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## **Integrated assessment of urban land carrying capacity (ULCC) for reducing earthquake risk disaster in Palu City**

**Key words:** land carrying capacity, urban area, earthquake disaster, Palu City

### **Introduction**

The land is one of the main components of the environment, the fundamental matrix of life (Onishi, 1994; Singer, 2014; Xiao et al., 2021). However, land has a limited carrying capacity, therefore must be well maintained to avoid damage or degradation (Stocking & Murnaghan, 2002). The pressure of high population growth in various places has resulted in pressure on land as well beyond its natural carrying capacity (Goldshleger, Ben-Dor, Lugassi & Eshel, 2010). Several studies have shown that land quality is deteriorated due to misuse, one of which includes overuse or over-capacity (Dougill, Twyman, Thomas & Sporton, 2002; Boix & Zinck, 2008). Improper land

use requires high costs for repairs; especially when the degradation reaches an irreversible stage (Sudershan, 2003; Gupta & Sharma, 2010). Similar to non-renewable natural resources, rational land use is also an influential indicator of development (Chang & Wu, 2011) and economic growth (Pilvere, Nipers & Upite, 2014). The aforementioned is even related to the concept of sustainable development (Akıncı, Özalp & Turgut, 2013). Sustainable development can be defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Atlas Powder Company, 1987; Munasinghe, 1993; Feizizadeh & Blaschke, 2012).

Rapid population growth requires new areas to meet primary needs, especially in urban areas. In turn, this need causes natural resources such as forests, grasslands, wetlands, and agricultural land to be converted into settlements or

industrial estates (Tian & Sun, 2018). This will ultimately lead to land use that is not following its potential and exceeds its carrying capacity (Symeonakis, Calvo-Cases & Arnau-Rosalen, 2007). Land-use planning that allows good inheritance of land resources for future generations is very important to be considered. Thus, an integrated approach is needed for land use planning that takes into account long-term sustainability (Smardon, 2008). Efforts that can be taken for this planning are applying a planned and sustainable land use which is following their capabilities and potential based on urban land carrying capacity (ULCC).

Urban land carrying capacity is part of the evaluation of the environmental carrying capacity which refers to its maximum carrying capacity. Although the carrying capacity of an area is not constant, this suggests a kind of human-environmental lead-lag relationship. Carrying capacity is conceptualized as a load or even full load, an important dimension of it. Projected economic, technological, and social growth rates and the material requirements needed decide the number of people a region can support with its land resources. To live on various time scales (Shi & Chen, 1991; Feng, 1994). Consequently, the carrying capacity of urban land can be defined as the level of human activity, population growth, land use patterns and extent, and physical development that the urban environment can support without significant and irreversible damage (Sarma et al., 2012).

The impact of earthquakes in urban areas is a complete problem that is exacerbated by multi-hazard and significant risk issues, a large inventory of vulner-

able physical components, and socioeconomic issues. Given the impact caused by an earthquake is a complex issue, efforts to manage and minimize the effects of this disaster must be considered carefully. In this case, it is very important to predict when and where an earthquake may occur. The foundation and vital rationale for practical risk reduction activities are rational urban risk predictions and projected losses from future significant earthquakes.

Therefore, specific emergency preparedness and procedures should be established, especially in urban centers that were most strongly affected by the earthquakes, i.e. during and before the earthquake where this requires calculating the impact of the earthquake on the physical and social environment. Population, buildings, infrastructure, systems, and socio-economic activities are all “elements at risk” in urban areas (Erdik, Durukal, Aydinoglu, Fahjan & Siyahi, 2006) so that the potential for earthquake hazards must be factored into the measurement of the land’s carrying capacity for urban planning.

This research took place in Palu City, a national urban area in Indonesia with limited urban development due to the threat of an earthquake. In the need for sustainable urban development, it is necessary to study the land carrying capacity to reduce the risk of earthquake disasters. This can be done through three stages of analysis, including mapping of earthquake-prone areas through micro-zoning of earthquake vulnerability, assessing the land capability, and conducting a comparative analysis regarding the land capability and spatial planning.

## Material and methods

### The study area and data source

Palu City is located in Central Sulawesi Province with an area of 395.06 km<sup>2</sup>. This city consists of eight districts, namely West Palu District, Tatanga District, Ulujadi District, South Palu District, East Palu District, Mantikulore District, North Palu District, and Tawaeli District. Palu City is one of the national urban areas designed by the national spatial plan (Government Regulation No 26 of 2008 regarding National Territorial Layout Plan) as a center for import-export activities or a gateway to the international area and a center for industrial activities. On the other hand, Palu City is on the Palu-Koro fault line, an active fault that stretches 170 km along the mainland of island of Sulawesi, moving at a speed of  $35 \pm 8$  mm per year. Since the 19<sup>th</sup> century, earthquakes have frequently occurred in Central Sulawesi, some of which were of high magnitude, including in 1968 (6.7 SR), 1993 (5.8 SR), 2005 (6.2 SR), and 2008 (6.7 SR) (7.4 SR) (Bellier et al., 2001).

This research uses applied methods with quantitative and superimpose approaches. The research data was processed using the geographical information systems (GIS) as a tool; field observations support primary and secondary data. To achieve the main purposes of this research, the following stages are taken: (1) mapping of earthquake prone areas with seismic micro-zonation; (2) land capability assessment; and (3) comparative analysis of land capability and spatial planning in Palu up to 2030.

### *Mapping of earthquake prone areas with seismic micro-zonation*

Mapping of earthquake-prone areas of seismic micro-zonation was carried out through microtremor analysis. The aim is to determine the characteristics of the soil layer based on the dominant period parameters and amplification factors. Micro-zonation of microtremor divides an area based on certain parameters by considering characteristics, including ground vibration, amplification factor, and dominant period.

The analysis carried out in this study consisted of (1) analysis of horizontal-vertical spectral ratio (HVSR), namely comparing the spectrum of the horizontal component with the vertical component of the microwave; and (2) analysis of dominant frequency and dominant period, namely determining the frequency value of rock layers in the area so that the type and characteristics of the rock. The microtremor data used in this study were 36 data collection points in Palu City. The data is then processed using the HVSR method to obtain the dominant frequency value. The result will determine the level of earthquake vulnerability. The dominant frequency value will calculate the wave speed value (amplification) to a depth of 30 m (Vs30) which is used to determine the level of disaster risk that occurs through the peak ground acceleration (PGA) value. Furthermore, to obtain a micro-zoning map, data processing uses the overlay technique and GIS weighting by providing the highest earthquake vulnerability value for each PGA parameter, amplification (Vs30), while the maximum period was obtained using the analytical hierarchy process (AHP) method. This earthquake micro-zonation map was then

verified using field survey data showing the location of the destroyed buildings and classified according to the modified Mercalli intensity (MMI) class.

*Land capability assessment*

To determine the carrying capacity of land in Palu City, a land capability analysis was carried out. This analysis aims to obtain an overview of the level of land capability to be developed as an urban area through the determination of the land capability unit (LCU), which consists of LCU morphology, slope stability LCU, foundation stability LCU, and water availability LCU. The method used in this analysis is a map overlay and

input data to each LCU using a thematic map with a scale of 1:25,000, as shown in Table 1.

The total land capability is classification is measured by the overlay of each LCU. It multiplies the final value weight to get the resulting map using the AHP principle (Sharififar, Ghorbani & Karimi, 2013). Digital spatial analysis method using GIS produces a land capability classification map as output.

*Comparative analysis of land capability and spatial planning in Palu 2030*

The comparative analysis aims to determine land use capability combining land capability analysis, hazard

TABLE 1. Evaluation of land capability unit (LCU)

LCU	Data	Classification of LCU	Score
1. Morphology	a) topography b) morphology	a) very high morphology b) high morphology c) moderate morphology d) low morphology e) very low morphology	1 2 3 4 5
2. Slope stability	a) topography b) morphology c) slope d) geology e) hydrogeology f) rainfall g) land use h) geological hazard	a) high slope stability b) moderate slope stability c) low slope stability d) very low slope stability	1 2 3 4
3. Foundation stability	a) geology b) hydrology c) land use d) geological hazard e) land use	a) low foundation stability b) moderate foundation stability c) high foundation stability	1 2 3
4. Water availability	a) hydrology b) climatology c) morphology d) topography e) geology f) land use existing	a) very low water availability b) low water availability c) medium water availability d) high water availability e) very high water availability	1 2 3 4 5

mapping, and spatial planning 2030. Its result estimates the range of integrated area development. Furthermore, the area estimation leads the strategy to improve spatial planning in Palu based on the carrying capacity of the land. The method was carried out to determine land capability mapping overlay, hazard maps, and spatial planning up to 2030, as stated in the results of land capability analysis of Palu's spatial planning in 2010–2030. In addition, one of the considerations to preparing the spatial planning is the threat of an earthquake in Palu.

## Results and discussion

### Earthquake hazard mapping with seismic micro-zonation

A micro-zonation process is initiated in the area which is prone to earthquakes. In this study, seismic micro-zonation was used on a 1:25,000 scale detail map. According to microtremor measurements, it leads to the vibration properties in the subsoil layer (Nakamura, 2000). The results of seismic micro-

-zonation analysis measured three parameters for further calculations by giving the highest class in earthquake-prone areas, with parameters and classification as shown in Table 2.

Based on National Earthquake Hazard Reduction Program (BSSC, 2001), the dominant period values there are in the range of 0.4–0.6 s. This means the entire study area is prone to earthquakes with a very high risk of damage (> 0.6 s), especially in most of Mantikulore District and Tawaeli District. These areas include Ulujadi District, Mantikulore District, and Tawaeli District with a dominant period ranging from 0.4 to 0.6 s. Areas with a dominant period of fewer than 0.4 s indicate a layer of hard soil with a fairly low risk of damage, especially in parts of South Palu District, West Palu District, North Palu District, and Ulujadi District.

The amplification value of Palu ranges from 1.01 to 7.56 m·s<sup>-1</sup>. The harder the soil, the greater the shear wave velocity and the smaller the shock amplification factor will be. Most of the amplification values were 3.18 (alluvial/sediment), especially in Ulujadi

TABLE 2. Parameters for the preparation of the Palu City earthquake micro-zonation map

Parameter	Class division	Score
Dominant period	< 0.4 (alluvial/sediment)	1
	0.4–0.6 (alluvial/sediment)	2
	> 0.6 (granit/metamorf)	3
Amplification	1.01–3.18 (alluvial/sediment)	1
	3.19–5.37 (alluvial/sediment)	2
	5.38–7.56 (granit/metamorf)	3
Peak ground acceleration (PGA)	0.59–0.68 (medium-high)	1
	0.69–0.78 (high)	2
	0.79–0.88 (very high)	3

District, Tatanga District, South Palu District, North Palu District, and Tawaeli District.

The PGA value obtained is the value of the wave acceleration in the bedrock report that occurred due to the earthquake. The value will be smaller since the epicenter distance is caused by the absorption of earthquake energy in the soil medium. The distribution of the PGA values in Palu City consists of: (1) 0.59–0.68 equivalent to the MMI X-scale which causes damage to strong wooden buildings and foundations, most of which are located in the eastern of Mantikulore District and Ulujadi District; (2) 0.69–0.78 is equivalent to MMI XI-scale which causes large soil cracks, landslides, broken bridges, yet wooden buildings standstill, most of which are in the center of Palu City; (3) 0.79–0.88 equivalent to MMI

XII-scale which causes damage on a massive scale, blurred vision and discarded objects, most of which are in the center as well as eastern parts of Palu. Figure 1 shows a map of earthquake-prone areas according to both seismic micro-zonation and the damage scale.

Based on the map, 52.09% or 205.81 km<sup>2</sup> of Palu City is dominated by areas with a moderate level of danger located in Tawaeli District, West Palu District, Ulujadi District, North Palu District, Mantikulore District, and Tatanga District; high earthquake hazards were in Tawaeli District, East Palu District, South Palu, West Palu and Ulujadi District with the scale number of 22.47% or 88.76 km<sup>2</sup>; while the low earthquake hazard with the scale number of 25.43% or 100.49 km<sup>2</sup> included Mantikulore District, Tawaeli District and Ulujadi District.

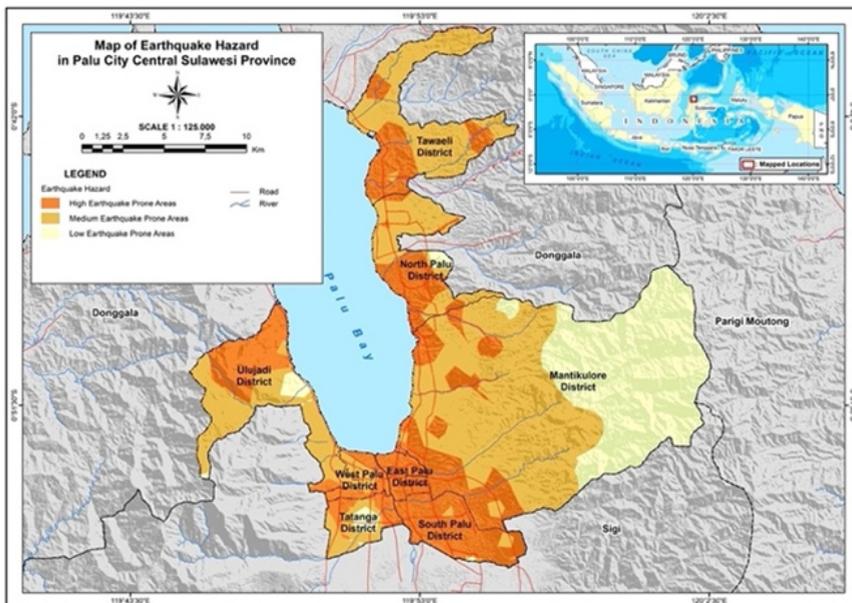


FIGURE 1. The map of earthquake-prone areas in Palu City

## Land capability assessment

Land capability assessment proceeds the physical aspects measured by overlaying maps, assigning values, as well as weighting to each parameter. The results stated land capability of Palu grouped into five classes, namely Class A to Class E with proper management with very low to very high-level capability. Class A means to be very low, Class B is the land capability of low, Class C refers to be medium-level capability Class D is high high-level, and Class E means to be very high. This classification is shown in Figure 2.

From the land capability map shown in Figure 3, most of Palu City is dominated by low-level land capability (with the number of 23.92%) to very low (with the number of 31.51%). It indicates Palu has physical limitation in city development.

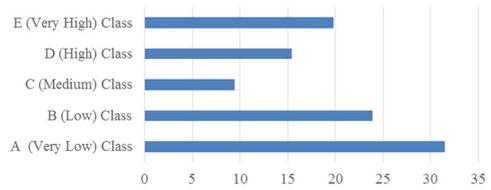


FIGURE 2. Value and class of land capability in Palu City

## Integration of land suitability and spatial planning of Palu City 2030

The environment leads the action to evaluate land suitability for spatial planning in Palu. It was done by comparing an area's spatial plan with the land's capability to determine the suitability of the two. The results will show that the area currently under development can be classified as suitable, conditional, and unsuitable land, as shown in Table 3.

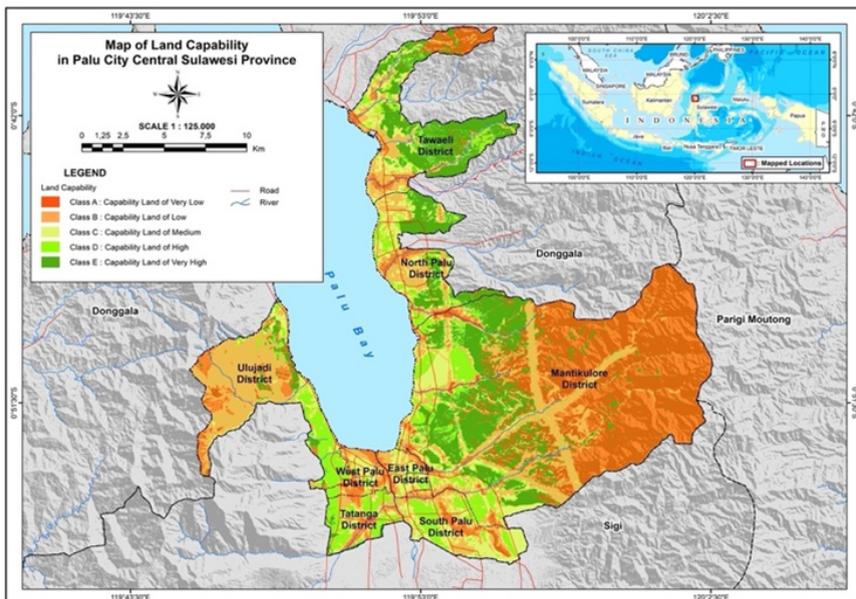


FIGURE 3. Land capability in Palu City

TABLE 3. Compatibility of the Palu spatial plan and ULCC in Palu City

Parameter	Area [%]	Classification
Class A with high earthquake prones with protected areas	9.12	suitable
Class B with medium earthquake prones with protected areas	26.52	suitable
Class C with low earthquake prones with protected areas	20.43	suitable
Class D with high earthquake prones with built-up areas	21.21	unsuitable
Class E with medium earthquake prones with built-up areas	21.57	conditional
Class F with low earthquake prones with built-up areas	1.15	suitable

Palu spatial planning in 2030 is dominated by the land’s carrying capacity with proper management for protected areas (with the number of 56.07%). The land carrying capacity was grouped into six classes, namely Class A to Class F with the earthquake-prone area. The classification leads to a high to medium level of earthquake threat, and thus, the 1.15% of the built-up area is acceptable, notably, those in Class F. Conditional

land suitability is given to the spatial use plan in built-up areas with the threat of an earthquake but is in Class C land capability class covering 20.43% of the total area of Palu City. The number indicates land development is not suitable for the urban area since it is in the high level of earthquake-prone areas as in Class D (with the number of 21.21%) of the total area of Palu City. A good evaluation of land capability measures the good qual-

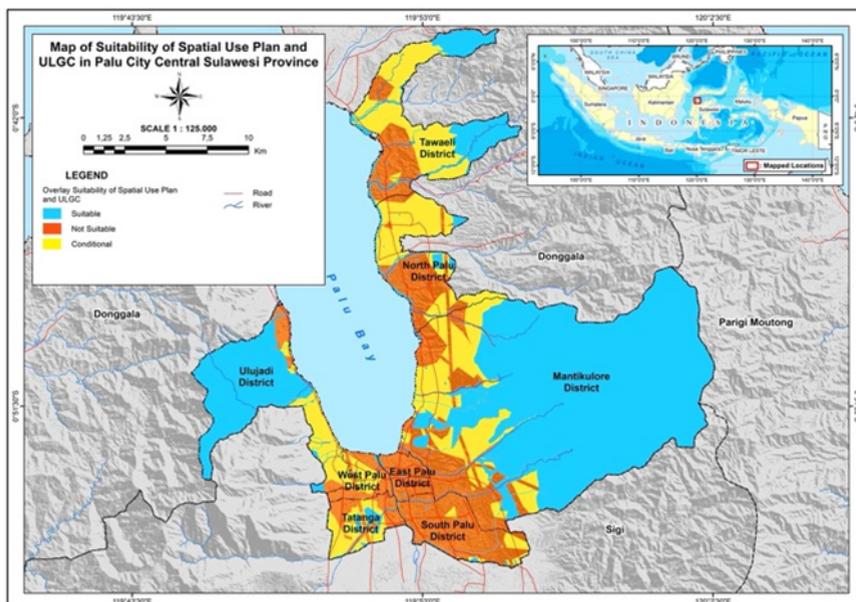


FIGURE 4. Map of suitability of spatial use plan and ULCC in Palu City

ity of spatial planning. This avoids the allocation of spatial use that is inconsistent with the capacity of the land. Thus, it requires special attention for the future development plan of Palu City. Figure 4 shows the land suitability distribution in Palu City.

The type of land use that is unsuitable for urban development, in general, is dominated by residential area land use (with the number of 66.42%), as shown in Figure 5. Good urban spatial planning avoids the allocation of space use that is not under the capacity of the land, hence, this requires a good plan development for the future.

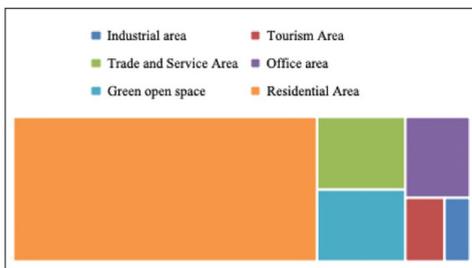


FIGURE 5. Type of land use that is not suitable for urban development in Palu City (Class D)

## Conclusions

Improvement and long-term sustainability of the quality of life in human settlements today is the main problem facing urban planners, hence, given the scarcity of natural resources and inadequate infrastructure, one of the strategies is using ULCC. Besides a dynamic city policy to reorganize land carrying capacity is important to improve the state of urban development and the quality of life of human settlements. This study found some “weaknesses” in the spatial

planning of Palu to be corrected so that the potential for developing the area is increasingly limited.

The spatial planning Palu City tends to limit regional development by regulating land use and expanding protected areas. There is, however, high demand for both urbanization land and urban development to use land with carrying capacity. Unsuitable land, as a result, the use of land that does not meet the carrying capacity requirements must be regulated and controlled. The limitation of this study devised the carrying capacity of earthquake hazards (excluding other natural disasters) analysis and land capability analysis. Urban land carrying capacity as previous studies has used seismic micro-zonation analysis as a basis for evaluating earthquake-prone areas on a very comprehensive scale.

The application of seismic micro-zonation analysis has been carried out for urban planners in several cities in the world (Chávez-García & Cuenca, 1998; Marcelloni et al., 1998; Lungu, Aldea, Cornea & Arion, 2000; Faccioli & Pessina, 2001; Fäh, Kind, Lang & Giardini, 2001; Ansal et al., 2004). Yokohama City in Japan uses seismic micro-zonation to measure and evaluate industrial as well as population centers by considering various zones, suitable soil conditions, and seismic design coefficients for various types of structures located in different zones; Armenian cities in Colombia using a three-dimensional layers model and combined them with seismic responses to obtain spatial variations in seismic responses were examined by damage assessments of Armenia (Slob, Hack, Scarpas, van Bemmelen & Duque, 2002). Besides, Siliviri City and Istanbul

City in Turkey (Ansal et al., 2004; Gupta & Nair, 2010) have developed seismic micro-zonation maps and assessed damage scenarios.

Furthermore, a land-use development intensity assessment to address the need for optimizing land and utilization is required. The need for comprehensive assessment tends to focus on the current development scale, the identification of factors driving development, temporal-spatial differentiation and patterns of urban land expansion, the productivity and efficiency of construction land use, and the assessment of development potential. To achieve the goal of sustainable development, three indicators (size, efficiency, and potential) need to be considered at the same time.

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## Summary

### **Integrated assessment of urban land carrying capacity (ULCC) for reducing earthquake risk disaster in Palu City.**

Assessment of the carrying capacity of urban land is very important to evaluate and obtain an overview of the level of land capability through the classification of the carrying capacity of the area so that it becomes the basis for future urban development. This research was conducted in Palu City, which is national city in Indonesia with limited urban development due to its prone to earthquakes. For urban development, it is necessary to study the carrying capacity of land to reduce the risk of earthquake disasters, through three stages of analysis, namely mapping of earthquake-prone areas using the earthquake hazard mapping with seismic micro-zonation; land capability assessment; and integration of land suitability with planning and spatial planning of Palu City. Based on the findings of this study, 74.56% of Palu City is an earthquake-prone area dominated by land

capability Classes A to B, namely low to very low land capability classes (55.43%), implying that they have urban physical constraints. However, if it is integrated with the Palu City spatial plan until 2030, most (78.79%) are already in accordance with the carrying capacity of their land, especially in protected areas, but there are still land developments that are not suitable for carrying capacity (21.21%), especially in cultivation areas with risks earthquake disaster. Land use plans that are not in accordance with their carrying capacity must be managed strictly as a tool for disaster mitigation that is urgently needed.

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