ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol.52 , No. 3, 2020 (427 – 436)
DOI: http://dx.doi.org/10.22146/ijg.44591 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Spatial dynamics model of land availability and population growth prediction in Bengkulu City

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Received: 2019-05-18
Accapted: 2020-12-08

Keywords:
land availability;
built-up area;
dynamic system models;
spatial dynamics models

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Abstract. Bengkulu City is the center for almost all activities and has high population growth rate. Because of the high population growth rate, human needs for space and land will increase. Land availability will continue to decline, while it cannot increase the existing area. This will impact on the carrying capacity of the environment, so it needs predictions for land availability. This study used a spatial dynamics model which is an analysis of the dynamic system model and the suitability of built-up area. The carrying capacity to reach the excellent quality when the length of the built-up area is 30-70% of total area that can be used. The results showed that the built-up area will reach 70% in 2030, which mean it will exceed the environmental carrying capacity threshold. The results showed there were differences between the distribution patterns of built-up area in the spatial dynamics model and Spatial Planning Bengkulu City in 2032 at Kampung Melayu Subdistrict, Selebar Subdistrict, Singaran Pati Subdistrict and Sungai Serut Subdistrict.

1. Introduction

Indonesia is known as a country that has abundant natural resources, one of its natural resources is in the coastal area. The coastal area is one of the areas with the highest activity, according to (MacDonald, 2005) around 70% of the world's population lives in coastal areas. Open coastal areas made the activities increased. Population growth and technological development, the environment was changed and adapted to the way of human life. Bengkulu Province is one of the provinces bordering to the Indian Ocean with the length of Bengkulu's coastline is 525 km and most of the population lives in the coastal area (Cahayadinata & Arianti, 2016). This can be shown from the population growth rate of Bengkulu Province which was 1.67% in 2000 to 2010. The growth rate also has increased 1.69% in 2010 to 2016 (Statistics, 2018). Bengkulu City has the most significant population growth rate in Bengkulu Province which was 3.2% from 2007 to 2017, nearly three times more than the national growth rate. This happened not only because of the high birth rate, but also because of the high migration rate (Agency, 2018).

The large number of the population will increase the demand for the land, while the land stay permanently. When it is over the limit, the carrying capacity will decrease (Ariani & Harini, 2012).The carrying capacity reach the good quality when the length of the built-up area is 30-70% of a total area that can be used (Novia, Supriatna, & Anggrahita, 2019); (Prăvălie, et al., 2020) . Based on that, it is necessary to predict the land availability for built-up land by a spatial dynamic model. We intend analysis of dynamic system models to obtain mathematical prediction results of the relationship between population growth and land availability (Supriatna, Supriatna, Koestoer, & Takarina, 2016) .The main analysis in this model is the simulation analysis and the accuracy generated by the relationship between variables described in the causal loop diagram (CLD). The relationship between population growth and land availability can be understood in more detail by interpreting the behavior and trends of the model formed. This understanding is useful for gaining insights in estimating future trends and help spatial planning policies in the future.

2. The Methods

This study used quantitative and spatial analysis based on population growth and physical data in Bengkulu City. Spatial modelling was used to determine the temporal and mathematical land use change. The spatial model was obtained from the limiting factor in the selection for the built -up area. The selected built up area location was influenced by the limiting factor where the population will occupy an appropriate, safe and strategic area and use it as built-up area when the land is still available (Jat, Choudhary, & Saxena, 2017); (Balcik & Kacuzu, 2016); (Khan & Jhariya, 2016). The limiting factors comprise physical factors and accessibility factors. The physical factors include slope, distance from river, and distance from protected areas. Slope is an angle formed by the ground surface with a horizontal plane. The built up are generally on a gentle and strength slope because it requires more economical cost to build and safe from disasters (Ghosh & Debbarma, 2019). The distance from river in this study is the space on the right and left of the river which is determined as the boundary of river protection. The distance from protected area in this study is the space around the protected area (buffer area). Accessibility factors comprise distance from the road network and distance from the centre of economic activity. The distance from the road network is the space on the left and right of the road starts from the axis of the road. Roads are an important factor in the formation of built-up area, because it made easier for residents to mobilize people, goods, or services (Zhou & Lin, 2019). The centre of economic activity is the radius from the center of economic activity that affects the quality of service in meeting the economic needs of the population and can be achieved by residents. Through the center of economic activity, residents can get their daily needs, besides that residents can also sell their products from their business (Testa, 2020). Center of economic activity in this study is a large center of economic activity in the form of markets and malls that provide primary, secondary, and tertiary needs for the population.

The data was collected from literature studies, institutional surveys and field surveys. We obtained administration and population data from Central Bureau of Statistics of Bengkulu City. Spatial Plan of Bengkulu City, road networks, river networks, protected areas, center of economic activity were obtained from Local Development Planning Agency of Bengkulu City and The Indonesian Geospatial Information Agency. Land cover data obtained from Supervised Classification Landsat 5 TM C1 Level-1 image on May 26, 2007, Landsat 5 TM C1 Level-1 image on October 13, 2011 and Landsat 8 Image OLI / TIRS C1 Level-1 dated June 22, 2017 from USGS. In this study the classification is divided into 5 classes, water area, non-agricultural area, agricultural area, open field area and built up area. The training area is created by using supporting data from field data and Google Earth maps. This study used random sampling method with 100 samples in each year of analysis. The determining and collecting sample are conducted by using data from field inspections, then the next step is determining and selecting training area for collecting land cover type statistical information. The retrieval of statistical information was conducted by taking pixel samples from each land cover class and determining the location on a composite image. We used the statistical information of every land cover class for running separability function and accuracy function. The classification method used is the maximum likelihood classification (MLC) method (Balcik & Kacuzu, 2016). Accuracy of classification was indicated by an average of overall accuracy and kappa accuracy. Landsat 5 TM C1 Level-1 image on May 26, 2007 has 85,86% overall acc1uracy and 85,03% of kappa accuracy. Landsat 5 TM C1 Level-1 image on October 13, 2011 has 87,98% overall accuracy and 87,28% of kappa accuracy. Landsat 8 Image OLI / TIRS C1 Level-1 dated June 22, 2017 has 88,51% overall accuracy and 88,35% of kappa accuracy. These results meet the conditions set by USGS (> 85%). The results obtained show that the map of Landsat image classification results can be used.

The slope data obtained from DEM NAS 0912-11, DEM NAS 0912-12, DEM NAS 0912-13, DEM NAS 0912-14. Data processing of population growth and land availability used the dynamic system model with PowerSim Studio 10 software. The modelling is done using quantitative approach, then the model will be a mathematical, statistical or computer formula that is described in a diagram model called a Causal Loop Diagram (Elsawah, et al., 2017); (Gu, Guo, Fan, & Chan, 2016); (Coletta, et al., 2020). CLD is the disclosure of a causal relationship (incidental relationship) into a specific image language to understand the concept of the behavior of the phenomenon (Debolini, et al., 2018). Based on Figure 1, Causal Loop Diagram (CLD) population growth model with land availability, there are 5 feedbacks which were 2 negative feedback and 3 positive feedback, then the model validation is done using a simple statistical method, namely Average Mean Error (AME) between simulation and empiric data (Supriatna, Supriatna, Koestoer, & Takarina, 2016).

Spatial dynamics model development was done by predicting the development of the built-up area. The spatial dynamics development steps model was done by following (Supriatna, Supriatna, Koestoer, & Takarina, 2016); (Novia, Supriatna, & Anggrahita, 2019); (Asfari, Supriatna, & Rizqihandari, 2017). First, the development of the built-up area is based on the built-up area dynamic system simulation results. Second, the development of built-up area is based on the results of the built-up area suitability analysis by using grid of 100 m x 100 m (1 ha), so that each existing grid has a value that represents the weight of built-up area suitability. Third, the built-up area was developed by following the distribution of the appropriate area for the built-up area (Prăvălie, et al., 2020). If the suitable are is packed, then the development will continue in area that less suitable for built-up area. Buffer analysis were used to analyse the distance from the river. Then the map of suitability build-up area was formed from overlay analysis, scoring, and querying of physical and accessibility variables (Table 1).

The suitability of built-up area classification was divided into 3 classes (suitable, less suitable and unsuitable) based on the results of the sum of the maximum score of 5 variables which is equal to 15. As previously explained, the prediction of the spatial dynamics model is done by following the distribution of the suitable area for built-up area, which has total score over 11.6. If the land availability for suitable built-up area is packed, then the built-up area will be developed in the less suitable area for built-up land, which has total score 8.4 to 11.6 (less suitable area). Meanwhile, the unsuitable area should be avoided as could as possible because the physical and accessibility conditions have a low score which is only 5 to 8.3 (Supriatna, Supriatna, Koestoer, & Takarina, 2016).

There are several assumptions used in this study: First, the built up area are develops following the analysis of the suitability of built up area (development vertically excluded), the built up area are develops according to the suitable area at the beginning of development, then the development occurs in areas that are less suitable for the built up area. Second, there is no change in the earthquake and tsunami prone areas in Bengkulu City during the year of the simulation carried out. Third, no additional road networks were made during the year of the simulation carried out. Fourth, the limitation area is an area in which absolutely no development may

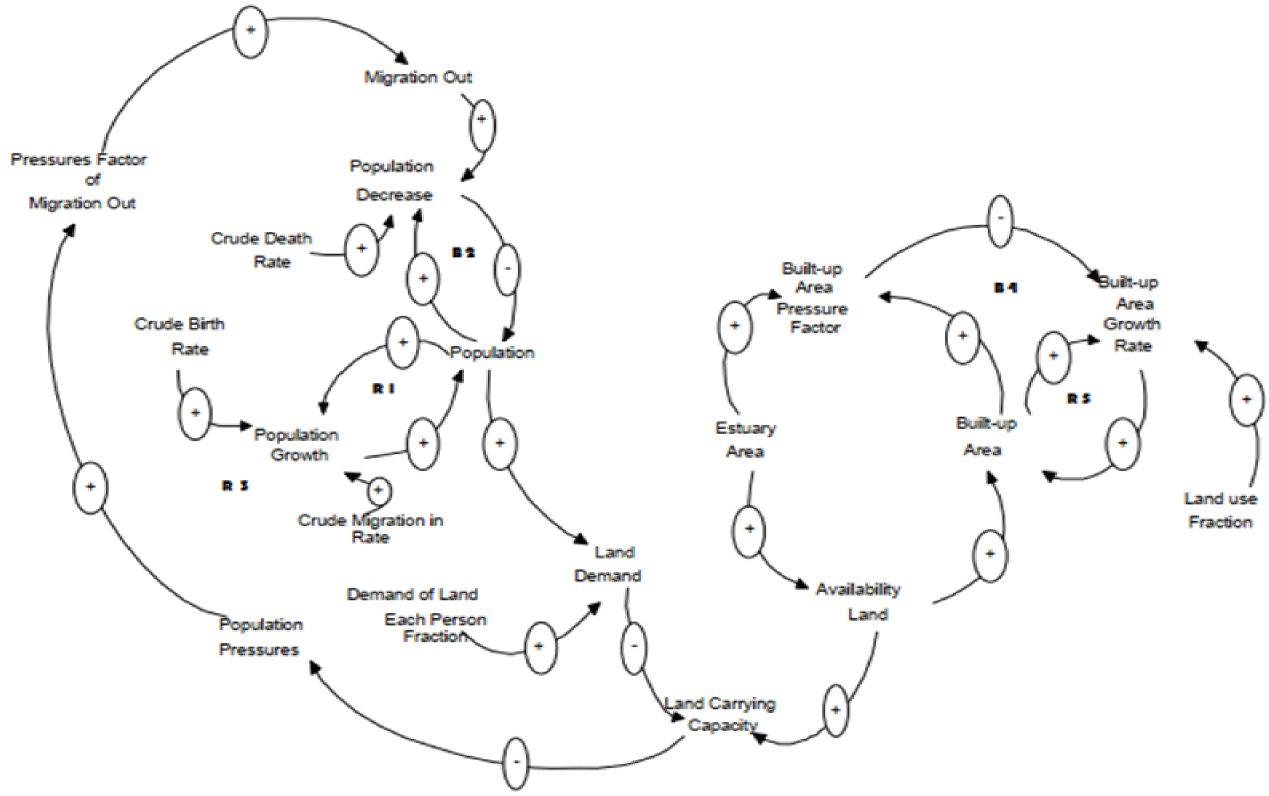

Figure 1. Causal Loop Diagram on Modelling

Table 1. Matrix Scores for Physical Variables and Accessibility Variables of The Suitability Built-up Area

Variables	Classification	Score	Weight Category	Source
Slope	0% - 8%	3	High	Indonesian National Standard 03-1733-2004 on Procedures for the Development of Built Environment
	9% - 15%	2	Moderate	
	>15%	1	Low	
Distance from river	>100 m	3	High	Bengkulu City Regional Regulation No.4 of 2012 concerning the Bengkulu City Regional Spatial Plan 2012 - 2032
	51 - 100 m	2	Moderate	
	0 - 50 m	1	Low	
Distance from road	20 m for arterial roads and> 10 m for collector roads - 100 m	3	High	(Heksano, Agustin, & Hasyim, 2014)
	101 - 750 m	2	Moderate	
	0-20 m for arterial roads and 0-10 m for collector roads or> 750 m	1	Low	
Distance from the centre of economic activities	0 - 2000 m	3	High	Bengkulu City Regional Regulation No.4 of 2012 concerning Bengkulu City Regional Spatial Planning 2012 - 2032
	2001 - 2500 m	2	Moderate	
	> 2500 m	1	Low	
Distance from protected area	*>500 m*	*3*	High	Minister of Public Works Regulation No. 05 / PRT / M / 2008 concerning Regulation on Provision and Utilization of Green Open Space in Urban Areas
	100 – 500 m	2	Moderate	
	0 – 100 m	1	Low	Bengkulu City Regional Regulation No.4 of 2012 concerning Bengkulu City Regional Spatial Planning 2012 - 2032

occur. Fifth, there is no development of the center of economic activity during the simulation year that was conducted.

3. Result And Discussion

Development of Built-up Area in Bengkulu City

In this study, the built-up area was seen based on land cover changes within 10 years adjusted to population data that used Landsat 4-5 TM C1 Level-1 images dated May 26, 2007, Landsat 4-5 TM C1 Level-1 dated October 13, 2011 and Landsat Image 8 OLI / TIRS C1 Level-1 dated June 22, 2017. In general, the built-up area was increased every year in each subdistrict and significantly spread on southern part of Bengkulu City. The highest changes occurred in 2011 to 2017 in Selebar Subdistrict, which about 439.19 ha of agricultural land and non-agricultural land to become built-up area (Figure 2). While the lowest area of land cover changes in 2007 to 2017 was in Teluk Segara Subdistrict.

Simulation and Model Accuracy

The area in this model is the area that can be used to develop built-up area, which is the total area of Bengkulu City except the water area (1,054.76 Ha) and protected area (2,379.75 Ha) according to the Spatial Plan of Bengkulu City (RTRW) in 2012 – 2032, so the area of Bengkulu City used in this model is 15.256, 96 Ha. After simulating the model of the relationship between population growth and land availability with the Stock Flow Diagram (Figure 3).

Then the Dimensional Consistency Analysis has the shape of variable and dimension that got from Stock and Flow Diagram (SFD) of land availability and built-up area model as follows:

1. Constanta Crude Birth Rate = 3,4<<%/year>>
2. Constanta Crude Death Rate = 0,8<<%/year>>
3. Constanta Crude Migration out Rate = 1,6<<%/year>>
4. Constanta Crude Migration in Rate = 1,9<<%/year>>
5. Aux Land Carrying Capacity = 'Availability Land'/'Land Demand'

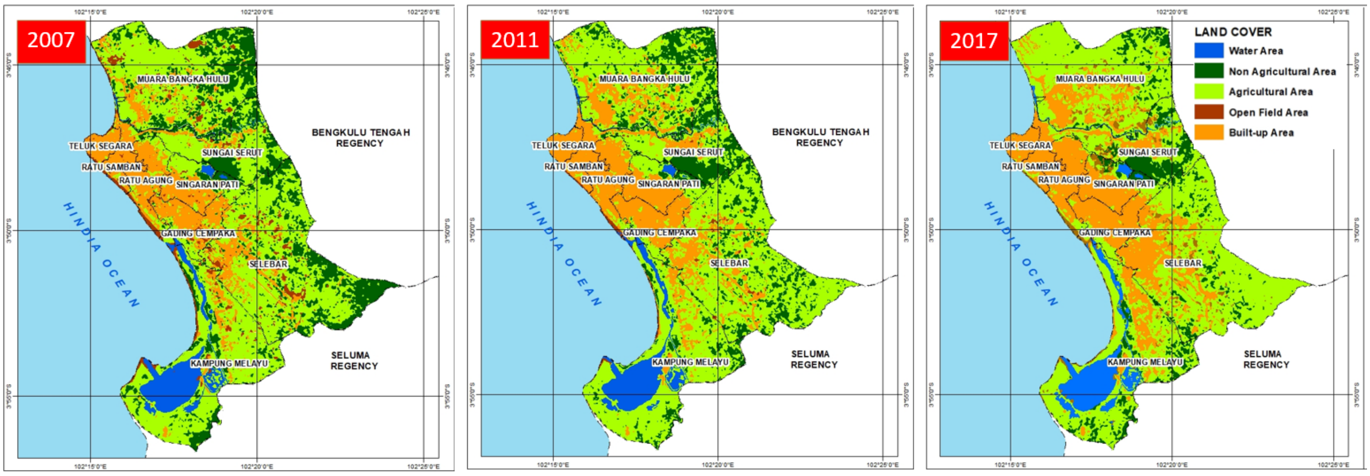

Figure 2. Land Cover Changes in 2007, 2011 and 2017 in Bengkulu City

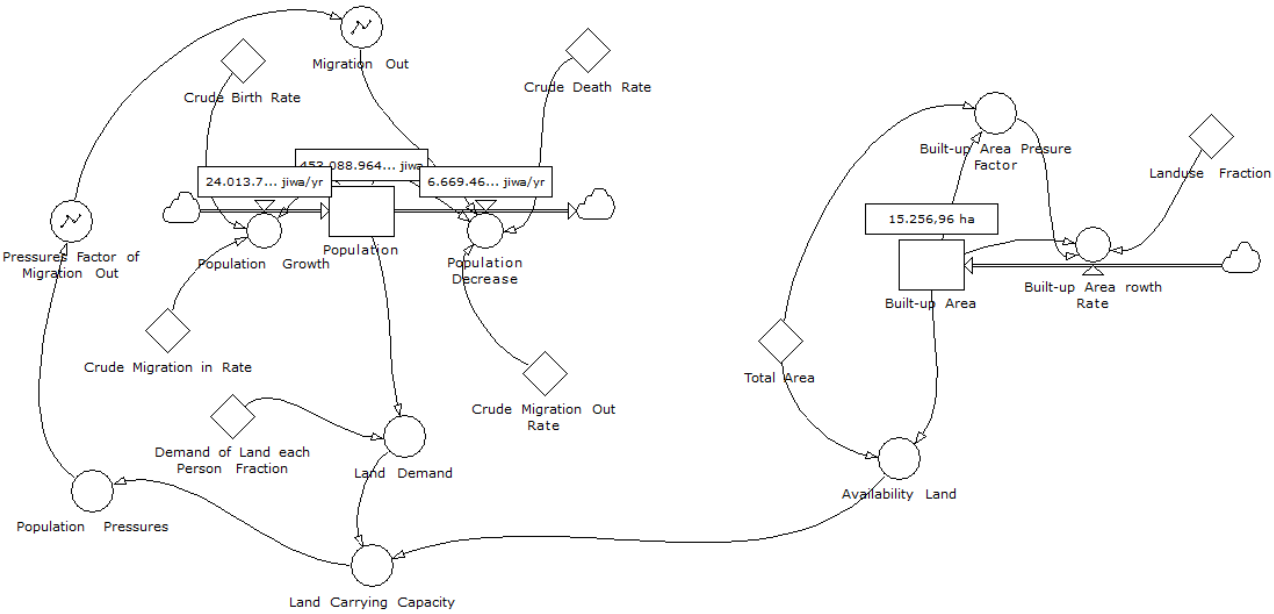

Figure 3. Stock and Flow Diagram (SFD) System Dynamics Model for Land Availability and Built-up Area

6. Aux Migration Out = GRAPH('Migration out Pressure Factor',0,1,{0.23,0.42,0.6,0.94,1.23,1.7,2.16,2.65,3.42,4.06,5// in:0;Max:5//})
7. Aux Pressures Factor of Migration Out = GRAPH ('Population Pressures',0,1, {0,0,0.045,0.09,0.116,0.17,0.245,0.32,0.45,0.626,1// Min:0;Max:1//})
8. Aux Built-up Area Pressure Factor = 'Built-up Area'/'Total Area'
9. Aux Demand of Land each Person Fraction = 0,25<<ha/ Person>>
10. Constanta Land use Fraction = 9,09<<%/year >>
11. Aux Land Demand = Population*' Demand of Land each Person Fraction '
12. Aux Availability Land = 'Total Area'-'Built-up Area'
13. Flow Built-up Area Growth Rate = ('Built-up Area'*'Land use Fraction')*(1-'Built-up Area Pressure Factor')
14. Constanta Total Area = 15256,96<<ha>>
15. Stock Population = 270079<<Person>>
16. Flow Population Decrease = (Population*'Crude Death Rate')+('Crude Migration out Rate'*'Migration Out'*Population)
17. Flow Population Growth = (Population*'Crude Birth Rate')+(Population*'Crude Migration in Rate')
18. Aux Population Pressures= 1/'Land Carrying Capacity
19. stock Built-up Area = 3513,629<<ha>>

Flow Diagram (SFD) of land availability and built-up area model as follows it is necessary to test the accuracy of the simulation model to knew validity level of the model. Accuracy test was done by using a simple error test, namely Average Mean Error (AME) between the built-up area and the population growth variable. The accuracy of the testing period was adjusted to the actual data from 2007 to 2017. In the population subsystem, the actual data of the population in the last 10 years has an average of 320,039 people, this number did not show much difference with the average of the simulation results which was 332,510 people. Based on the actual and simulation data, the results of the Average Mean Error (AME) was 3.89% so the model was valid and can be used for further analysis. In the built-up area subsystem, the actual data showed of 4,524.23 Ha, while the average simulation results showed not much differences, which was 4,933.55 Ha. The results of the AME was 0,04%, it was valid and can be used for further analysis.

Prediction of Population Growth and Land Availability

We illustrate the relationship between population growth and land availability in Figure 4, where there is a meeting point between built-up area lines and land availability in 2020 (green graph and red graph). In that year, the available land will be built up to 50% of total area (7,528.40 Ha) with a population of 450,058 people. Table 2 also shows that in 2025 the built-up area will increase to 60% (9,238.07 Ha). These numbers are almost similar to the carrying capacity, where the maximum score for built-up area is 70% of the total area. The figure of 70% will be achieved when the built-up area is 10,794.93 Ha, the population is 659,556 people and the availability of land is 4,462.02 Ha. However, in the discussion part of this paper, the built-up area percentage will be assessed up to 80% and 90% to describe the length of the

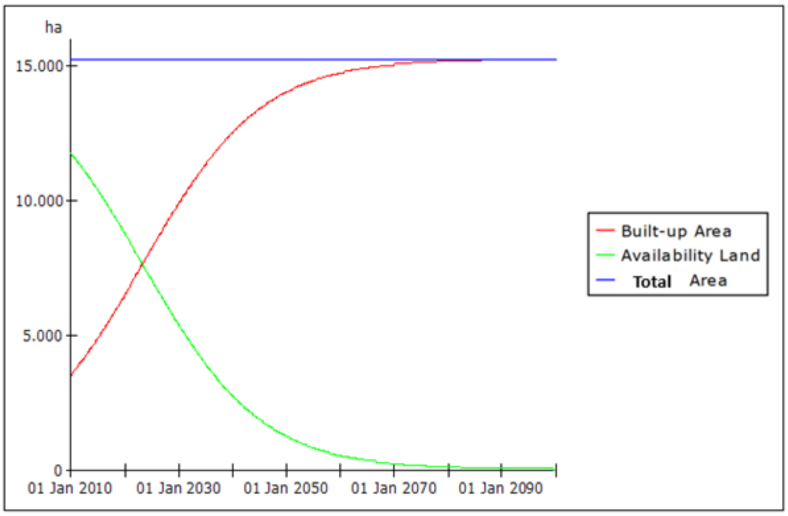

Figure 4. Graph of the Relationship between Total Area, Built Area, and Land Availability until 2100

Table 2. Prediction Results of Dynamic System Simulation on Population, Built-in Area, and Land Availability in 2020, 2025, 2030, 2036 and 2045

Year	Population (people)	Built-up Area (Ha)	Percentage (%)	Land Availability (Ha)
2020	450.058	7.528,40	50%	7.728,56
2025	544.829	9.238,07	60%	6.018,88
2030	659.556	10.794,93	70%	4.462,02
2036	829.548	12.310,74	80%	2.946,22
2045	1.170.110	13.802,59	90%	1.454,36

built-up area spatially, which will slow down and become a sigmoid and then show that the built-up area has crossed the threshold.

Suitability of Built-up Area for Spatial Dynamics

From the scoring of five variables which were physical variables (slope, distance from the river and distance from the protected area) and accessibility (distance from the road and distance from the centre of economic activity) that have been used, the suitability of the built up area can be determined based on Table 1 in Methods. The less suitable area was assumed as the second choice to develop the built-up area, while the unsuitable area are assumed as the avoided area because it is located in the limitation area such as protected area and water area. Based on Figure 5, in general, almost all sub-districts have high percentage for suitable built -up area and low percentage for unsuitable built up area. Regions with the highest proportion of suitable built up area is located in Teluk Segara Subdistrict with 98.23% of the total sub-district. The low percentage of suitable built up area is located in Kampung Melayu District, Sungai Serut and Selebar District.

The Spatial Dynamics Model of Population Growth and Land Availability in 2020

In general, the results of the simulation model in 2020 shows that the built up area will increase significantly up to 50% of the total study area. In 2020 the population will also increase to 450,058 people. Then in 2020, the length of the built up area will increase to 7,528.40 Ha so that the

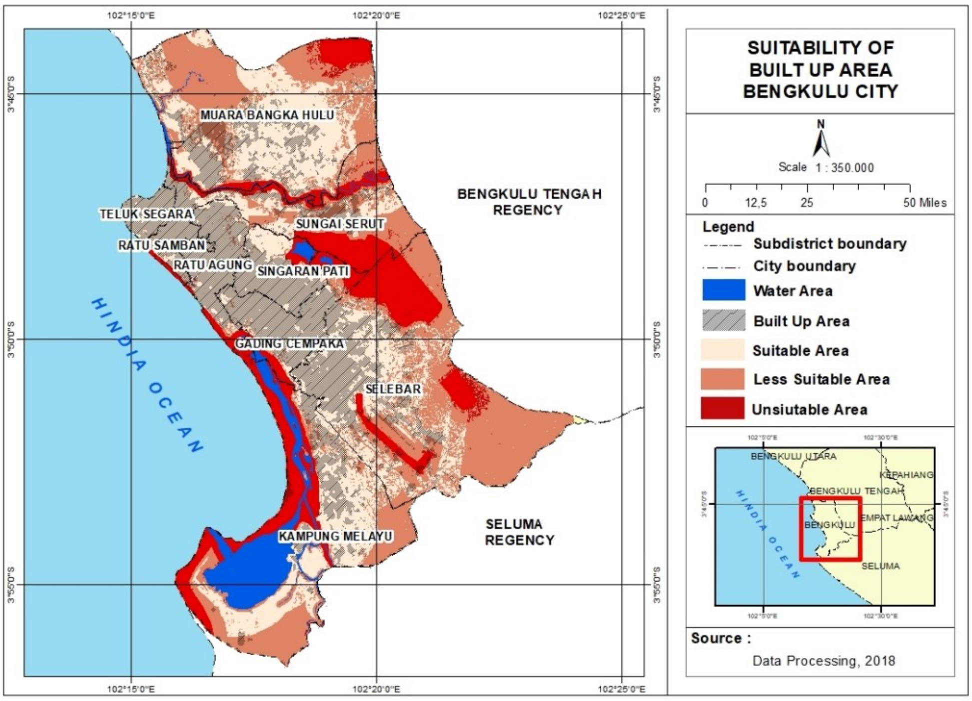

Figure 5. Suitability of Built up Area in Bengkulu City

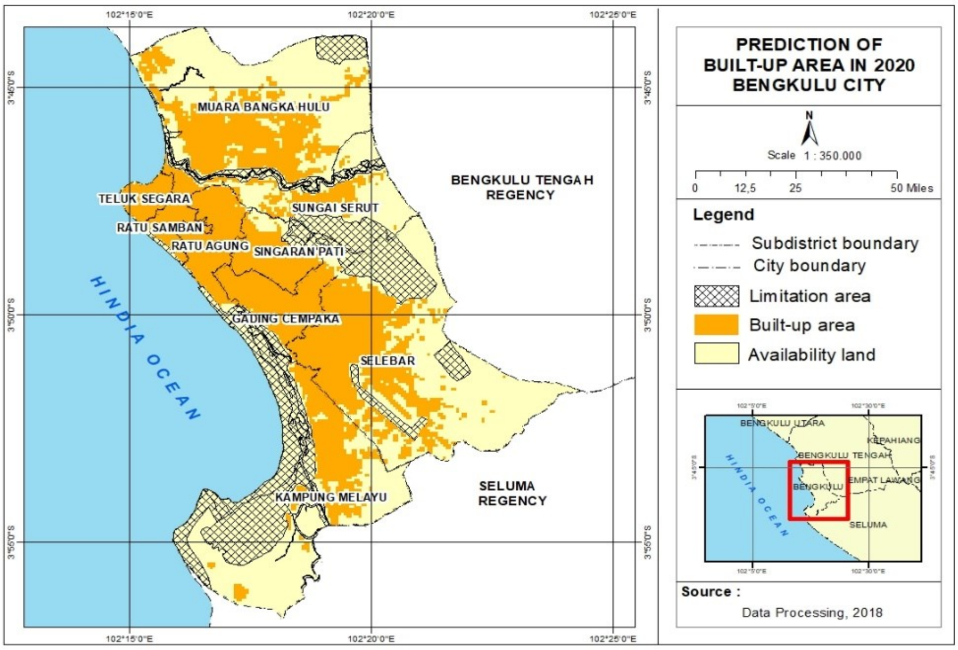

Figure 6. Map Prediction of Built up Area in Bengkulu City 2020

remaining available land is 7728.56 Ha. Based on Figure 6. the development area is still located in the area that suitable for built-up area. The development of the new built up area will be located near the existing suitable built up area. These area are located in the northwest and central part of Bengkulu City, such as Teluk Segara, Ratu Agung, Ratu Samban, Singaran Pati and Gading Cempaka Subdistrict so that in 2020 the built-up area will spread to the eastern and northern parts of Bengkulu City, which have suitable area such as Selebar and Muara Bangka Hulu Subdistrict.

The Spatial Dynamics Model of Population Growth and Land Availability in 2025

The results of the model in 2025 show the built-up area will increase up to 60% of the total area. In 2025 the population will increase to 544,828 people, the length of the built-up area will increase to 9,238.07 Ha, so the land availability is 6,018.88 Ha. The development of built-up area in 2025 have the same pattern as the development in 2020 where the development area is still located in the area that suitable for built-up area, but in 2025 the area will expand to the southern and northern parts of the Bengkulu city such as Kampung Melayu and Muara Bangka Hulu Subdistrict (Figure 7).

The Spatial Dynamics Model of Population Growth and Land Availability in 2030

The built-up area in 2030 will increase up to 70% of the total area and the built-up development area has become denser and uncontrolled its maximum capacity. In 2030 the population will increase to 659,556 people and the built-up area also increase to 10,794.94 Ha, so the land availability in that year is 4,462.02 Ha. Based on Figure 8, the built-up development area in 2030 has a disticnt pattern with the

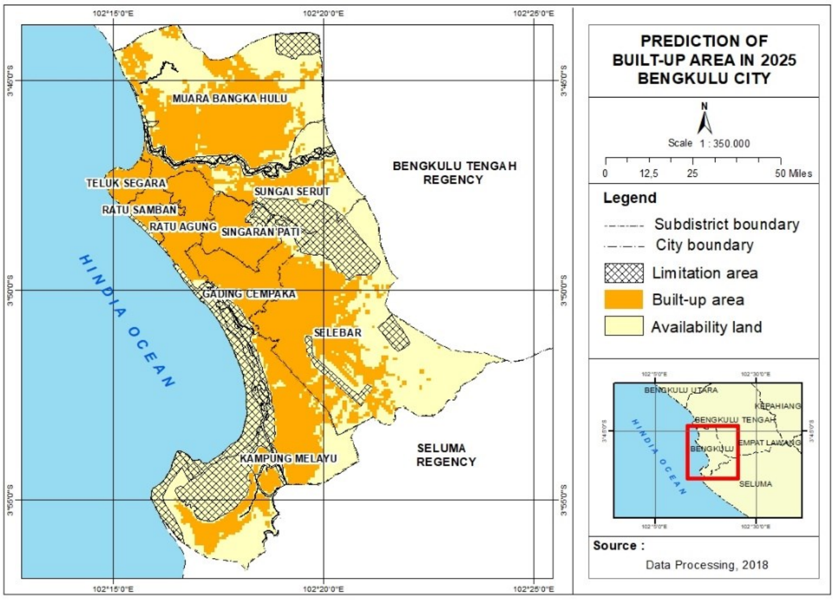

Figure 7. Prediction Map of Built up Area in Bengkulu City in 2025

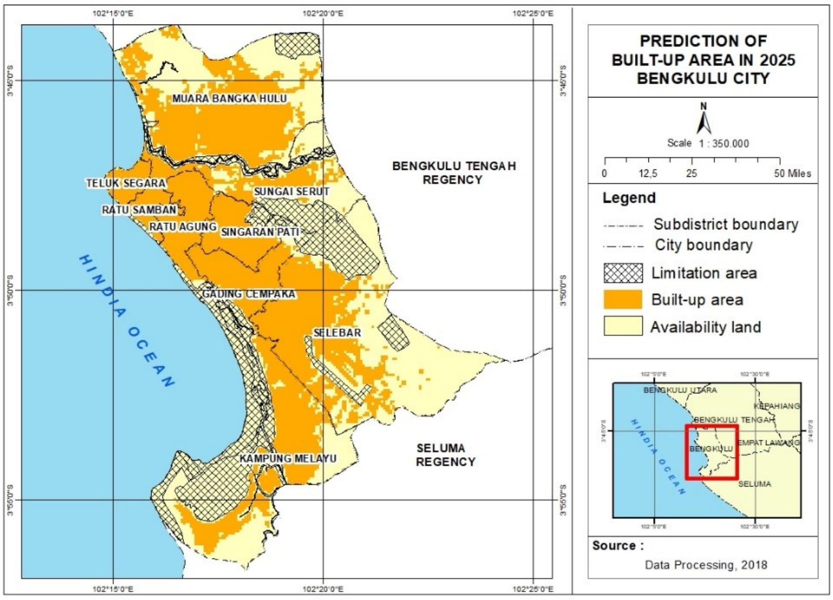

Figure 8. Prediction Map of Built up Area in Bengkulu City 2030

development in 2025.

In 2030 the development will spread on the less suitable area because the suitable area will be packed. This development will move from the northwest and central part of Bengkulu City such as Teluk Segara, Ratu Agung, Ratu Samban, Singaran Pati and Gading Cempaka, then spread to the north, southeast and south of Bengkulu City which has a small area for the suitable area and then spread into less suitable area such as Muara Bangka Hulu, Selebar and Kampung Melayu Subdistrict.

The Spatial Dynamics Model of Population Growth and Land Availability in 2036

The results of the model in 2036 show that the built-up area will increase up to 80% of the total area where the built-up area becomes denser and more uncontrolled or exceeded its maximum capacity. In 2036 the population will increase to 829.549 people and the built-up area also increase to 12.310,74 Ha, so the land availability in that year is 2946,22 Ha. Figure 9 show the built-up development area in 2036 has a similar pattern to built-up area in 2030, which is spread to less suitable area because the suitable area will be packed. In 2036 the built-up prediction area spread evenly in the central, northern, southeast and southern parts of Bengkulu City such as in the Serut River, Muara Bangka Hulu, Selebar and Kampung Melayu Subdstrict.

The Spatial Dynamics Model of Population Growth and Land Availability in 2045

The built-up area in 2045 will increase up to 90% of the total area, or in other words the area is almost packed with built up area. In 2036 the population will increase to

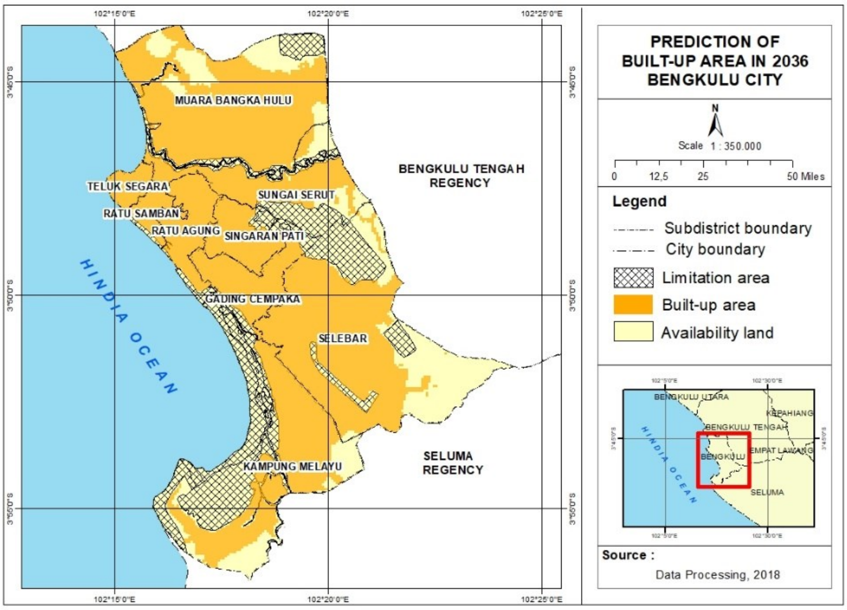

Figure 9. Map Prediction of Built up Area in Bengkulu City 2036

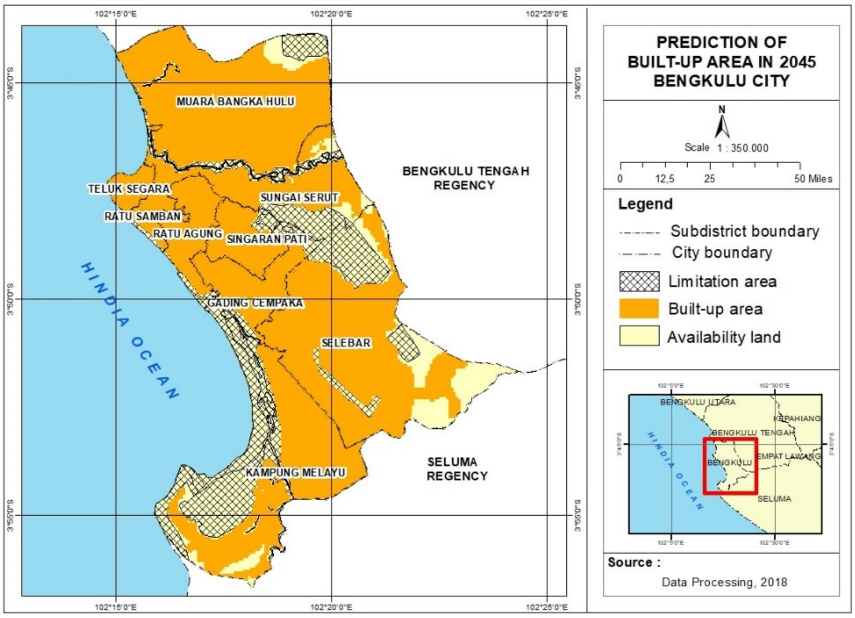

Figure 10. Map Prediction of Land Built up Area in Bengkulu City 2045

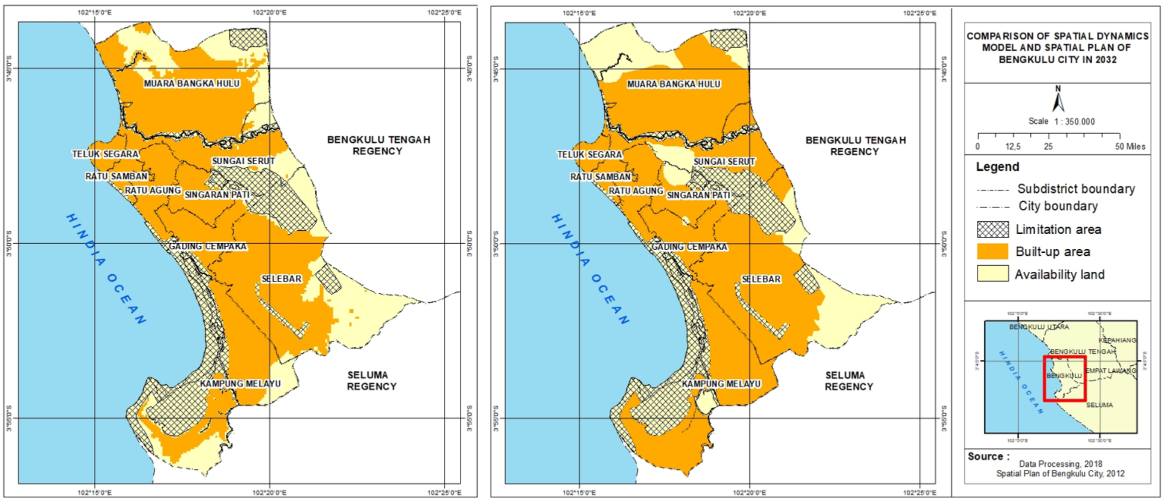

Figure 11. Built-up Area on Spatial Dynamics Model (left) and Spatial Plan of Bengkulu City in 2032 (right)

1.170.110 people and the built-up area also increase to 13.802,59 Ha, so the land availability is only 1.454,36 Ha. Based on Figure 10, even though 90% part of the entire area is a built-up area, there is no built-up area in the less suitable area. The built-up area in 2045 will disperse in the northern, southern, southeast and east parts of Bengkulu City which have a less suitable area for built-up area development such as Muara Bangka Hulu, Kampung Melayu, Selebar and Sungai Serut Subdistrict.

The Comparison of Spatial Dynamics Model in 2032 and Spatial Plan of Bengkulu City in 2032

Based on physical and accessibility variables in the suitability analysis that used in the spatial dynamics model analysis, it shows that Bengkulu City is suitable for built-up area in the western part, but the eastward part is less suitable for built-up area. It will spread based on the spatial dynamics model for 2032 to the north, east and south part of Bengkulu City is same to the Spatial Plan of Bengkulu City 2032 (Figure 11).

The biggest difference was in Kampung Melayu Subdistrict. In spatial dynamics model, the built-up will fulfill about three-quarter of the area, while in a spatial plan of Bengkulu City, the built-up area will fulfill almost the entire area. This happened because the spatial dynamics model uses suitability analysis of built-up area where there was less suitable area for built-up area in Kampung Melayu, contrast to the spatial plan of Bengkulu City where the suitability factors aren't the main factor. Besides, there's an enormous difference between Selebar and Singaran Pati Subdistrict. In the spatial dynamics model, the protected is not suitable for the built-up area development, while in a spatial plan of Bengkulu City the built-up area is too close to the protected area. Another difference is found between the Sungai Serut and Singaran Pati Subdistrict where the spatial dynamics model is limited to suitability of built-up area. While in the Spatial Plan of Bengkulu City, it designated some areas in these two sub-districts as agricultural land.

4. Conclusion

The spatial dynamics model shows that the built-up area will continue to increase, meet the suitable capacity of the built-up area and develop in a less suitable area for the built-up area. Bengkulu City is predicted to have 50% of built-up area in 2020, 60% of built-up area in 2025 and reach the environmental carrying capacity threshold up to 70% of built -up area in 2030. Built-up area will exceed the threshold up to 80% in 2036 and 90% in 2045. The results of the study show that there are difference between the spatial dynamics model of built-up area in 2032 and spatial plan of Bengkulu City in 2032 because spatial plan of Bengkulu City in 2032 does not consider suitability of built-up area and there is development plans close to the protected area. The controlling population growth and appropriate land use planning needs to conduct so the selected region can be developed according to the carrying capacity. Appropriate land use should conduct from now on, so the built-up area will not develop into protected areas and can be developed according to the current spatial planning system.

Acknowledgement

We would like to express our deep gratitude to Local Development Planning Agency of Bengkulu City, Central Bureau of Statistics of Bengkulu City and The Indonesian Geospatial Information Agency for helped us to get some data and recommendation which we used in this research.

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