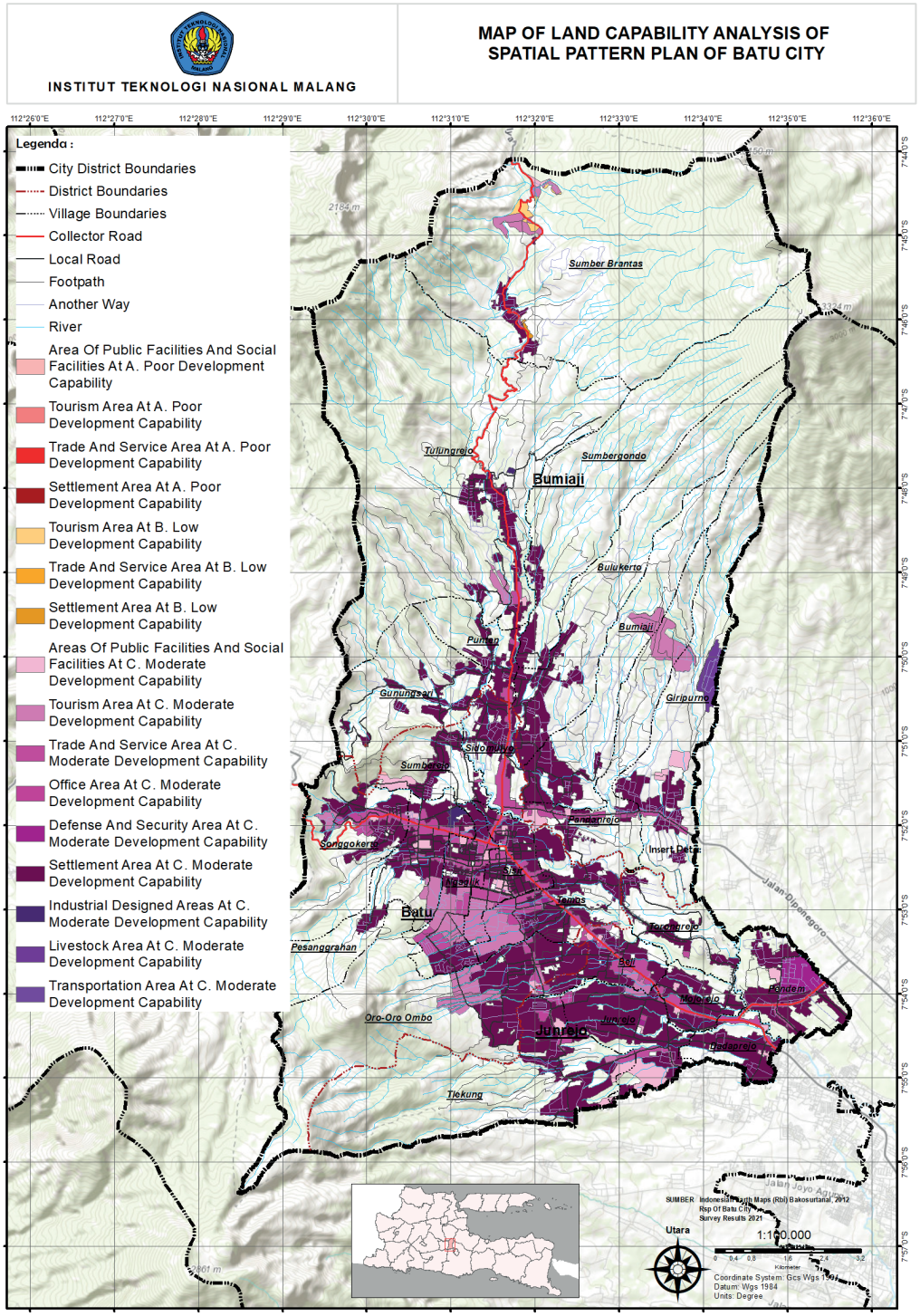

Fig. 3. Suitability Analysis of Land Capability and the Land Use Plan of Batu City

Figure d presents the results of combining 3 indicators shown in Fig. d . These results show that 3,784.28 ha of land can be used in Batu City as a residential area when considering water carrying capacity indicators. The highest land availability is observed in Junrejo sub-district. In Fig. d, it can also be seen that most of the recommended land is characterized by moderate land capability and is located in the city activity center.

DISCUSSION

The role of environmental carrying capacity is to provide an overview of the maximum limit that can be sustained by nature. In urban development, its role is vital amid economic and population growth issues. Sustainable development plans integrate economic and social challenges to maintain the balance of nature (Świąder et al. 2020). It is expected for a growing city to have an upper threshold for urban development at a certain carrying capacity point.

Batu City does not have an upper threshold because physical development is carried out massively, even in areas with low land capacity. In contrast, the environmental carrying capacity is a comprehensive reform that coordinates economic development and environmental protection (Su & Yu 2020), especially in cities in mountainous areas. The dilemma is to maximize the use of natural resources with reducing the risk of natural damage.

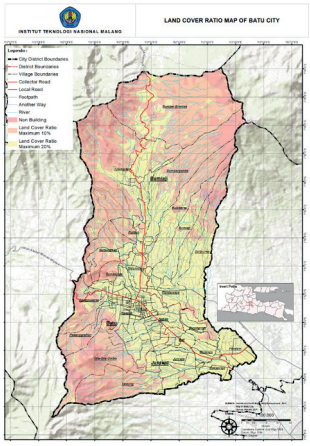

Fig. 4a

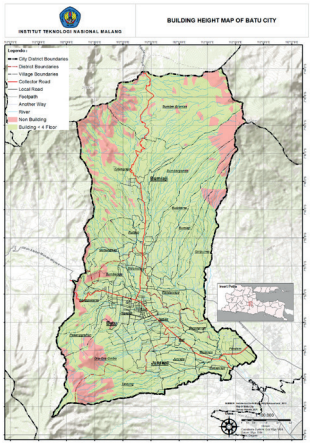

Fig. 4b

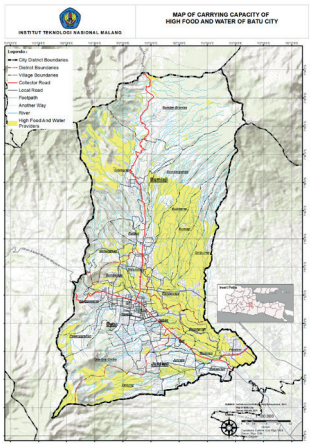

Fig. 4c

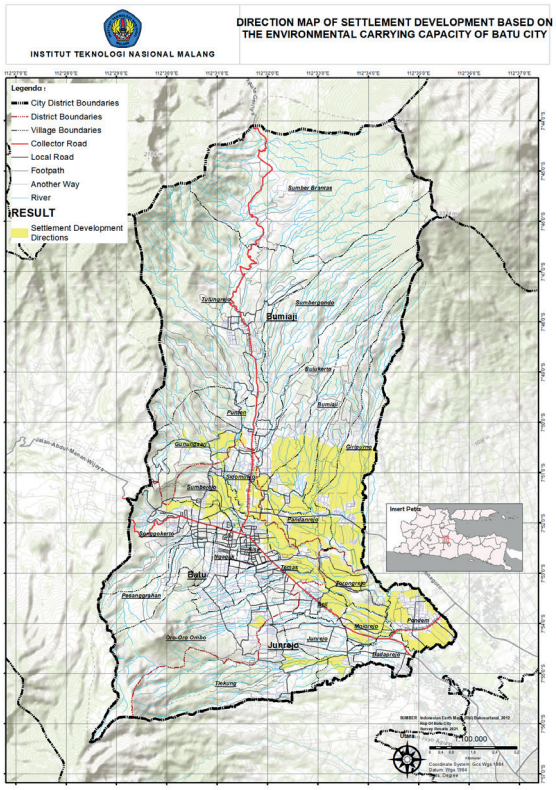

Fig. 4d

Fig. 4. Settlement Development Plan of Batu City

CONCLUSION

The results showed that most of the land in Batu City was characterized by medium capacity of 13,365.14 ha, of which 4,258.57 ha was not suitable for land use. At low land capability, the total area of unsuitable land use is 2,383.3 ha. Spatial analysis showed that the development of residential areas should be directed at the land with a medium capacity of 3,784.28 ha.

The high attractiveness of the city for tourism requires establishing policies and setting the threshold for the city's capacity. In addition, Batu City is located upstream, where its watershed has an impact on other cities in the vicinity, which is another reason for setting a city-carrying capacity threshold. If this is not done, the increase in the number of residents in Batu City as an upstream and tourist city will significantly impact the environment and threaten the city's sustainability.

In future studies, the settlement area plan that considers the environmental carrying capacity can be developed. In addition, it is necessary to develop indicators for environmental policies for urban areas in the upstream regions, including indicators for determining residential areas.

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