



Simulation of environmental carrying capacity in Bogor City, Indonesia, which rely on rainfall as water supply

¹Muhammad Ramdhan, ²Yuli Suharnoto, ³Suria D. Tarigan, ⁴Hadi S. Arifin

¹ Study Program of Natural Resources and Environmental Management, Graduate School of Bogor Agricultural University (IPB), Bogor, Indonesia; ² Departement of Civil and Environmental Engineering, Faculty of Technical Agriculture, Bogor Agricultural University (IPB), Bogor, Indonesia; ³ Department of Soil Science and Land Resources, Faculty of Agriculture, Bogor Agricultural University (IPB), Bogor, Indonesia; ⁴ Department of Landscape Architecture, Faculty of Agriculture, Bogor Agricultural University (IPB), Bogor, Indonesia. Corresponding author: M. Ramdhan, ramdhan_98@apps.ipb.ac.id.com

Abstract. Bogor is known as the rain city of Indonesia. Rain is one of the important water resources for human needs. Environmental balance can be known from the availability of water sources that are useful to meet the needs of the community. Environmental carrying capacity is the ability of the environment to support human other living organism's needs. One way to determine the environmental carrying capacity is to approach the availability and needs of water. The purpose of this research is to simulate the environmental carrying capacity status based on monthly water availability from rainfall and water requirement in Bogor City from 1990 to 2100. The method used to determine environmental carrying capacity is quantitative analysis through comparison between the calculation of water availability and water needs. Result of calculation of environmental carrying capacity status based on water availability and water requirement in Bogor City if following LH regulation no. 17/2009, Bogor city has deficit of water resources since 1990.

Key Words: water needs, data prediction, urban water, rain water, water availability.

Introduction. Bogor is a water city. Many of the names of places in Bogor City are derived from terms associated with water, such as: Ci which in Sudanese means water (example: Cipakancilan, Ciapus, Cipeucang), Parung which means river whose shallow river and its current is heavy, Bantar meaning river with slow current. This illustrates that the area of the Bogor City and its surroundings is a region rich in water resources (Soelaeman 2003).

As a city in a developing country, Bogor City currently faces water-related environmental problems. In the long dry season Bogor City experiencing water shortage (kotabogor.go.id; merdeka.com; poskotanews.com). In the rainy season the city of Bogor also experienced flood disaster caused by very high rainfall (Ramdhan et al 2018). Improper water management has a negative impact on water availability. It can also cause environmental disaster if the environmental carrying capacity of water is exceeded (Samekto & Winata 2010).

Environmental issues are becoming a global challenge today due to the absence of a balance between the living organisms and the availability of environmental carrying capacity (GFN 2010). Carrying capacity of environment derived from nature is a factor that participates in the formation of community welfare. Determination of the carrying capacity of the environment is done by knowing the capacity of the environment to meet and support human activities of inhabitants in order to ensure their survival (Setyaningrum & Prasetya 2017). Bogor City is one of the areas that are stated to have passed the threshold of the carrying capacity of its environment in the utilization of water resources (Prastowo 2010).

Modeling simulations can be performed to calculate the environmental carrying capacity (Qing et al 2012; Safuan et al 2012).

The purpose of this paper is to predict the environmental carrying capacity status based on availability and water requirement in Bogor City by using data simulation from 1990 to 2100. Carrying capacity will be calculated by comparison approach between water availability and its demand.

Material and Method

Study sites. The research was done in the administrative area of Bogor City, West Java Province. Geographically Bogor City lies in the coordinate range of 106° 43 '59.2 " E - 106° 50' 54.8" E; 6° 30 '38.6 "S - 6° 40' 48.5" S (Figure 1), Bogor City is surrounded by Bogor Regency area in southern part of Jakarta. Bogor City has an average minimum height of 190 m and a maximum of 330 m above sea level (BPS 2017).

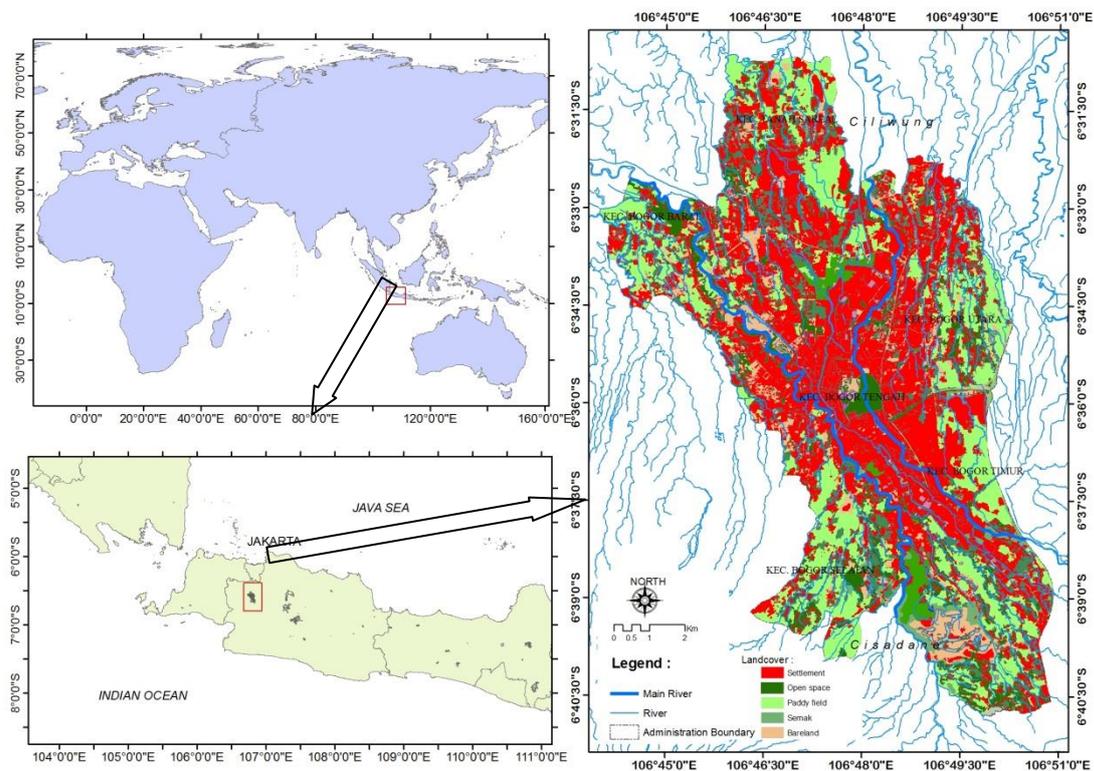


Figure 1. Location of the study area (Bogor City).

Materials. The data used in this research are:

1. Data on the population of Bogor City in the figures of 2012, 2015 and 2017 were obtained from the Central Bureau of Statistics Bogor City;
2. Earth Rupa Map of Indonesia scale 1:25.000 Bogor City, Bappeda City Bogor;
3. Land Cover Map Result of Landsat Image Classification (Irianti 2008);
4. Bogor City monthly rainfall data from TRMM satellite, downloaded from <https://disc.gsfc.nasa.gov/>

Methods. The Calculation of the environmental carrying capacity in this study was conducted based on the comparison between the need and availability of water with the used variables: Variable water availability with indicator: coefficient of run off land cover; the average value of monthly rainfall; and area. Water needs variable with indicator: population and water requirement for decent living.

Spatial data analysis is done using geographic information processing system (GIS), whereas for non-spatial data was analyzed using software that has the ability of

calculation and graphic making. Non-spatial data processing is done to calculate the runoff coefficient, water availability, projected water demand data (population), water requirements, and to know the ratio and status of environmental carrying capacity 1990 - 2100. Schematically the data analysis process is presented in Figure 2.

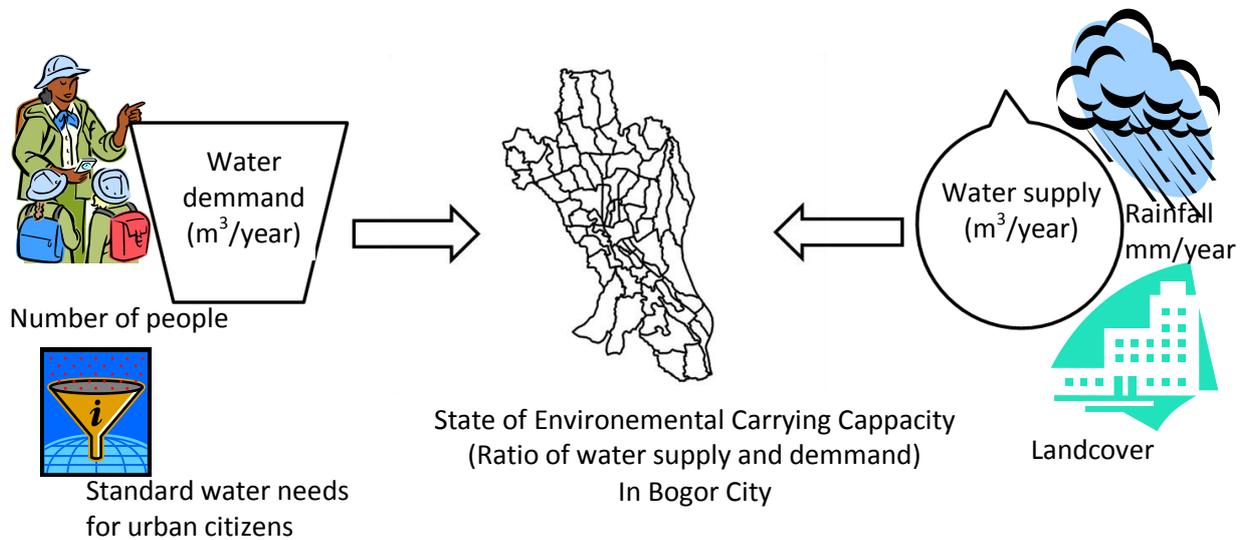


Figure 2. Flow chart of the environmental carrying capacity status with water supply and demand approach.

Data analysis

Population data. Data concerning the inhabitant's number was obtained from the results of population census in Indonesia conducted every ten years once in 1990, 2000 and 2010. Also data on the number of city residents Bogor from BPS (BPS 2012, 2015, 2017) was considered as shown in Table 1. Using simple linear regression techniques was determined the number of residents from 1990 to 2100.

Table 1
Population number evolution in Bogor City, Indonesia

Year	Population (Individuals)
1990	271,711
2000	750,819
2010	950,334
2011	987,315
2012	1,004,831
2013	1,013,019
2014	1,030,720
2015	1,047,922
2016	1,064,687

Source: BPS (2012), BPS (2015), BPS (2017).

Rainfall data. Monthly rainfall data for 10 years in the Bogor City was obtained from the Tropical Rainfall Measuring Mission (TRMM) (Table 2). TRMM data is precipitation data obtained from TRMM meteorological satellites with PR (Precipitation Radar) sensors, TMI (TRMM Microwave Imager), and VIRS (Visible and Infrared Scanners), CERES (Clouds and the Earth's Radiant Energy System), and LIS (Lightning Imaging Sensor).

Rain data used is monthly data level 3 with a spatial resolution of $0.25^\circ \times 0.25^\circ$. Type 3B43 was used in this study because it is a compilation of satellite radiowave data supported by data of rainfall stations attached to the earth's surface (Syaifulah 2014).

Table 2

Monthly rainfall TRMM data in Bogor City during 2006-2015

<i>Month</i>	<i>Rainfall (mm)</i>									
	<i>2006</i>	<i>2007</i>	<i>2008</i>	<i>2009</i>	<i>2010</i>	<i>2011</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>
January	529.00	331.25	355.23	349.24	326.47	234.63	263.36	524.31	681.73	353.36
February	372.63	594.08	380.30	279.15	367.33	143.19	373.80	299.72	374.00	407.60
March	336.05	396.66	455.01	295.17	467.28	201.49	221.06	378.38	478.76	410.51
April	352.09	447.57	457.76	326.53	187.24	325.04	365.30	441.68	419.41	293.76
May	217.10	213.67	187.65	340.07	320.59	244.03	243.43	407.29	324.49	205.27
June	104.77	146.41	109.59	180.09	247.75	190.10	91.99	142.52	183.44	97.13
July	63.15	72.49	59.85	85.42	220.55	117.66	58.24	314.66	281.16	44.34
August	54.71	106.00	137.72	39.13	276.69	62.89	47.17	164.86	231.44	81.00
September	65.65	143.43	168.45	101.00	515.97	77.72	126.07	126.07	68.28	51.77
October	118.42	305.15	279.52	375.23	414.86	298.55	346.36	283.77	179.94	103.60
November	273.32	407.72	497.85	389.63	405.74	362.17	443.49	296.04	498.85	532.49
December	452.80	562.81	298.29	268.54	273.40	241.76	401.63	521.08	360.75	423.55
Sum	2,939.68	3,727.25	3,387.23	3,029.21	4,023.87	2,499.22	2,981.90	3,900.39	4,082.27	3,004.40
Average	244.97	310.60	282.27	252.43	335.32	208.27	248.49	325.03	340.19	250.37

Source: <https://disc.gsfc.nasa.gov> [gscf.nasa.gov](https://disc.gsfc.nasa.gov)

The prediction of rainfall value was done using Fourier method, by using the formula:

$$X_k = \sum_{j=0}^{N-1} x_j e^{-2\pi \frac{j}{N} i k}$$

Where:

k is the frequency of the component;

x_0, \dots, x_{N-1} is the input value of the rainfall model;

N is the number of the original number as the total input time series to be calculated.

The model generated used 5 components with amplitude and phase properties as shown in Figure 3. Furthermore the series of data was used periodically to predict rainfall values before 2004 and after 2016.

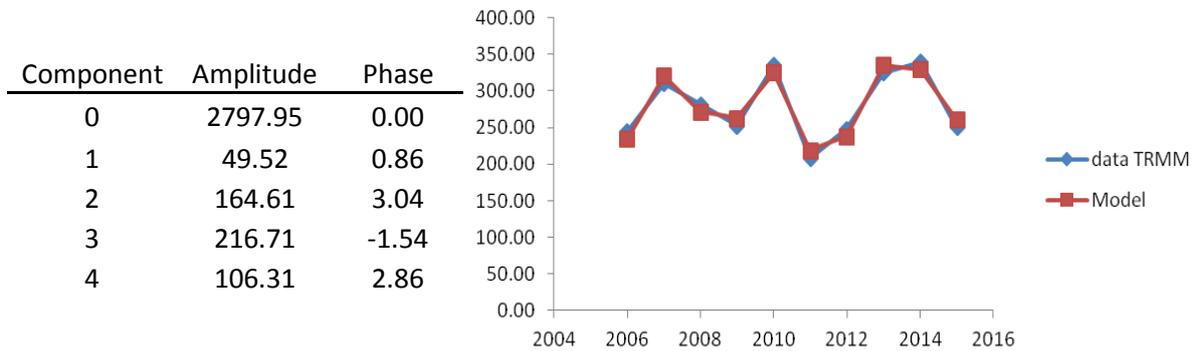


Figure 3. The 10 year cycle of TRMM data used to obtain predicted monthly average rainfall data in Bogor City.

Land cover data. Land cover data was obtained from the interpretation of landsat imagery from 1972, 1983, 1992, 2000, 2005 from Irianti (2008). Joined with the results of data processing land cover map from landsat imagery data year of 2014, was obtained built up and open area. The result was then projected using regression techniques to obtain land cover data from 1970 up to 2020 (Figure 4).

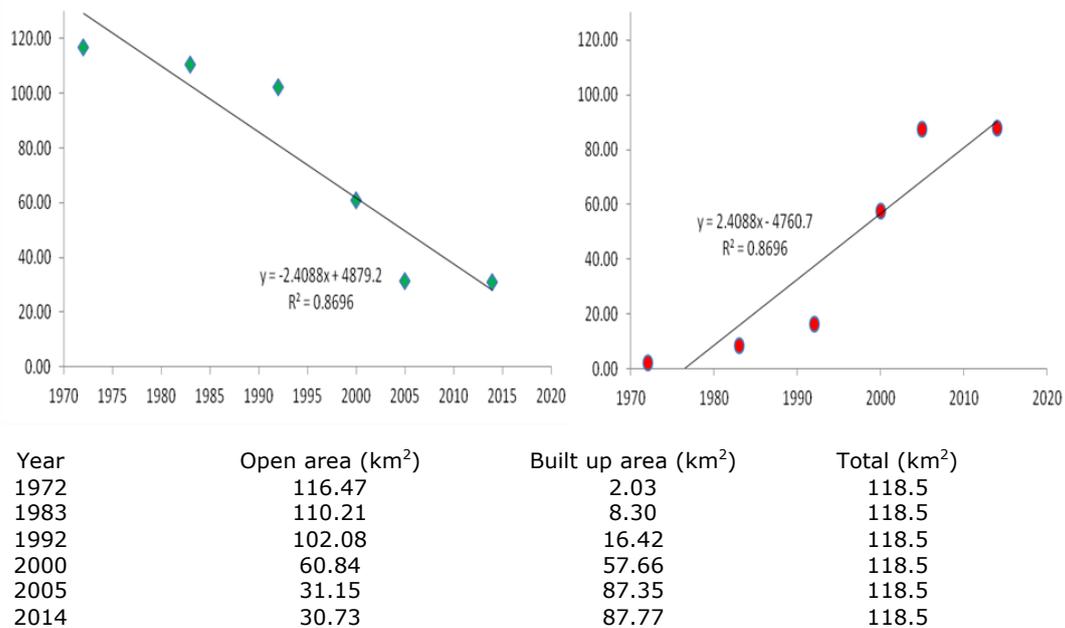


Figure 4. Time-series land cover data for Bogor City along with the linear regression graph.

Land cover will determine the coefficient value for rainwater runoff. MENLH (2009) has determined the amount of rainfall runoff coefficient (C) for each land (Table 3).

Table 3
Rainwater runoff coefficient based on LH Regulation No. 17/2009 MENLH (2009)

<i>Description</i>	<i>C_i</i>	<i>Land Cover Group</i>	<i>Modus of Maximum C_i</i>
City, Asphalt road, rooftop	0.7–0.9	Built-up area	0.9
Industrial area	0.5–0.9		
Multi-unit housing, business area	0.6–0.7		
Housing complex	0.4–0.6		
Villa	0.3–0.5		
Park, grave yard	0.1–0.3	Open area	0.35
Heavy soil garden:			
a) >7 %	0.25–0.35		
b) 2–7%	0.18–0.22		
c) <2%	0.13–0.17		
Soft soil garden:			
a) >7 %	0.15–0.2		
b) 2–7%	0.10–0.15		
c) <2%	0.05–0.10		
Hard soil	0.4		
Grass yard	0.35		
Agricultural area	0.3		
Forest	0.18		

The maximum C_i value for each land cover group was taken as the multiplier coefficient of the model. It is assumed that the more rain water runoff that occurs, the more water that can be utilized to meet the needs of Bogor City residents.

Water supply. Analysis of water availability in Bogor City takes into account the availability of water by referring to the Regulation of LH No. 17 of 2009 (MENLH 2009) on Guidelines for the Determination of Environmental Support Capacity in Spatial Planning, as follows:

$$C = \frac{\sum (C_i \times A_i)}{\sum A_i}$$

$$S A = 10 \times C \times R \times A$$

Where :

- S A = Water availability (m³/year);
- C = weighted runoff coefficient;
- C_i = coefficient of landcover overtopping-i;
- A_i = area of landcover-i (ha) from Bogor Bappeda data;
- R = average algebra of monthly rainfall area (mm / month) TRMM;
- A = Total Area (ha);
- 10 = conversion factor from mm.ha to meter.

Water demand. The water requirement is the amount of water used for various designations or activities of the community in a particular area. The method to calculate the water requirement refers to Regulation LH No. 17/2009 (MENLH 2009), as follows:

$$DA = N \times KHL_A$$

Where:

DA = Total Water Requirement (m³/year);

N = Number of Population (person);

KHL_A = Worthy needs of water for live with 4 versions

Version 1. Value of water requirement = 1,600 m³ water/capita/year(Regulation LH No. 17/2009 (MENLH 2009))

Version 2. Value of water requirement = 1,000 m³ water/capita/year (WHO 2005)

Version 3. Value of water requirement = 182.5 m³ water/capita/year (SNI 19-6728.1-2002 (BSN 2002))

Version 4. Value of water requirement = 113.15 m³ water/capita/year (Sutjahjo et al 2011).

Carrying capacity status. Determination of environmental carrying capacity was done by supply and demand approach. This carrying capacity status can be determined after the known water availability and water demand in the research area. The comparison between the condition of water availability and the water requirement in the research area becomes the basis in determining the environmental carrying capacity status. If the ratio is of >1 means the supply condition is greater than the demand, so the carrying capacity is still good. Whereas if the ratio <1 means more demand than supply so that environmental conditions exceeded the carrying capacity.

Results

Population of Bogor City. Bogor City entered into the category of metropolitan city, because their inhabitants have reached more than 1 million individuals (Soembodo 2012). Currently the population of Bogor City is dominated by workers. Population data shows as much as 70-82% of the workforce living in Bogor works as laborers (BPS 2017). As a buffer city of Jakarta, the population growth in Bogor City tends to increase.

With linear regression model we obtained the function to predict the population in the city of Bogor with the following formula.

$$Y = 29.151 x - 57.660.992$$

Where:

Y = Number of population in Bogor City year-x

X = Real number that showing the year of Anno Domini.

Figure 5 shows the linear regression graph of the previously known population. Growth trends look positive, with a fairly high level of confidence that is R² = 0.9567. Growth every year is 0.03%, or if the current population of the city of Bogor amounted to 1 million, then next year is expected to increase about 30,000 people. This figure is smaller than the rate of population growth of city of Bogor issued by BPS (2017) that is equal to 2.38%.

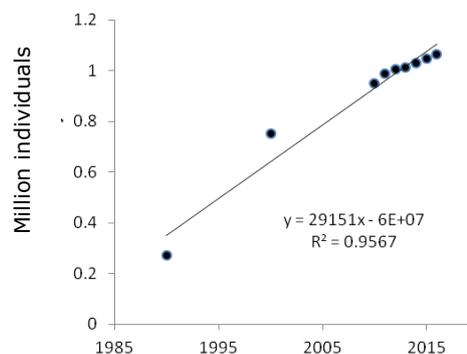


Figure 5. Graph of linear regression of population growth per year in Bogor City.

Water availability. The availability of water is a function of time, which is abundant/excessive during the rainy season and decreases in the dry season. The overall amount of fresh water of the world is limited. The total inventory cannot be reduced or increased, but with water resources development and management efforts, its distribution by time and space can be adjusted according the needs (Putuhena 2004). The amount of water availability is closely related to rainfall and land use in Bogor City. It is assumed that Bogor city residents can take advantage of rainwater runoff that falls into the city of Bogor to meet the needs of daily living.

The calculation of water availability per year in Bogor City in 1990-2100 using TRMM rainfall data that has been projected in the fourier function is shown in Figure 6. There is an increase in supply from 1990 to 2030, this is caused by the change in composition of land cover in model. In 2030 it is predicted that the land cover in Bogor city will become an entirely wake up area. After 2026 the supply will follow the rainfall pattern of Bogor City. The minimum water availability in the model is 159,708,359.3 m³/year, which occurred in 1991 and the maximum water availability was 429,355,432.1 m³/year in 2033, 2043, 2053, 2063, 2073, 2083 and 2093.

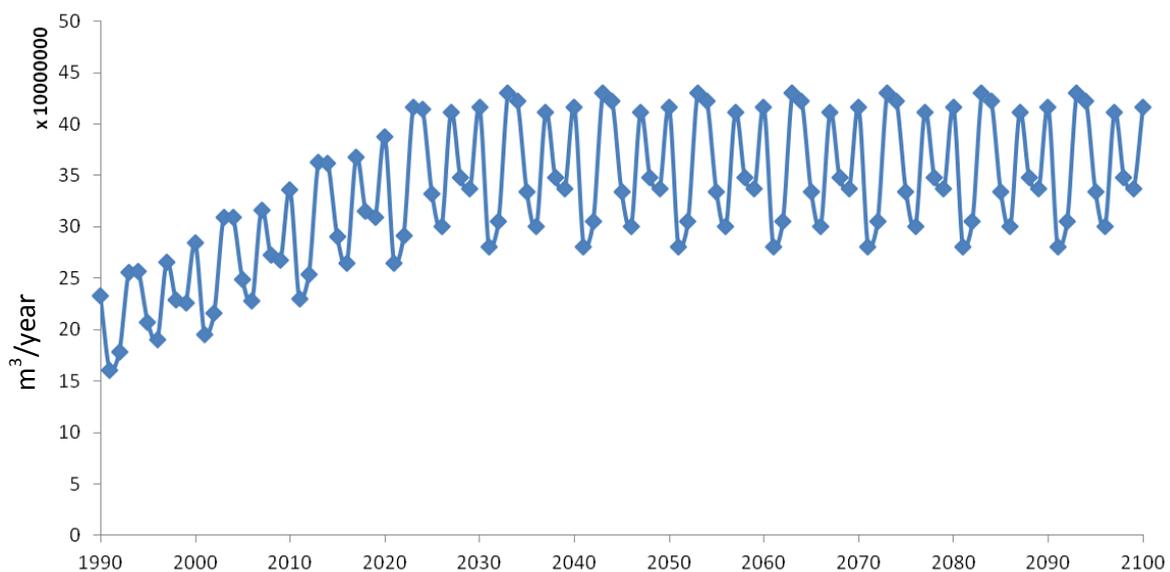


Figure 6. Graph of water availability per year from 1990 to 2100 in Bogor City.

Water requirement. The determinant factor in calculating water requirement in this research is the population and water requirement per capita for Bogor City. The water requirement for the standard Regulation LH No. 17/2009 (MENLH 2009) follows the calculation for the fulfillment of decent water standards for the Indonesian people multiplied by the number of safety factors as much as 2x, the amount is 1600 m³ water/capita/year. This ministerial regulation takes into account the virtual water demand for the population. This means the fulfillment of staple food needs is also calculated as the need for water. WHO (2005) criteria for total water needs of 1000-2000 m³/capita/year. For this study, the WHO standard minimum value is 1,000 m³ water/capita/year. As if for BSN (2002) and Sutjahjo et al (2011), the number of decent water needs only take into account the raw water needs for the life of urban communities. SNI is based on research from the Ministry of Public Works on raw water requirements for regional planning in Indonesia; the needs of urban communities with population of more than 1 million individuals are 250 L/capita/day. While Sutjahjo et al (2011) calculations were based on water requirements in 4 major cities of Indonesia, namely Jakarta, Medan, Bogor and Malang. The average water demand for average middle-aged households in the four cities is 155 L/capita/day. Figure 7 show the water demand in Bogor City for each version of water needs.

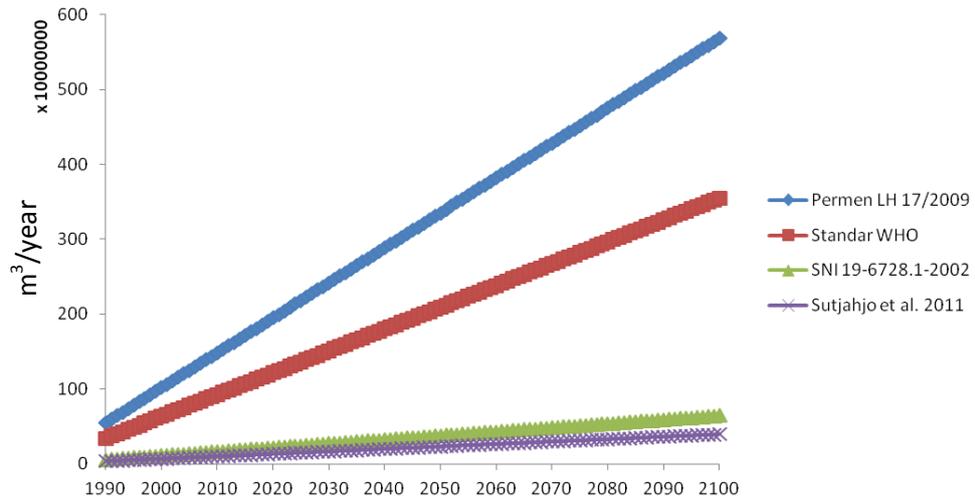


Figure 7. Graph of water demand in Bogor City for 1990-2100.

Status of the environment carrying capacity. Analysis of environmental carrying capacity with water (ECC-W) approach is the ratio between the conditions of water availability with the water requirement in a region. The higher the value of water availability, the greater the ratio, the more assured is the availability of water resources to meet the needs of a community. Based on this comparison, the ratio of ECC-W is shown in Figure 8. Figures ratio 1 is used as a barrier between the surplus conditions of water resources with water resource deficit. If the value of supply is equal to demand, then the ratio will be equal to 1. So if the ratio is >1 there is a surplus condition, otherwise if the ratio is <1 then there is a water resources deficit condition.

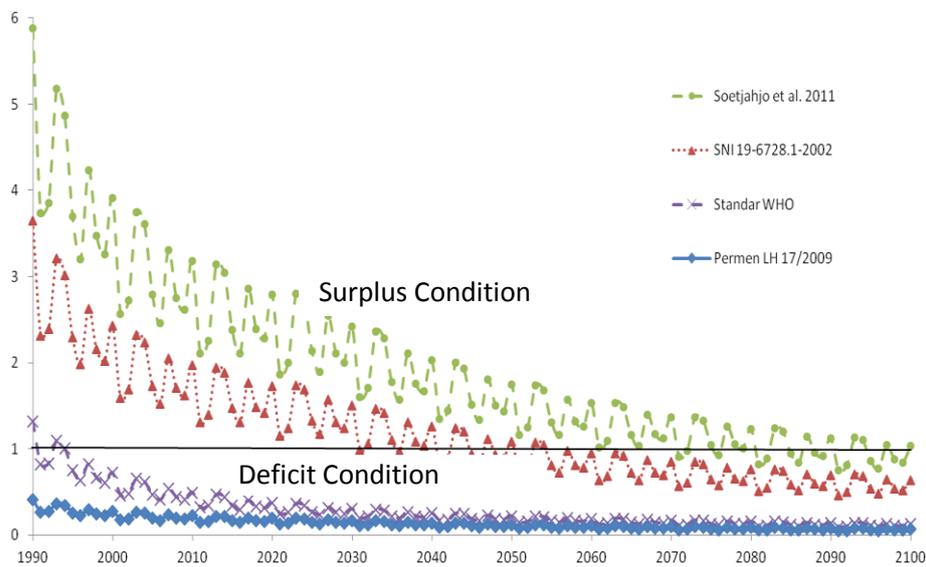


Figure 8. Graph of the ratio of environmental carrying capacity of Bogor City water for 1990-2100.

In the Figure 8 can be seen that when was used the value of the feasibility of water use based on Regulation LH No. 17/2009 then the city of Bogor has been in deficit condition since 1990 which is in accordance with Prastowo (2010) which classify the city of Bogor as an overshoot region of power status support its aquatic environment. When using the minimum feasibility value of WHO (2005), then the city has been deficit water resources since 1991. But in reality, the people of Bogor city today still can meet the daily water needs. This shows that the value of the number of needs used by the Regulation LH No.

17/2009 (MENLH 2009) and WHO (2005) is to over-estimate the Bogor City water demand.

When we use the value of SNI 19-6728.1-2002 as the feasibility standard of urban water needs, then in 2031 Bogor City is predicted to experience a deficit of water resources. Furthermore, when we use the reference Soetjahjo et al (2011) as the water supply feasibility standard for Bogor City, then is predicted that in 2071 Bogor City will be challenged by a deficit of water resources.

Conclusions. Bogor City has simulated the environmental carrying capacity with the approach of water needs and supplies. The result is highly dependent on the value of water demand for Bogor City. If we consider Regulation LH No. 17/2009 (MENLH 2009) or WHO standard as a reference, then the present year (2018) Bogor City experiencing deficit of water resources.

By using the standard need of water of 250 L/capita/day (BSN 2002), in 2018 Bogor City experiencing a surplus of water, but simulation results show that at least in 2031 Bogor City likely will experience water deficit. Otherway, when the simulation was done by the smallest water need version of 155 L/capita/day then resulted that Bogor City will experience water deficit in 2071.

Acknowledgements. We would like to thank AIC-IPB Urban water cluster which has helped us in conducting this research; to the Ministry of Marine and Fisheries Republic of Indonesia which has supported the grant for scholarship of the main author.

References

- Irianti E. F., 2008 [Land use change, land clearing, and green open space of Bogor City year 1905-2005]. Thesis, Landscape Architecture Study Program, Faculty of Agriculture, Bogor Agricultural University, Bogor. [In Indonesian].
- Prastowo, 2010 Environmental carrying capacity aspects of water resources. Working Paper P4W, Crestpent Press, Bogor, Indonesia. [In Indonesian].
- Putuhena F., 2004 [Water supply and demand, transformation of water resources management policy]. LIPI Press, Jakarta, Indonesia. [In Indonesian].
- Ramdhan M., Arifin H. S., Suharnoto Y., Tarigan S. D., 2018 Towards water sensitive city: Lesson learned from Bogor flood hazard in 2017. The 2nd International Conference on Energy, Environmental and Information System, E3S Web Conference, Volume 31, EDP Sciences, Les Ulis Cedex, France. <https://doi.org/10.1051/e3sconf/20183109012>.
- Safuan H. M., Towers I. N., Javanoski Z., Sidhu H. S., 2012 Coupled logistic carrying capacity model. *Anziam Journal* 53:C172-C184.
- Samekto C., Winata E. S., 2010 [Potential water resources in Indonesia]. National Seminar: Application of water supply technology for regencies / cities in Indonesia, PTL-BPPT, Jakarta, Indonesia. [In Indonesian].
- Setyaningrum N., Prasetya G. A., 2017 [Analysis of water supply and demand for environmental support capacity: A case study in Bojonegoro District]. Proceedings of National Seminar on Geomatics 2017: Innovation of Technology for Providing Geospatial Information for Sustainable Development, Geospatial Information Agency, Cibinong. [In Indonesian].
- Soelaeman E., 2003 *Toponimi Bogor*. Majelis Penulis Publisher, Bogor, 235 p.
- Soembodo B., 2012 [Urban ecology]. PT. Revka Petra Media, Surabaya. [In Indonesian].
- Sutjahjo N., Anggraini F., Pamekas R., 2011 [Consumption and drinking water customers in big and metropolitan cities]. *Jurnal Permukiman* 6(3):138-146. [In Indonesian].
- Syaifullah M. D., 2014 [Validation of TRMM data on actual rainfall data in three watersheds in Indonesia]. *Jurnal Meteorologi Dan Geofisika* 15(2):109-118. [In Indonesian].
- Xiao-Qing Z., Hui R., Qi Y., Lan H. E. C., Hui Y. H., 2012 Scenarios simulation on carrying capacity of water resources in Kunming City. *Procedia Earth and Planetary Science*, 5:107-112.

- *** BPS, 2012 Bogor city in figures 2012, Central Bureau of Statistics, Bogor, Indonesia.
- *** BPS, 2015 Bogor city in figures 2015, Central Bureau of Statistics, Bogor, Indonesia.
- *** BPS, 2017 Bogor city in figures 2017, Central Bureau of Statistics, Bogor, Indonesia.
- *** BSN, 2002 [Preparation of the resources balance sheet, Part 1: Spatial water resources]. SNI 19-6728.1-2002, National Standardization Agency, Jakarta, Indonesia. [In Indonesian].
- *** GFN, 2010 The ecological wealth of nations. Earth's biocapacity as a new framework for international cooperation. Global Footprint Network, Oakland, California.
- *** MENLH, 2009 [Regulation No. 17/2009 of the state minister of the environment of Republic of Indonesia, about guidance to determine the capacity of environment support in spatial planning]. Deputy V-Environmental planning, Jakarta. [In Indonesian].
- *** https://kotabogor.go.id/index.php/show_post/detail/1951/Bima-Bersama-Warga-Ikuti-Sholat-Istisqa-di-Sempur, Accessed 04 April 2018.
- *** <https://www.merdeka.com/peristiwa/musim-kemarau-taman-kota-bogor-rusak-parah.html>, Accessed 04 April 2018.
- *** <http://poskotanews.com/2015/07/25/kota-hujan-bogor-kekeringan>, Accessed 04 April 2018.
- *** http://disc.gsfc.nasa.gov/datasets/WC_Multisen_prec_025_V001 Accessed 14 January 2018.

Received: 03 April 2018. Accepted: 24 May 2018. Published online: 25 July 2018.

Authors:

Muhammad Ramdhan, Graduate School of Bogor Agricultural University (IPB), Study Program of Natural Resources and Environmental Management, Indonesia, Bogor 16680, e-mail: ramdhan_98@apps.ipb.ac.id.com
 Yuli Suharnoto, Bogor Agricultural University (IPB), Faculty of Technical Agriculture, Department of Civil and Environmental Engineering, Indonesia, Bogor 16680, e-mail: y_suharnoto@yahoo.com
 Suria Darma Tarigan, Bogor Agricultural University (IPB), Faculty of Agriculture, Department of Soil Science and Land Resources, Indonesia, Bogor 16680, e-mail: surya.tarigan@yahoo.com
 Hadi Susilo Arifin, Bogor Agricultural University (IPB), Faculty of Agriculture, Department of Landscape Architecture, Indonesia, Bogor 16680, e-mail: hadisusiloarifin@gmail.com

This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

How to cite this article:

Ramdhan M., Suharnoto Y., Tarigan S. D., Arifin H. S., 2018 Simulation of environmental carrying capacity in Bogor City, Indonesia, which rely on rainfall as water supply. AES Bioflux 10(2):68-78.