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Spatial dynamics model for sustainability landscape in Cimandiri Estuary, West Java, Indonesia

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Abstract

Population in Estuary Cimandiri area and the Pelabuhanratu Town increase continuously, which will cause an occurrence of land use changes from open space to built-up area. Due to the need of built up area, while the existing land area is very limited, so the shortage land will occur in the future. In this context, spatial dynamic model based on a combination between system dynamics and Geographic Information System (GIS) has to be elaborated for land availability model in Cimandiri Estuary, West Java. Thus, the existing surface can be a sustainability landscape. Population growth projection has an exponential growth pattern. Built-up area variable has a sigmoid pattern, which means that the land in estuarine area will be occupied for built-up activities in the future. Land availability variable has a decay pattern, which means that the available land will be run out to be used up by human settlement. The relationship between population growth and land availability will be contradictory. The intervention effect 60% ratio land restriction of built-up area will delay the development of built-up area, and after those delays it will remain constant. The projection of populations growth is implemented through projection development of built-up area which adapted by the landscape to be a sustainability landscape.

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Keywords: estuary; availability land; built-up area; system dynamics; spatial dynamics.

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1. Introduction

Planning in a growth region usually use to the economic factor forward compared to that of the environmental balance factor, including ecosystem balance. It cannot be separated from the landscape characteristics. According to Guneroglu *et al.* (2015), the landscape characteristics of coastal area are the typology identification of landscape in various scales (geographic) for protecting the existing landscape and spatial in rural and urban area, where degradation in coastal area is a real phenomenon that has to be evaluated in a management planning of coastal area including estuary. The estuary management cannot be separated from the existing landscape. So that it needs a sustainable landscape.

Sustainable landscape is an example of key concept and priority in the research of the relations between landscape, ecosystems and human prosperity (Mussachio, 2013). Landscape in estuary cannot be separated from coastal (terrestrial) and coast (sea). It makes management of estuary area be more precisely. Landscape approach, is a broader application in an attempt to adjust the contradiction between the different interests in land and water resources. Landscape approach has considerable calculation in solving competition for land demand (Sayer *et al.*, 2015). Bohnet and Bailin (2015) state that the landscape is a description and as a results of human activities, the different ways that involve in the natural, cultural, social, perceptual, aesthetic components, among geological factors, soils, climate, flora, fauna, land use, settlement, religion, memory, mental, sounds, smells, colours, patterns, and shapes which interact and understanding among communities.

Estuary area is a region that is extremely important, both in terms of physical and terrestrial ecosystems and waters. Most of estuaries area is used phisically for human activities (factories, buildings, ports, etc), because land around the estuary was a relative rich of minerals and easy access for economic and business base. In the estuary aquatic ecosystems, many fish populations that breed to raise their population because estuary area is receive so many organic materials continuously from the stream and sufficient sunlight that illuminates the waters (Dyer, 1997).

Population in the estuary area of Cimandiri which increase continuously will cause the occurrence of land use change from open space to built-up area. The needs of built-up area increasing continuously while the existing land is very limited and will cause land shortage in estuary of Cimandiri. Eventually, it will causing the inadequate of land carrying capacity. The lack of land carrying capacity causing population pressures, environmental carrying capacity is not adequate anymore. It will be an impact on the damage of the existing landscape. Clarke *et al.* (2014) explained that at this time, the comprehension of estuary is very limited especially on populations around or which is utilizing and decision maker (government).

According to the discussion above, it is necessary to a spatial dynamic model for a sustainable landscape on estuary area. This model can be used for input to spatial planning in the estuary area which is environmental oriented.

In this case, which is used as a model is Cimandiri Estuary area that consist of two subdistricts (Pelabuhanratu and Simpenan), with Pelabuhanratu Town as the capital city of Sukabumi District, West Java Province. The administrative region that included in the estuary area is Pelabuhanratu Village, Jayanti Village, and Citarik Village at Pelabuhanratu Subdistrict. Loji Village and Cidadap Village at Simpenan Subdistrict.

According to **Table 1**, data from 2008 to 2014 showing the growth of population and built-up area, however, the population growth will increase continuously in line with economic development of Cimandiri Estuary Area. If the needs for land are increasing and the available land are decreasing, then will occur the shortage land, eventually, also occur the populations pressure which is causes the decreasing of land carrying capacity and the damage of landscape.

Table 1. The amount of Population and Built-up Area in Cimandiri Estuary Area

No.	Years	Population Amount (inhabitants)			Built-up Area (ha)		
		Pelabuhanratu *)	Simpenan *)	Summary	Pelabuhanratu *)	Simpenan *)	Summary
1	2008	93,679	48,048	141,727	308.23	49.56	357.79
2	2009	96,867	48,054	144,921	346.14	62.81	408.95
3	2010	99,842	48,281	148,123	375.89	93.35	469.24
4	2011	101,812	51,922	153,734	394.21	102.72	496.93
5	2012	103,005	53,519	156,524	411.56	111.51	523.07

6	2013	105,574	55,853	161,427	452.49	124.72	577.21
7	2014	107,811	57,900	165,711	505.21	143.83	649.04

*) Pelabuhanratu Subdistrict (Pelabuhanratu, Jayanti, and Citarik Village). Simpenan Subdistrict (Loji and Cidadap Village).

The application of spatial dynamic model is going to look at the availability of land and the built-up area in the future, so that the carrying capacity of the land can be met and the sustainable landscape can be maintained.

The purpose of modelling on this paper:

1. to analyze the relationship between built-up area and land availability of environmental oriented estuary area with system dynamics.
2. to intervent with the existing land restrictions, so the occurrence of built-up area will be appropriate with its carrying capacity to support the analyzing on spatial dynamic.
3. to assess the landscape characteristics of Cimandiri Estuary
4. to analyze the suitability of built-up area.

2. Methods

Landscape has a spatial properties with a certain hierarchy where every landscape consists of many different types of parts up on the smaller scale. The sustainable landscape is not only the interaction among the components of environmental, economic and social, but also by spatial configuration and cross-scale relationships (Wu, 2012). One application of Wu, 2012 is the application of spatial dynamic model.

Spatial dynamic is the result of a spatial model (GIS) and system dynamics. System dynamics GIS-based is the right method to describe the relationship and dependence between the population, built-up area and land carrying capacity in the future. System dynamics is also able to describe the behavior of the system when the intervention of the system.

Variation assesment spatially at different combinations of biodiversity and threat indicators allow us to set differential priorities for biodiversity conservation. Results of the study with spatial assesment can show a level of vulnerability for setting priorities to conservation planning in a region (Ruppert *et al.*, 2012). The variables used in the system dynamics, there are nineteen variables, such as population, built-up area, land needs, land availability. Data processing and analysis using the system dynamics software, whereas the spatial with its GIS using ArcGIS 9.1 software. The variable in spatial analysis is settlement development variable and settlement suitability variable that consist of variables such as elevation, slope, coast corridor line (100 meters), river corridor line (25 meters), road corridor line (25 meters), types of rocks (geology) and landuse. Regional scenario in the development of availability area with free simulation without take notice formerly to the existing spatial planning with driving factor variable (distance to the road and to the town center).

According to the explanation above, it seem that the model showed a causality relation into the causal loop diagram. Causal loop diagram is a connected arrow, where the upper arrow is the causes and the bottom arrow is the effects (Muhammadi *et al.* 2001). The system dynamics step create the causal loop diagram is determined by former with model used and assumption variable. The system dynamics can predict population growth within a estuary area which its limited land. This method can be simulated with spatial concept, by looking at to time and direction of bulit-up area development. In his research, Tian *et al.* (2014) state that the relationship between rural and urban was base on the restriction of rural and urban development that have an adjacent location. That case also will maintain the condition of rural-urban ecology from its rural-urban development dynamic.

The GIS analysis used overlay analysis with its result such as very suitable area, suitable area, and not suitable area for built-up area (settlement). This spatial analysis combined with system dynamics analysis result on the development of built-up area (settlement) with the existing availability land.

3. Result and Discussions

3.1. System Dynamics Model

System Thinking, System Practice (STSP) can be used for system dynamics as an attempt to simplifying the rules of natural science, and the results were succesfully simplifying the existing system of natural phenomena

(Checkland, 1999), also system dynamics can be defined as a method that is used for learning the system (Soesilo dan Karuniasa, 2014). According to the background on modelling issues as a story, a model variable and an assumption, then made a Causal Loop Diagram (CLD) from the model of land availability and built-up area that showed on **Figure 1.**

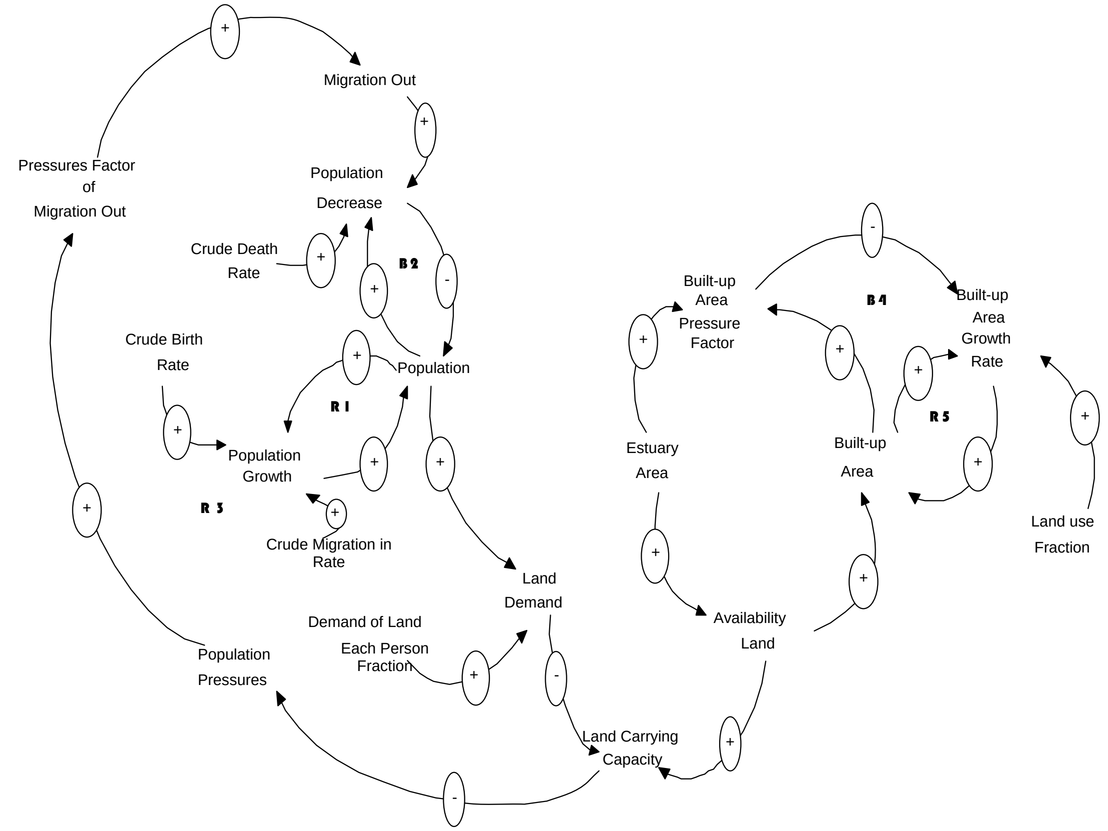

Fig. 1**.** The Causal Loop Diagram of the Land Availability and Built-up Area Model (Supriatna, 2014).

According to **Figure 1.** the Causal Loop Diagram of the land availability and built-up area model consist of five feedbacks, that is two negative feedbacks and three positive feedbacks.

1) R1: Population → Population Growth → Population
Population amount increase, then the population growth will increase. Population growth increase, then the population amount will also increase.

2) B2: Population → Population Decrease → Population
Population amount increase, then the mortality (population decrease) will increase. Conversely, if mortality (population decrease) increase, then the population amount will decrease.

3) R3: Population → Land Demand → Land Carrying Capacity → Population Pressures → Pressures Factor of Migration Out→ Migration Out → Population Decrease → Population
Population amount increase, then the land demand will also increase. Land demand decrease, then the land carrying capacity decrease. Land carrying capacity decrease, then the population pressures increasing. Population pressures increase, then the pressures factor of migration out will increase. Migration out (emigration) increase will causing the population decrease which population amount will decrease eventually.

4) B4: Built-up Area → Built-up Pressure Factor → Built-up Area Growth Rate → Built-up Area
Built-up area increasingly widespread, then the built-up area pressure factor also increasingly widespread, so the built-up area growth rate increasingly fast. The built-up area increasingly widespread, eventually.

5) R5: Built-up Area → Built-up Area Growth Rate → Built-up Area
Built-up area increasingly widespread causing built-up area growth rate increasingly fast. The built-up area

increasingly widespread, eventually.

According to Causal Loop Diagram (CLD), system dynamics model for land availability and built-up area, then the next is made Stock and Flow Diagram (SFD), that is showed by **Figure 2.**

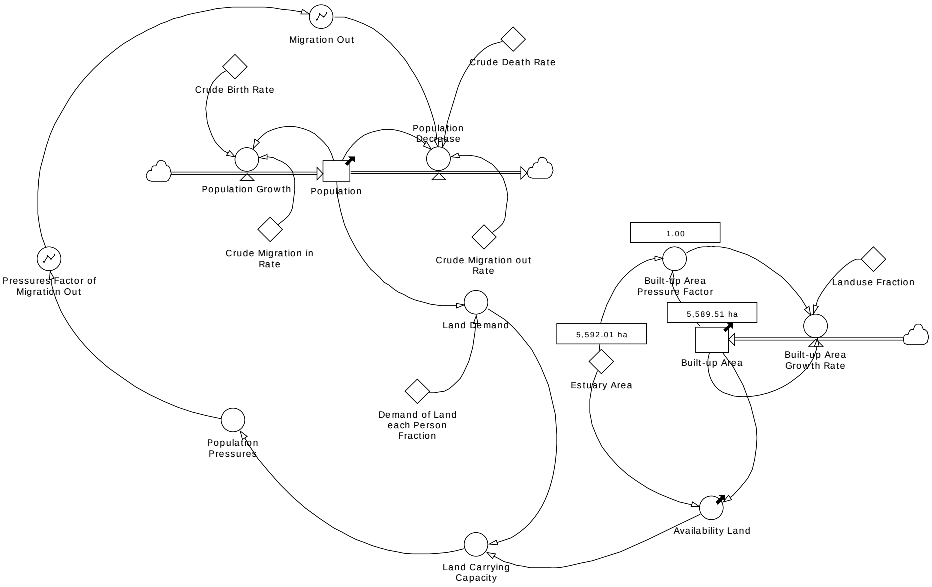

Fig. 2**.** Stock and Flow Diagram (SFD) System Dynamics Model for Land Availability and Built-up Area

4.2. Dimensional Consistency Analysis

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

1. stock Population = 69725<<Person>>
2. stock Built-up Area = 357.79<<ha>>
3. aux Land Carrying Capacity = 'Availability Land'/'Land Demand'
4. aux Availability Land = 'Estuary Area'-'Built-up Area'
5. aux Built-up Area Pressure Factor = 'Built-up Area'/'Estuary Area'
6. flow Built-up Area Growth Rate = ('Built-up Area'*'Land use Fraction')*(1-'Built-up Area Pressure Factor')
7. flow Population Growth = (Population*'Crude Birth Rate')+(Population*'Crude Migration in Rate')
8. flow Population Decrease = (Population*'Crude Death Rate')+('Crude Migration out Rate'*'Migration Out'*Population)
9. Constanta Crude Migration out Rate = 0.009<<%/year>>
10. Constanta Crude Death Rate = 0.02<<%/year>>
11. aux Demand of Land each Person Fraction = 0.0625<<ha/Person>>
12. Constanta Crude Migration in Rate = 0.38<<%/year>>
13. Constanta Crude Birth Rate = 1.65<<%/year>>
14. aux Population Pressures= 1/'Land Carrying Capacity'
15. Constanta Estuary Area = 5592.01<<ha>>
16. Constanta Land use Fraction = 11<<%/year >>
17. 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//Min:0;Max:5//})
18. 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//})

19. aux Land Demand = Population*' Demand of Land each Person Fraction '

Before doing the test of consistency between the model performance and empirical data, then do the consistency of analysis unit or dimensional analyzing (Muhammadi *et al.* 2001). Dimensional analyzing in unit form which is consistent from the Stock and Flow Diagram (SFD) of population development and built-up area model that is equalizing unit on every intersect variable. According to dimensional unit and analyzing then the entire model variable have been consistency with dimension ways.

According to the model variable, there are several assumptions that is used in the model, as follows:

1) Emigration pressure factor (population out), assumpted as one of impact from the population pressure in an area. In this model made non-linier functional approach from the population pressure. The assumption scale is 0-1 (Rina and Rika, 2012), where if the population pressures is high, then emigration pressures factor are also high.
2) Emigration is the movement of people/populations/communities from an origin area to the outside with purpose to work/stay (BPS, 2012). On this model, emigration factor assumpted as an impact from the factor of emigration pressures, then do the approach of non-linier function from the factor of emigration pressures. The assumption scale is 0-5, where if the factor of emigration pressures is high, then the occured emigration is also high.

4.3. Simulation Result

The following Line Graph illustrated the simulation result that shown on **Figure 3** and **4.**

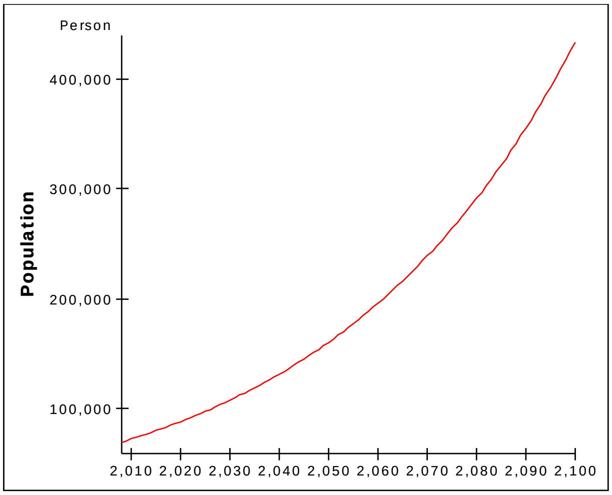

Figure 3a.

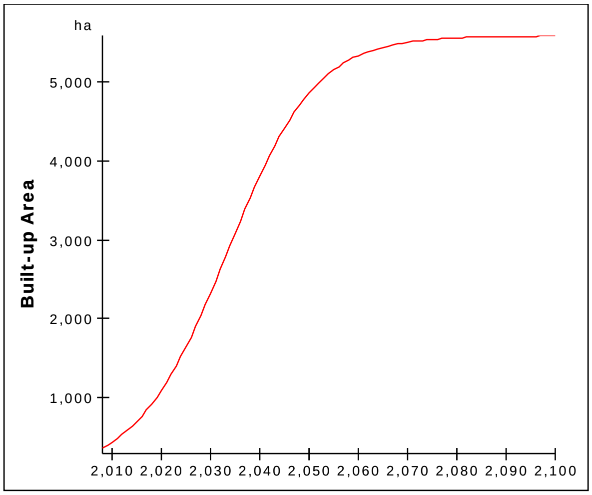

Figure 3b.

On the **Fig. 3a** and **Figure. 3b**, It can be seen that the amount of population have a unique pattern with the exponential growth pattern (behavior). The variable of built-up area also have a unique pattern then horizontal, therefore It has the feature of sigmoid pattern (behavior).

4.4. Model Validation

The validity of model performance to gain confidence that the model performance appropriate with the performance of real system are to compare between the model output and the empirical data, then do the statistical test to see the deviation with Average Mean Error (AME) that is the deviation accepted is <30%, due to many factors that cannot be controled on the model.

The result of validation test for the amount of population variable in 2008-2014 (**Figure 4a**) on this model showing that the AME value is **2.43%** and the model is valid. The average of the amount of population actually in 2008-2014 on Cimandiri Estuary Area are 75,909 inhabitants, while the average of the population amount from the simulation result at the same years are 74,068 inhabitants.

Model validation for variable of built-up area in the model of land availability and the development of population amount from 2008-2014 (**Figure 4b**) showing that the AME value is **13.00%** and the model is valid. The average of built-up area actually in 2008-2014 on Cimandiri Estuary Area are 498.89 ha, while the average of built-up area from the simulation result at the same years are 435.60 ha.

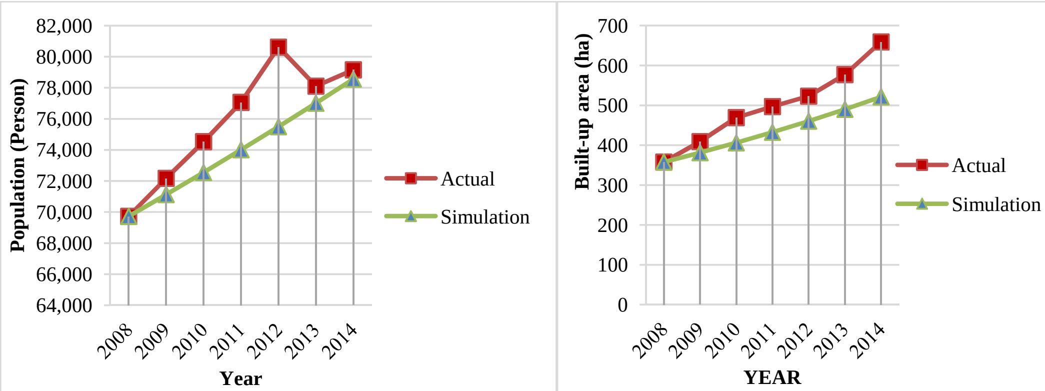

Figure 4a. **Figure 4b.**

Fig. **4a.** The amount of population, **Figure 4b.** The extensive of built-up area in 2008-2014.

4.5. Model Simulation

The analysis of relation model between the land availability and built-up area in Cimandiri Estuary is the part of the system of spatial model on estuary area environmentally based on the valid model, then the next step is doing the model analysis by doing the comparative simulation between the built-up area and the land availability until 2100 by looking for the time period of spatial planning that would be made start from 2020, 2032, 2052 and 2064 (Government of Sukabumi District, 2012).

On the **Figure 5**, showing the development of built-up area on Cimandiri Estuary is tend to rise, while the land availability is tend to fall. The encounter of development line of built-up area and land availability (50% from the extensive of estuary area) will occur in 2033. Then the comparison between the built-up area and the land availability reach the ratio of 70:30 in the years among 2041 and ratio of 80:20 in 2046. By looking to **Figure 5**, the comparison of the built-up area and the land availability will close into the ratio of 100:0 around 2074.

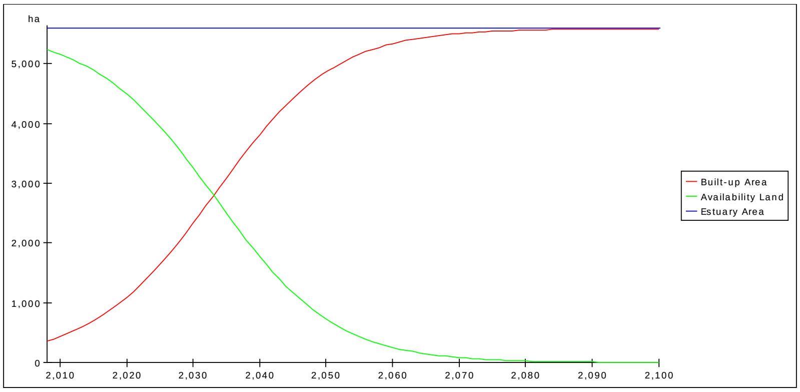

Fig. 5. The relation of the population amount and the built-up area with simulation until 2100.

The time period based on the spatial planning of Sukabumi District, in the exsisting condition of 2015, ratio of the comparison between the built-up area and the land availability is 13:87. The ratio of 2032 is 47:53, then 89:11 in 2052.

Behavior in **Figure 3,4 and 5,** is not accordance with the expectation due to the land in estuary area will exhausted, give an impact on the land carrying capacity that is exhausted will eventually ruin the existing landscape, so the environment is very disturbed in that area. The behavior that is accordance with the expectation has to be intervene. The potential for the kind of local planning in the local decision-making process is depending on individual interest of planner not on the nature systematics (Huber *et al.*, 2012). In the research of Niekerk *et al.* (2013), explain that the stress on watershed affecting the downstream system (estuary area), and will causing the environmental degradation as the effect of the construction directly happen on the functional zona in the estuary. The intervention will be doing on the forward scenario simulation.

4.6. Forward of Scenario Simulation

From the analysis result above, then need a regulation more than the existing spatial planning, that is by making the scenario where comparison between the built-up area and the non built-up area have to be maintained in ratio of 60:40 and the population capacity of decent living for an area with an environmental concept. The first forward scenario simulation is by doing **the structural intervention** with adding the constants variable of open space ratio regulation. The second step is by doing **the functional intervention** with giving the ratio of 60% (60% of built-up area and 40% of open space). These intervention is done based on reference from the existing spatial planning regulation. Basraouia *et al.* (2011) explain that awareness campaign also have been done to promote the sustainable development from the coastal area. Morality contract becoming the main key of these research who creating real involvement from the interest in ensure implementation of the planned in the future with an intervene.

These intervention taken by giving the regulation of open space ratio 60:40, then the land availability will be limited until 60%, while the open space is still 40%. Urban area in the estuary could supporting the land carrying capacity to its population, so the purpose to reach the estuary area with environmental concept can be realized. The result of forward scenario completely showed on **Figure 6** and **Figure 7.**

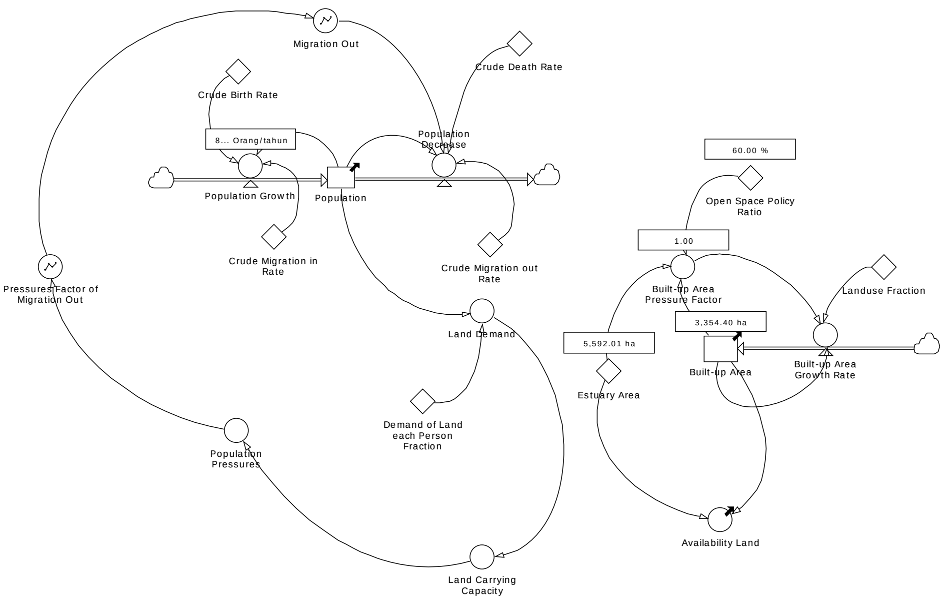

Fig. 6. Stock and Flow Diagram (SFD) on the relationship model between the built-up area and the land availability.

Figure 7, showing encounter of development line of the built-up area and the land availability (or 50% from the extensive of estuary area) will happen in 2042, or nine years longer than the simulation result without the intervention. Time period based on spatial planning of Sukabumi District, on these existing condition of 2015, the comparative ration between the built-up area and the land availability is 13:87. The ratio in 2032 is 37:63 or ten years longer than the simulation result without the intervention, the ratio in 2052 is 57:43 or thirty-two years longer than the simulation result without the intervention. The ratio in 2070 is close into 60:40, then the treatmen of spatial planning in 2070 forward with the application of eco-friendly technology, so the sustainable landscape can be realized.

In the research of Carvalho and Fidelis (2013), propose a reign model that capable to enrich the implementation from the planning of estuary by contributing strongly to the involvement of the whole stakeholder and the user in planning development, enable to conciliation of interest and participation of the decision-making, and in the framework of reign collaborative.

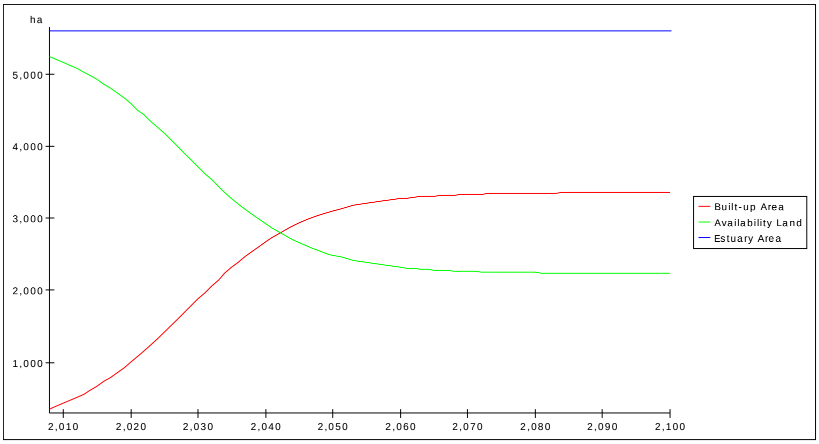

Fig. 7. The relationship between the amount of population and the built-up area with the simulation in 2100.

4.7. Suitability Landscape Area for Settlement

Intervention result between built-up area and population was implemented in space which have spatial pattern, that is to find the suitable area to be built. Suitability of built-up area (settlement) with sustainability landscape rules was made with 3 classification that is, very suitable, suitable, and not suitable which consist of variables are: slope (0-2%, 2-15%, 15-25%, 25-40%, and >40%), coast line corridor (100 meter), stream corridor (25 meter), road corridor (25 meter), types of rocks (geology), and land use. The result of forward scenario completely showed on **Figure 8.**

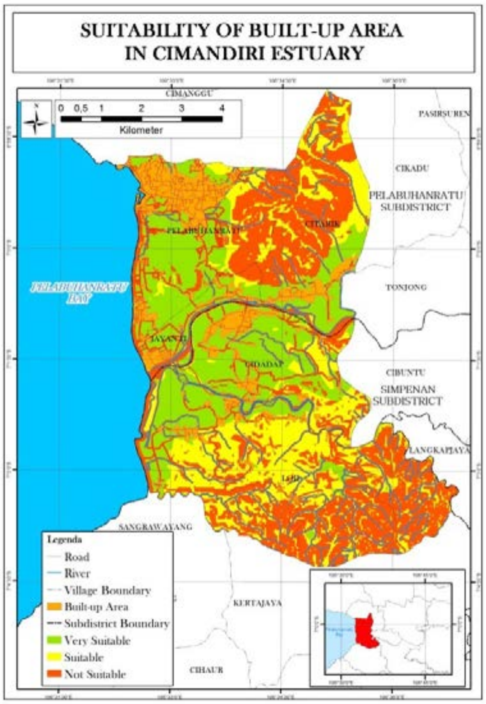

Fig. 8. Suitability of Built-up Area (Settlement) in Cimandiri Estuary

Most of suitability area is located along stream and Cimandiri Estuary, meanwhile most of not-suitability area is located on steep slope and hilly. The suitability area was based on variables which considering physical landscape and existing land use. The number of very suitable area reach about 1,748.29 ha (30%), meanwhile suitable area about 1,552.47 ha (27%), and not-suitable area reach about 2,434.22 ha (42%). The results are suitable with land sustainability multi-criteria (Zolekar & Bhagat, 2015), (Romano *et al*., 2015).

4.8. Discussion

The calculation based on system dynamics prediction between population, built-up area, and availability land with the intervention, and then be implemented into suitability area with spatially (Nguyen *et al.*, 2015). Built-up area map in 2020 (five years from now), 2032 (the end of Regional Spatial Planning for Sukabumi Regency), 2052 (the end of Regional Spatial Planning 2032 – 2052), and 2064 which is all of suitable area and very suitable area has been fully built, were made by considering the distance from city center activities (Pelabuhanratu Town) and road network. This method is used driving factor approach from the used variables (Mondino *et al.*, 2015). **Figure 8b and 8c,** showed the region which is "allowed" to be built in 2020 and 2032

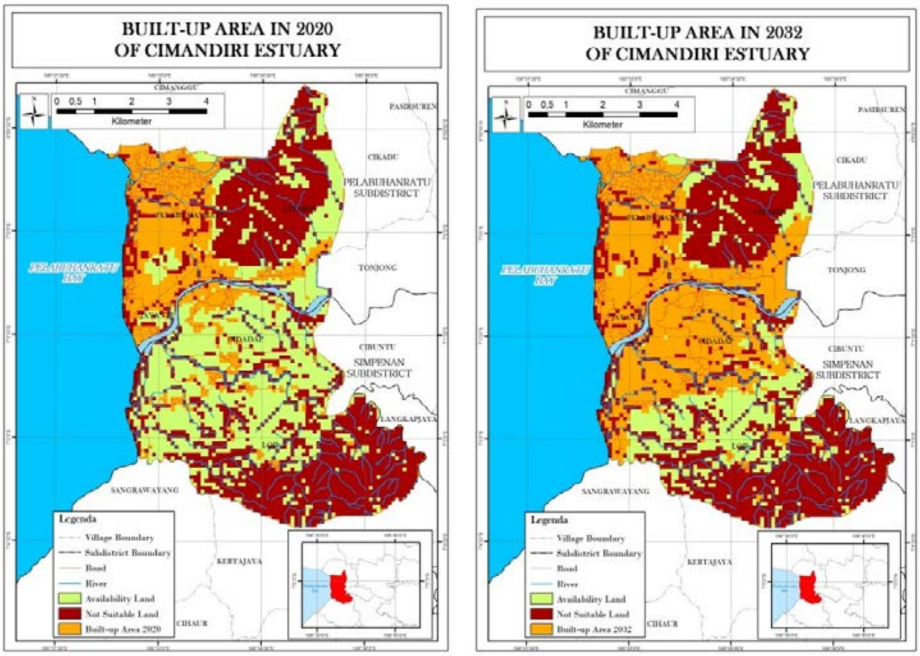

Fig. 9a and 9b**.** The estimate of built-up area growth in 2020 and 2032

The number of suitable area for built-up area based on system dynamics model result in 2020 reach about 2,628.47 ha or about 47.00% from wide total of research region. Most of regions that will be occupied are in Pelabuhanratu Town and Jayanti Village. In 2032, which is Regional Spatial Planning 2012-2032 ended, the region that allowed be built about 1,240.90 ha or 22.19%. Built-up area has been spreaded and almost cover the region around Cimandiri Estuary. Suitability area only left in southern and northern of research region. This model shows the spatial dynamics from built-up area growth over the land availability (Elhorst, 2012).

In 2052, suitable region for settlement only left about 149 ha (2,66%) and spread far from Cimandiri stream. In 2064, the growth of built-up area (settlement) on suitable area will be run out. **Figure 8d and 8e,** showed the region which is "allowed" to be built in 2052 and 2064.

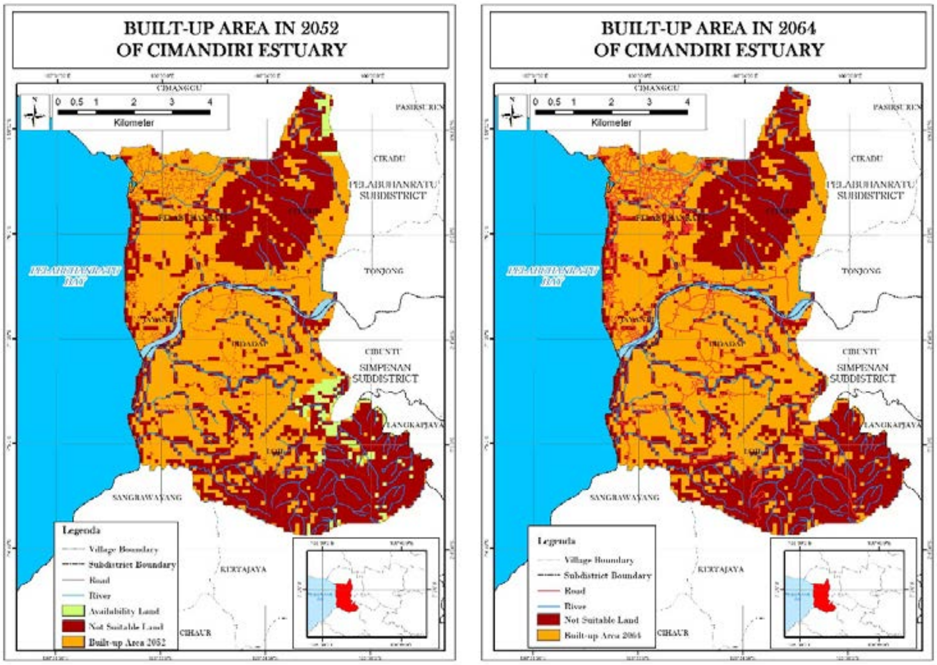

Fig. 10a and 10b. The estimate of built-up area growth in 2052 and 2064.

4. Conclusions

The results of the analysis can be summarized as follows:

a. Built-up area as a variable has a sigmoid pattern, which mean land for built-up area will be run out. Land availability variable have decay pattern, which mean available land will be run out for built-up area. Relation between two variables is contradictory.
b. The number of built-up area will be run out about 60% in 2037, therefore the intervention policy about vertical development or expanded region need to be required.
c. The result of intervention with restriction on land for built-up area about 60% will delay the growth of built-up area, which is finally be stable in 2064.
d. Spatial dynamics produce the growth of settlement consistently with existing landscape, so sustainability of landscape can be preserved.

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