Modeling of Ecologic Urban Green Structure in System Dynamics

Mirza Fuady

Department of Architecture, Faculty of Engineering, Syiah Kuala University, Darussalam
Banda Aceh 23111, Indonesia
Corresponding Author: mirzafuady2@gmail.com

Abstract

Increasing population number while city's land limited, led to the growth of physical development in Banda Aceh is done by converting agricultural land and other open spaces to become built up area. This condition leads to reduction of urban green structure or green open space which will impacted in reducing the role of the ecological functions of green open space in the city. One of the ecological function is CO_2 absorption by vegetation, particularly by number of trees in the urban forest which have high capability in the absorption of CO_2. If decreasing trend of green open space and urban forest keep goes on, while number of energy consumption in the activity of population and numbers of vehicles keep goes up, then it's predicted there will be an increase volume of CO_2 in the city which cannot fully balance by the natural ability of CO_2 absorption by plants, so that will impact in declining health quality in the city of Banda Aceh. This study aims to determine the extent of the urban forest required to absorb CO_2 due to population activities and vehicle numbers in Banda Aceh using system dynamics modeling. The model was built using Powersim 2.5 program, which consisting of interrelated sub systems of population, number of vehicles and the number of plants.
Simulation results from year 2015 to 2025, showed increasing number of population and vehicles, and the needs for the number of plants and urban forest area. Simulation results is made in three scenarios, namely progressive, conservative and sustainable, which may be used as consideration in the arrangement of green open space policy in the city of Banda Aceh.

Keywords : carbon dioxide absorption, urban forest, green open space, powersim

Introduction

After the rehabilitation and reconstruction process of tsunami disaster in 2004, the development of Banda Aceh showed progress in multi sector development where variety of activities grew in the city. As capital city of Aceh province, Banda Aceh serves as center of government activities, center of socio–economic and community services, also trade and industrial. The city has area of approximately 6,136 hectares with growing population of 249,499 people (BPS, 2015). As the population and economic activity growth, varies physical development proceeded rapidly in the city.

One of the most noticeable activities impact due to the rapid physical development of infrastructure in the city of Banda Aceh is decreasing area of urban green open space and increasing gas emissions such as carbon dioxide (CO_2) due to increasing transportation activities and other energy consumption. Increasing levels of CO_2 pollution is not healthy to the city environment and can reduce human health, therefore the concentration of CO_2 in the air should be maintained low. According to Pauliet and Kaliszuk (2005), green open spaces as urban green structures plays important role to support sustainable and healthy urban life.

One way to decrease CO_2 levels in urban areas is to reduce carbon emissions (Dachlan, 2011) and the other way is to build urban forest as part of urban green structures (Li, *et al.*, 2005). Urban forest is the most effective carbon sinks to reduce the increasing carbon emissions in the atmosphere (Irwan, 2005). Photosynthesis process by plants in the urban forest is important process in the carbon cycle and maintaining CO_2 in atmospheric at the same time. This process also plays role in oxygen cycle. To help address natural forest degradation, it is necessary to build urban forest, because of the presence of urban forests is important in neutralizing the effects of air pollution as well as maintaining the quality of the air to keep them clean (Purnomohadi, 2006).

This study aims to determine the extent of the urban forest required to absorb CO_2 due to population activities and vehicle numbers in Banda Aceh using system dynamics modeling. The benefits and practical contribution of this research is that it can be used as consideration for decision makers or policy makers in planning for the sustainable city of Banda Aceh, especially with regard to the presence of green open space and urban forest.

Methods

This research try to analyze and compile urban forest model in Banda Aceh based on aspect of its ecological function of CO_2 absorption in system dynamics approach using Powersim 2.51 software, which is powerful and easy to use. The approach begins with defining problems dynamically, proceeds through mapping and modeling stages, to steps for building confidence in the model and its policy implications. Model compilation of system dynamics of urban forest divided into population sub–model and urban forest CO_2 absorption sub–model. Based on model of system dynamics, it will show the prediction of each variable behavior in simulation period of 2015–2025.

Powersim software will help to see the behavior of the model created. The stages in making a model of a dynamic system are (a) identification of problem behavior, (b) create a computer model, (c) testing and analysis the models. At the time of running the simulation model, the variables will be interconnected to form a system that can mimic the actual conditions. These variables will be illustrated with some of the symbol, which is the main symbol of the flow symbol and always associated with the level symbol. In this study the condition level is urban forest as part of green open space in city of Banda Aceh. Powersim software will work to build a causal loop diagrams, flow chart, make a graph of time which describes the behavior of the model in the time table.

The systems dynamics model of green open space for the city of Banda Aceh is arranged for several purposes, namely:

a) Understanding the processes that occur in the system. Models must be able to describe the mechanisms of the processes that occur in the system in relation to achieve the research objectives.
b) Prediction. Only quantitative models that can make predictions. In this connection, accuracy of the model becomes important.
c) Support decision making. The model is based on the understanding of the process and has the ability to be used as a predictive tool for planners to assist in the decision making process.

Supporting material used in this study as secondary data collected from several government offices such Master plan of Banda Aceh in 2009–2029 by Bappeda, Banda Aceh in figure 2015 by BPS, and document of green open space management from the Department of Sanitation and Beauty of the city of Banda Aceh (DKK, 2014). It also made direct observations of the use of spaces in the city which include recording images as the primary data. Other secondary data also had been collected from a variety of other related literatures.

Results and Discussion

Conceptualization of System Dynamics Model

According Avianto (2006), the conceptualization of the system in system dynamics model aims to provide an overview of the systems studied in the form of a diagram. Diagram is used in the form of a causal loop diagram. This diagram illustrates the relationship between the components in the system which are interrelated.

Basically the city is formed by several components or elements. Components of urban divided into two main components, namely the physical and non–physical components. Urban constituent components are basically linked interconnections, therefore in the process of structuring and management of urban space should need to pay attention to all components and assume that each of these components are interrelated and are in one unified system.

Urban green structure or green open space is one of the components of the city whose existence is strongly influenced by the constituent components of the city, therefore, to optimize the arrangement of urban green open spaces also need to pay attention to all components of the existing urban areas. Presented in Figure 1 circumference causal diagram (causal loop diagram) of urban green open space system of Banda Aceh.

From the diagram it shows growing population will lead to the increasing demand for land. Increasing levels of land requirement will result in increasing accretion of land which will be use as for housing development and others that in the end will have impact on the reduction of urban green open space. Another activity which affects the green open space and its ecological function are domestic and transportation activities on using energy of fossil fuel which require oxygen and produce CO_2. The availability of urban green open space and its ecological function has to be prepared properly to balance the ecosystem and keep the city in health.

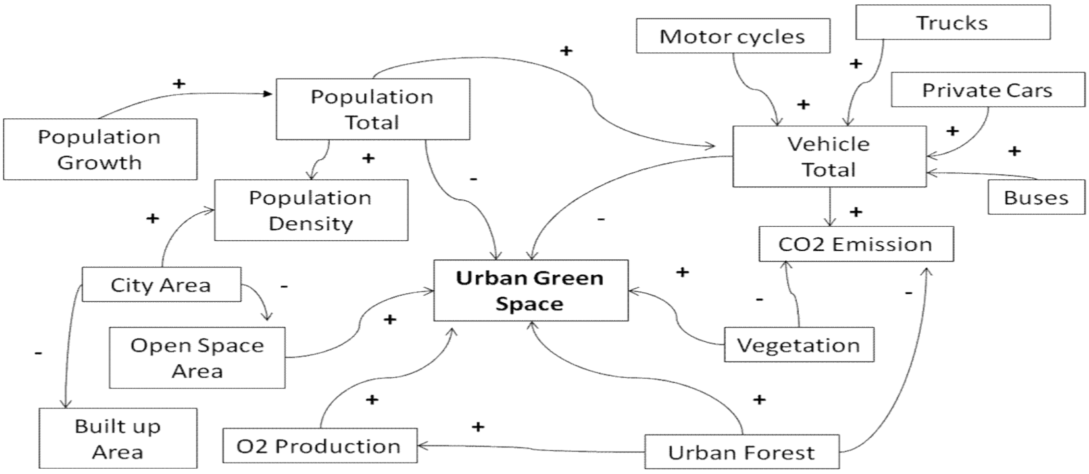

Figure 1. Causal loop diagram of urban green open space system

Model Formulation

Model is built and divided into two sub models which are (a) the population sub–model and (b) urban forest CO_2 absorption sub–model. In the sub–model, it shows the relationship and interconnections between the components that exist. Flow diagram and explanation of the relationship between components in each sub model will be presented in the following pictures.

Population Sub–model

In this model (see Figure 2), the population is considered as a level (accumulation) which can increase and decrease due to certain processes. Technically flow causes an increase or decrease in the level called flow or rate. In this model the process that led to the growth of population due to births and in–migration (immigration) factors, while the rate which reduces the number of population in the city caused by the deaths and out–migration (emigration) factors.

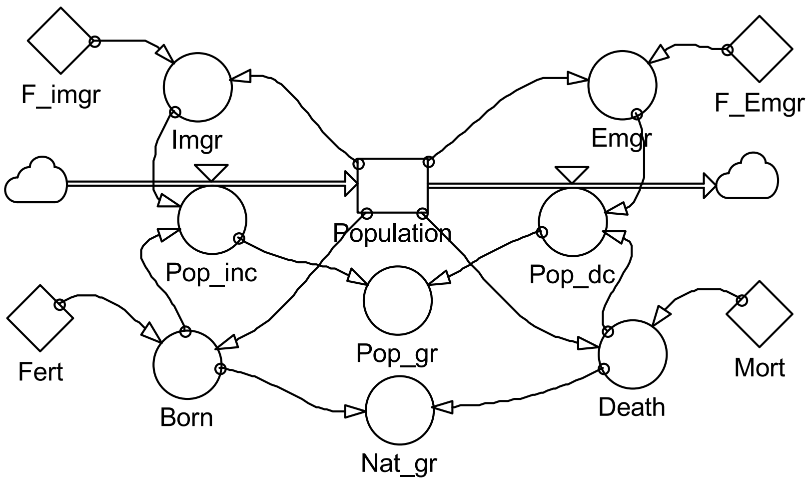

Figure 2. Flow diagram of population sub–model.

Calculation of Carbon Dioxide Absorption

Approximate calculation of CO_2 absorption was conducted to determine the distribution and number of vegetation in each district in the city of Banda Aceh. Results of CO_2 absorption by vegetation will be compared with the amount of CO_2 emissions. Broad values that have been classified in vegetation classes are presented in Table 1. The ability to absorb by vegetation class is known as ability of the existing condition of vegetation to absorb CO_2.

Table 1. CO_2 absorption by vegetation

Green structure vegetation	CO_2 absorption (tons/ha/year)
Plantation	52.3952
Grass	3.2976
Forest	58.2576
Bushes	3.2976

The ability of vegetation to absorb CO_2 by Iverson (Tinambunan, 2006), are: (a) for plantation vegetation is 52.3952 tons of CO_2/ha/year; (b) grass is 3.2976 tons of CO_2/ha/year; (c) forest is 58.2576 tons of CO_2/ha/year; and (d) bushes are 3.2976 tons of CO_2/ha/year. To estimate the CO_2 absorption using secondary data that will be obtained vegetation absorption value for each type of area (such as plantation, grass, forest, bushes) in the districts in the city of Banda Aceh. Calculation of CO2 absorption by vegetation type is presented in Table 2.

Table 2. CO_2 absorption by vegetation in Banda Aceh

No	District	Plantation	Grass	Forest	Bushes	Total (tons)
1	Meuraxa	1,019.61	23.08	116.52	206.10	1,365.31
2	Jaya Baru	597.31	–	–	209.40	806.70
3	Banda Raya	1,309.88	–	–	649.63	1,959.51
4	Baiturrahman	–	–	–	87.39	87.39
5	Lueng Bata	1,257.48	3.30	–	77.49	1,338.28
6	Kuta Alam	–	–	–	13.19	13.19
7	Kuta Raja	2,910.03	–	–	–	2,910.03
8	Syiah Kuala	7,602.54	–	233.03	98.93	7,934.50
9	Ulee Kareng	9,630.24	3.30	–	346.25	9,979.78
	Total	24,327.09	29.68	349.55	1,688.37	26,394.69

Based on calculations in Table 2, the maximum CO_2 absorption by the vegetation found in the Ulee Kareng district, about 9,979.78 tons of CO_2. Greatest absorption due to the amount of vegetated area in this district is quite extensive. While the smallest absorption found in Kuta Alam district in the amount of 13.19 tons of CO_2.

Estimated total amount of CO_2 that can be absorbed by vegetation type based on the existing condition of vegetation in the city of Banda Aceh is approximately 26,394.69 tons. Two districts which are located in the city center: Kuta Alam and Baiturrahman have less absorption, due to very small area of vegetation growth.

Value of total CO_2 emissions are estimated based on the energy used in the city of Banda Aceh. Energy is calculated by tabulating the data derived from the use of electricity, kerosene, gasoline and diesel. Total value is obtained based on the value of CO_2 calculated in accordance with Table 3 and 4.

In Table 3 it can be seen that the amount of CO_2 emissions in the city of Banda Aceh derived from the consumption of electricity, kerosene, gasoline and diesel was approximately 109,015.42 tons. CO_2 emissions that most of it comes from the source of electricity production in the amount of 108,328.79 tons.

Table 3. CO_2 emissions in the city of Banda Aceh

Source	Capacity (kwh)/ Consumption (ltr)	Emission factor (gr/Kwh–gr/ltr)	CO_2 (gr)	CO_2 (tons)
Electricity	238,609,598	454.00	108,328,757,492	108,328.76
Kerosene	38,171,000	2.52	96,190,920	96.19
Gasoline	111,110,000	2.30	255,553,000	255.55
Diesel	124,045,000	2.70	334,921,500	334.92
Total				109,015.42

Difference in CO_2 emissions generated and the ability of vegetation absorption obtained from the classification of the type of vegetation to absorb CO_2 emissions are presented in Table 4.

Table 4. Difference in CO_2 emissions to CO_2 absorption by vegetation

Region	CO_2 emission (tons)	CO_2 absorption by vegetation (tons)	Difference (tons)
City of Banda Aceh	109,015.42	26,394.69	–82,620.74

The results of calculating the difference in absorption of CO_2 by vegetation to CO_2 emissions in the city of Banda Aceh, obtained the high existing lack of green space ability in the absorption of CO_2 which is about 82,620.74 tons due to the lack of vegetation in the city.

Urban Forest CO_2 Absorption Submodel

In this model (see Figure 3), urban forest is considered as variable rate to variable decision systems which are regulated by one or more policy structures. In this model the process that led to the needs for urban forest and its vegetation as an absorber of CO_2 is to offset the amount of CO_2 emissions from domestic activities in the use of electricity, gasoline, diesel and kerosene.

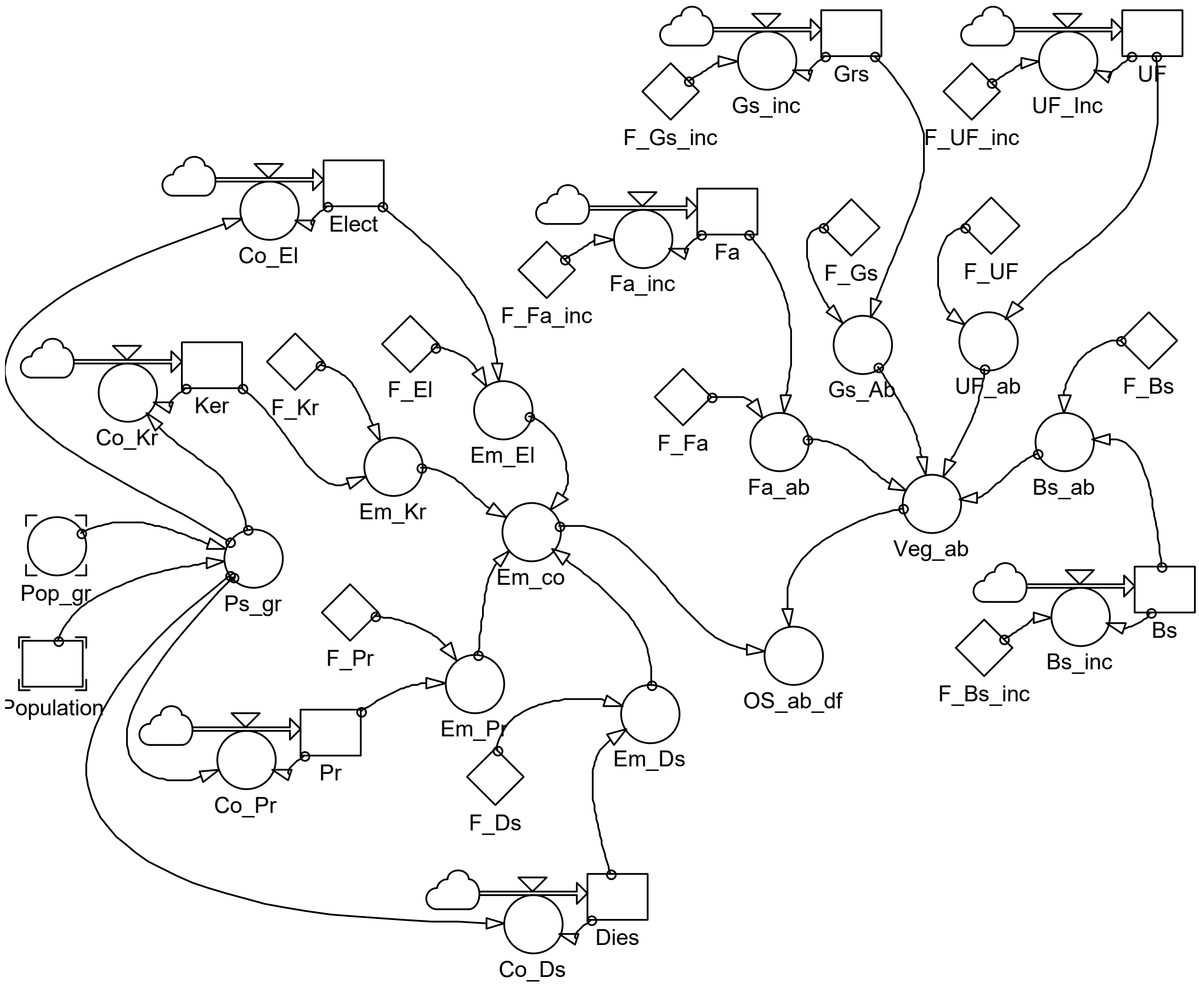

Figure 3. Flow diagram of UF–CO_2 absorption sub–model

Analysis of Model Behavior

Analysis of the model behavior is an attempt to understand the behavior of the system as a result of the assumptions in the model. Understanding models by computer simulation will inform the behavior of all variables in the model with respect to time.

Population Sub–model Behavior

Based on the results of simulations carried out on the population sub model, increasing numbers of population in the city of Banda Aceh, from 249,499 people in the beginning of the simulation year (2015), increase to 275,602 people by the end of the simulation year (2025). The following graph is presented in Figure 4, shows changes in the population of the city of Banda Aceh during the period of the simulation.

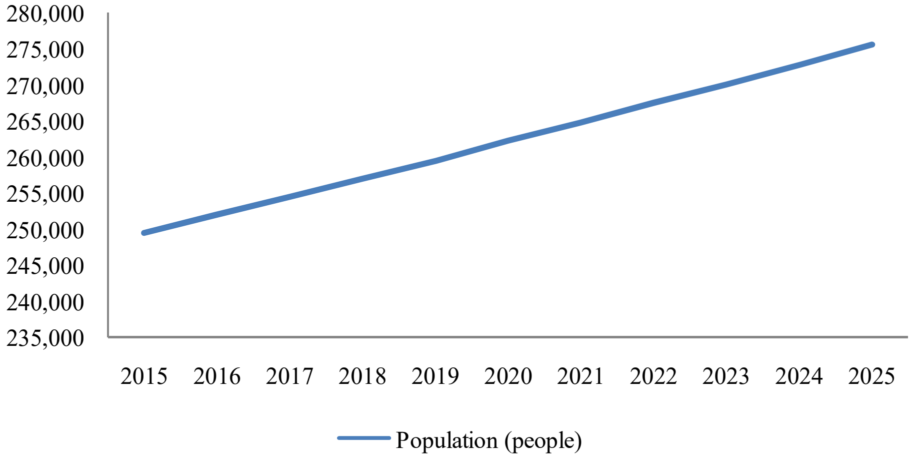

Figure 4. Population Growth

Urban Forest CO_2 Absorption Sub–model

The needs for urban forest as part of urban green open space to absorb CO_2 emissions from domestic activities in the use of electricity, gasoline, diesel and kerosene. Based on the results of simulations performed, it shows increasing needs of urban green open space. CO_2 emission rise from 109,015.42 tons in 2015 to 120,420.84 tons in 2025, while the absorption capacity of the existing vegetation only 26,394.69 tons in 2015 and 32,174.98 tons in 2025. Assuming the ability of CO_2 absorption by urban forest in urban green open space is 800 tons/ha (Dachlan, 2011), then the needs of green open space should be 150.52 ha of urban forest at the end of the simulation in 2025 to balance the CO_2 emissions rate (see Figure 5).

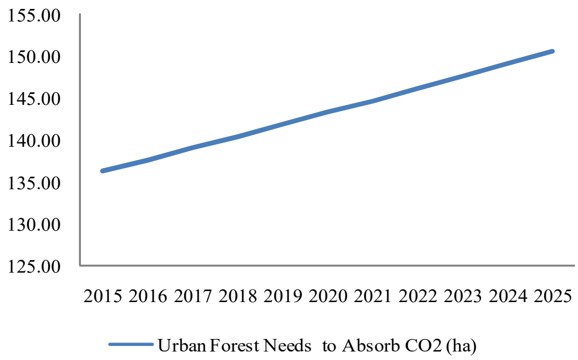

Figure 5. Urban Forest Needs to absorb CO_2

Based on the simulation, results shows increasing needs for the amount of vegetation in urban forest and especially the tree that has high ability to absorb CO_2. However, due to the small rate in the growing urban green space, resulting insufficiency of oxygen production and vegetation ability to absorb CO_2 emissions. The urban forest need to be planned for the adequacy of its wide and types of vegetation that has high ability to absorb CO_2.

Table 6. Intervention varibles of three scenarios

Variable	Progressive	Sustainable	Conservative
Population	Population growth rate increase by 1%	Population growth rate increase by 0.5%	Population growth rate increase by 1%
Urban Forest	Green space increase by 0.1%	Green space increase by 0.5%	Green space increase by 0.1%
Vegetation	Composition 1 Trembesi (40%), Mahoni (20%), Angsana (30%), Asam (10%)	Composition 2 Trembesi (50%), Mahoni (20%), Angsana (20%), Asam (10%)	Composition 3 Trembesi (10%), Mahoni (10%), Angsana (60%), Asam (20%)

Policy Analysis

Policy analysis was started by establishing scenarios. Three scenarios were applied for urban forest development simulation. Intervention variables applied are presented in Table 6 and vegetation composition in urban forest is presented in Table 7.

Table 7. Vegetation composition in urban forest

Local name	Scientific name	CO_2 absorption (kg/tree/year)	Absorption availability
Trembesi	Samanea saman	28,448.39	High
Mahoni	Swettiana mahagoni	295.739	Medium
Angsana	Pterocarpus indicus	11.1226	Low
Asam	Tamarindus indica	1.4931	Very Low

Scenario simulation (Table 8) showed that for all scenarios it is difficult to maintain urban forest existence. The most realistic scenario is sustainable scenario. A strong policy should be created to maintain urban green space and urban forest existence.

Table 8. Result of three scenarios simulation on population, urban forest and CO_2 absorption

Variable	Year	Scenario		
		Progressive	Sustainable	Conservative
Population Growth (people)	2015	249,499	249,499	249,499
	2025	275,602	262,258	275,602
Urban Forest Growth (ha)	2015	25.39	25.39	25.39
	2025	41.36	65.86	30.95
Vegetation Needs to Absorb CO_2 (ha)	2015	27.47	34.30	136.20
	2025	30.35	36.05	150.45

Conclusions

The presence of urban forest as element of the natural environment plays an important role in maintaining the quality of city life. The concept of ecology green structure in the city of Banda Aceh attempts to achieve ecologically healthy city. The needs of urban forest as part of urban green structure appropriate to ecological functions of CO_2 absorption which known from the calculation are:

a. Urban forest requirements based on the role of existing vegetations as CO_2 absorber there is a lack of 82,620.74 tons due to the lack of vegetation in the absorption of CO_2.
b. Vegetation composition should be planned wisely to avoid superfluous space, as the conservative scenario shows maximum area needs for vegetation in urban forest to absorb CO_2 in the area of 150.45 hectares in 2025 to balance the CO_2 emissions rate.
c. Land use control should be taken seriously by the government so that the presence of urban forest in the city will not degrade in the quality and quantity.

References

Amirin, T.M. (2011). *Pokok–pokok Teori Sistem*. Raja Grafindo Persada, Jakarta.

Avianto, T.W. (2006). *Tutorial Powersim*. Laboratorium Pembangunan dan Lingkungan. http://www.lablink.or.id/ (accessed on 6 Desember 2011 at 8.43).

Bappeda. (2009). *RTRW Kota Banda Aceh 2009–2029*. Bappeda Kota Banda Aceh.

BPS (2015). *Banda Aceh dalam Angka 2015*. Badan Pusat Statistik Kota Banda Aceh.

Cadenasso, ML., Pickett, STA. (2008). Urban Principles for Ecological Landscape Design and Management: Scientific Fundamentals. *Journal of Cities and the Environment*, 1, Issue 2 Article 4. The Barkeley Electronic Press.

Carreiro, M.M. (2008). *Ecology, Planning and Management of Urban Forests International Perspectives*. Springer, New York.

Chen, J. (2004). The Role of Green Structures in Development of the Sustainable City. *Master Thesis*, Department of Infrastructure, The Royal Institute of Technology, Stockholm.

Dachlan, E.N. (2011). Kebutuhan Luasan Areal Hutan Kota Sebagai Rosot (Sink) Gas CO_2 Untuk Mengantisipasi Penurunan Luasan Ruang Terbuka Hijau Di Kota Bogor. *Forum Geografi*: 25: 164 – 177.

Dinariana, D. (2011). Model Pengelolaan Ruang Terbuka Hijau sebagai Daerah Resapan di Wilayah DKI Jakarta. *Disertasi*, Sekolah Pasca Sarjana Institut Pertanian Bogor, Bogor.

DKK. (2014). *Management of Green Open Space in Banda Aceh*. Department of Sanitation and Beauty of the City of Banda Aceh.

DPU. (2008). Peraturan Menteri Pekerjaan Umum Nomor : 05/PRT/M/2008 Tentang *Pedoman Penyediaan dan Pemanfaatan Ruang Terbuka Hijau di Kawasan Perkotaan*. Departemen Pekerjaan Umum, Jakarta.

Faizah, F. (2011). Model Sistem Dinamis Ruang Terbuka Hijau Kota Medan Berdasarkan Faktor–faktor Lingkungan (Studi Kasus di Kecamatan Medan Polonia dan Medan Area). *Tesis*, Sekolah Pasca Sarjana Universitas Sumatera Utara, Medan.

Fuady, M. (2014). Green Open Space Model of Banda Aceh as Identity of the Humid Tropics Ecological City. *Dissertation*, Institut Teknologi Sepuluh Nopember, Surabaya.

Irwan, Z. D. (2005). *Tantangan Lingkungan dan Lanskap Hutan Kota*. Penerbit Bumi Aksara, Jakarta.

Li, F., Wang, R., Paulussen, J. and Liu, X. (2005). Comprehensive Concept Planning of Urban Greening Based on Ecological Principles: A Case Study in Beijing, China. *Journal of Landscape and Urban Planning,* 72: 325–336.

Mahmoud, A. H. A. and El–Sayed, M. A. (2011). Development of Sustainable Urban Green Areas in Egyptian New Cities: the Case of El–Sadat City. *Journal of Landscape and Urban Planning*, 101: 157–170.

Nazarrudin. (1996). *Penghijauan Kota*. Penerbit Penebar Swadaya, Jakarta.

Pauleit, S., Kaliszuk, E. (2005). Green Structure Pattern,in *Green Structure and Urban Planning, Final Report*. COST, Brussel.

Purnomohadi, N. (2006). *Ruang Terbuka Hijau Sebagai Unsur Utama Tata Ruang Kota*. Departemen Pekerjaan Umum, Jakarta.

Suwarli. (2011). Dinamika Perubahan Penggunaan Lahan dan Strategi Pengalokasian Ruang Terbuka Hijau Berdasarkan Penganggaran Daerah Berbasis Lingkungan (Studi Kasus Kota Bekasi). *Disertasi*, Sekolah Pasca Sarjana Institut Pertanian Bogor, Bogor.

Tinambunan, R. S. (2006). Analisis Kebutuhan Ruang Terbuka Hijau di Kota Pekanbaru. *Tesis*, Sekolah Pasca Sarjana Institut Pertanian Bogor, Bogor.

Waryono, T. (2005). Urgensi Mewujudkan Pembangunan Hutan Kota Melalui Kiat Kecil Menanam Dewasa Memanen. *Makalah dalam Workshop Kecil Menanam Dewasa Memanen*, Cibubur.