Spatial dynamics of land use change to hydrological response in the upstream of Ciliwung Watershed, West Java Province, Indonesia

[1]Erwin Hermawan, [2]Santun R. P. Sitorus, [2]Surya D. Tarigan, [3]Marimin

[1] Study Program of Natural Resources and Environmental Management, Graduate School of IPB University, Bogor, Indonesia; [2] Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Bogor, Indonesia; [3] Department of Agricultural Industrial Technology, Faculty of Agricultural Technology, IPB University, Bogor, Indonesia. Corresponding author: E. Hermawan, rwien.gfm@gmail.com

Abstract. Land use changes due to high development pressure in the Upstream of Ciliwung watershed cause this watershed to be classified as one of the degraded watersheds. The dynamics of land use change will have an impact on the hydrological response in a watershed area. The dynamics of hydrological characteristics show the performance of a watershed in ensuring the fulfillment of water needs. Image interpretation techniques from Landsat 7 ETM + imagery in 2008 and Landsat 8 imagery in 2018 were used to obtain land use information in the year 2008 and 2018. SWAT model was used to identify the impact of land use change on the hydrological response in the upstream of Ciliwung watershed. Based on the result analysis, during the period of the year 2008-2018 in the upstream of Ciliwung watershed there has been an increase built up area in the upstream of Ciliwung watershed which increased by 8.09% (1,182.55 Ha). The increase of built up area in 2018 had an impact on increasing CN values, surface runoff, river regime coefficients and annual flow coefficients, respectively 75.12, 1,361.25 mm/year, 57.07 and 0.49.

Key Words: SWAT Model, built up area, image interpretation, Landsat Imagery, surface runoff.

Introduction. Ciliwung watershed is one of the watersheds that have a strategic value in Indonesia. Ciliwung watershed has an area of about 347 km^2 with a main river length of around 117 Km. Ciliwung watershed is divided into three parts based on toposequences, which are upstream, middlestream and downstream (Ali et al 2016). The ecosystem in the upstream of Ciliwung watershed is an important part because it has a protection function for all parts of the watershed. Land use changes due to high development pressure in the Upstream of Ciliwung watershed cause this watershed to be classified as one of the degraded watersheds (Yustika et al 2012; Ruspendi et al 2016). Specifically, the dynamics of land use change will have an impact on the hydrological response in a watershed area. The dynamics of hydrological characteristics show the performance of a watershed in ensuring the fulfillment of water needs.

Indriastuti (2016) noted an increase in the amount of built up area by 18.64% during the period 2000–2010 in the upstream of Ciliwung Watershed area. This situation had an impact on increasing the value of the curve number (CN) in the upstream Ciliwung watershed from 54.17 to 63.46. Increasing the value of the CN in a watershed area will significantly influence the increase in the value of surface runoff. Based on this, an effort to increase infiltration capacity and decrease surface runoff is a priority through the preparation of sustainable land use planning.

Analysis of hydrological characteristics in an area can be evaluated using the SWAT (Soil and Water Assessment Tools) model developed by the World Association for Soil and Water Conservation (WASWAC). The application of the SWAT model includes assessing the impact of land use changes on hydrological characteristics in a watershed area (Mubarok et al 2015; Anand et al 2018; Lee et al 2019; Osei et al 2019).

This study aims to examine the dynamics of land use change to the hydrological response in the upstream Ciliwung watershed using the SWAT model.

Material and Method

Study sites. This research was conducted in January 2018 - August 2019 which is located at Upstream of Ciliwung Watershed, West Java Province, Indonesia. Geographically research area were located at 6° 37' 30" - 6° 46' 10" S and 106° 49' 36 "- 107° 0' 15" E with an area of ±14,617.62 Ha. The location of research area can be seen in Figure 1.

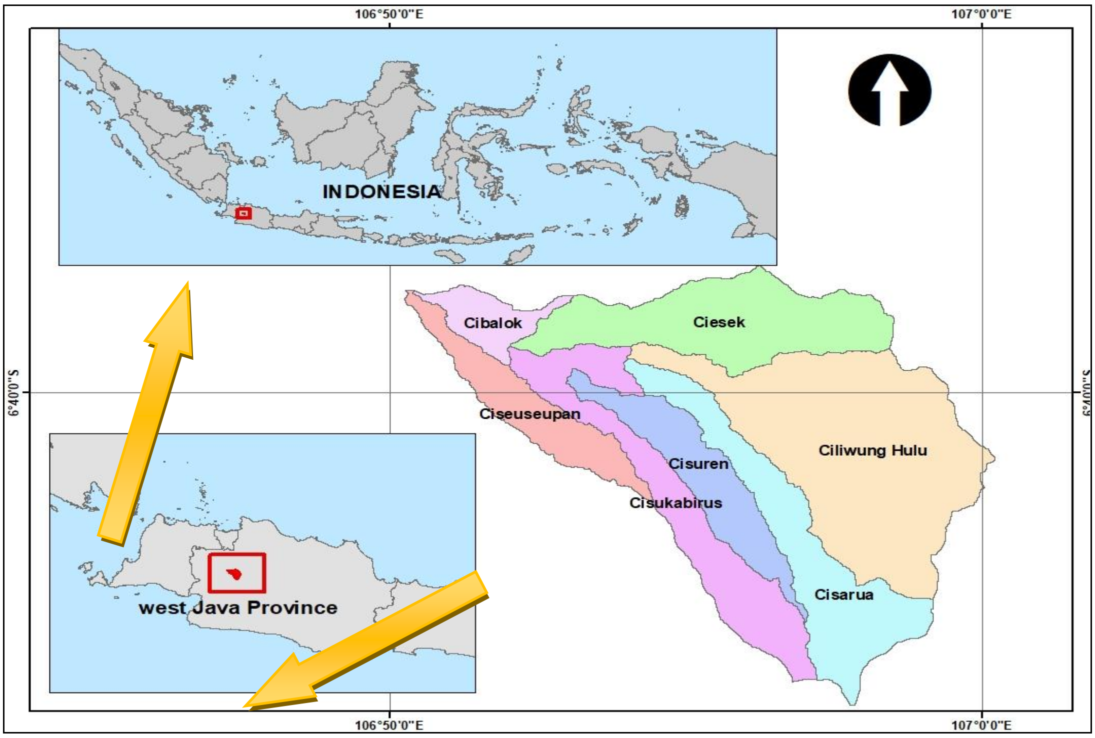

Figure 1. The location of research area, Upstream of Ciliwung watershed.

Materials. Materials used in this study included: (1) Landsat Imagery 7/ETM+ year 2008 and Landsat Imagery 8 OLI year 2018 were collected from http://glovis.usgs.gov/ (2) DEM SRTM with 30x30 m spatial resolution from http://srtm.csi.cgiar.org (3) Soil Map in scale 1:50.000 from Indonesian Center for Agricultural Land Resources (4) Climate data from the year 2008-2018 obtained from Katulampa, Gunung mas and Ciawi weather station (5) daily discharge records from the year 2008-2018 for Katulampa station which is the upstream of Cliwung watershed outflow obtained from the Water Resources Management Agency of Ciliwung – Cisadane.

Methods and data analysis. The first stage of the analysis carried out was to identify land use change in upstream of Ciliwung watershed. Image interpretation techniques from Landsat 7 ETM + imagery in 2008 and Landsat 8 imagery in 2018 were used to obtain land use information in the year 2008 and 2018. Field surveys were used to conduct accuracy assessment by comparing the results of image interpretation with actual field conditions. Accuracy values can be accepted when the accuracy value is >78% (Congalton 2001). The next stage was to identify the impact of land use change on the hydrological response in the upstream of Ciliwung watershed. Input data were used include land use in 2008 and 2018, soil maps, DEM SRTM and Climate data. The simulation results using the swat model produce a hydrologic response unit, which was calibrated and validated with observational discharge data. The outputs of the validated swat model were used to analyze the impact of land use change on the hydrological response in the upstream Ciliwung watershed. Flowchart of research methodology can be seen in Figure 2.

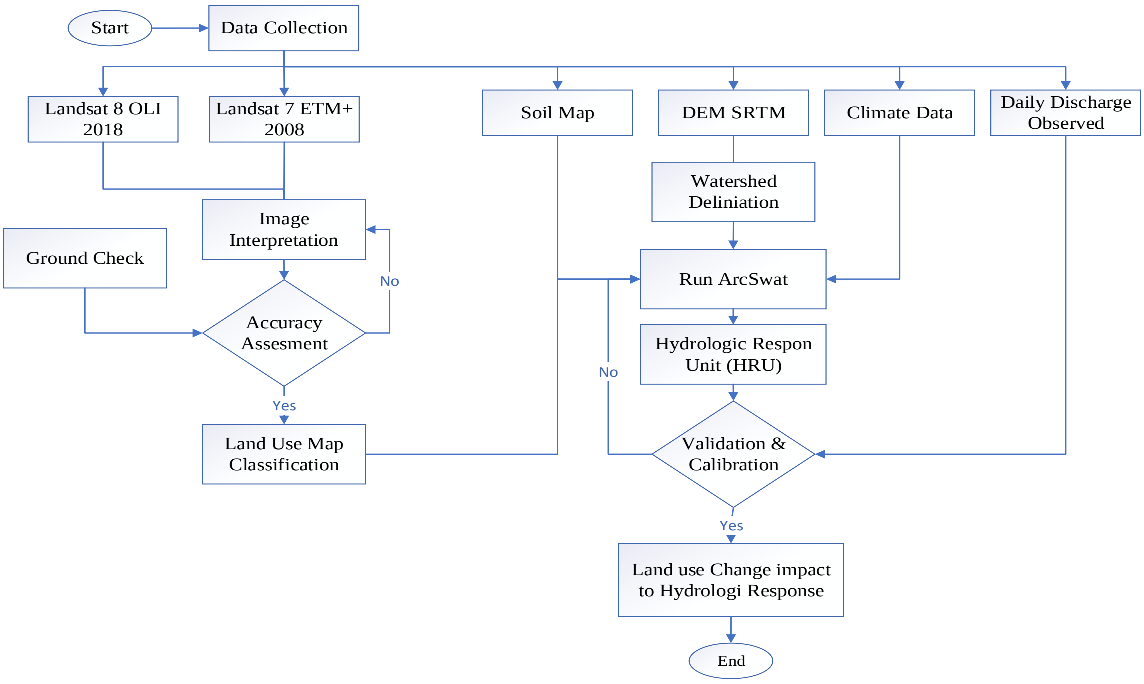

Figure 2. Flow chart of research methodology.

Results and Discussion

Analysis of land use change during the period of 2008-2018. Information on land use in the upstream of the Ciliwung watershed were obtained from the interpretation of Landsat 7 ETM + image in year 2008 and Landsat 8 OLI image in year 2018. Land use in the upstream of Ciliwung watershed were classified into 9 land use classes, including (1) Primary dry land forest, (2) Secondary dry land forest (3) Shrubs (4) Built up area (5) Dryland farming (6) Barren Land (7) Plantation and (8) Water bodies.

The results of the land use interpretation from landsat imagery in 2018 have been verified through field surveys. The result of analysis show that accuracy assessment value is 85% which significantly indicates the land use information resulting from image interpretation is acceptable. The results of land use classification in year 2008 and 2018 are presented in Figure 3 and 4.

Significantly, during the period 2008-2018 in the upstream of Ciliwung watershed, an increase in the built up area took place by 8.09% or an area of 1,182.55 Ha. The increase of built up area was characterized by increasingly dense settlements and the rapid development of hotels, villas and restaurants in the Puncak area, Bogor. An increase in area also occurred in the primary dryland forest area of 142.79 Ha. This is due to the handover of forest area management from Perum Perhutani III - West Java and Banten to the Mount Gede Pangrango National Park Center in 2014 (Dewi 2015). In addition, the increase in primary dry forest area is an effort of the Ciliwung - Citarum Watershed Management Agency to preserve forests through rehabilitation "Forest" programs.

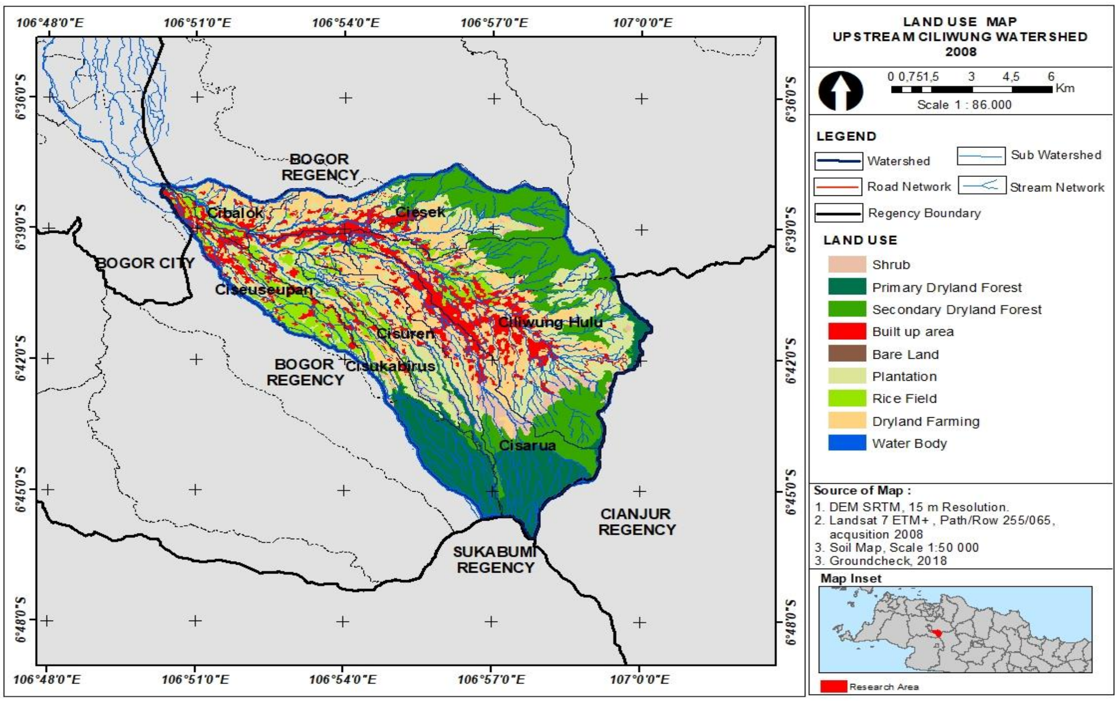

Figure 3. Land use map of the Upstream of Ciliwung Watershed in the year 2008.

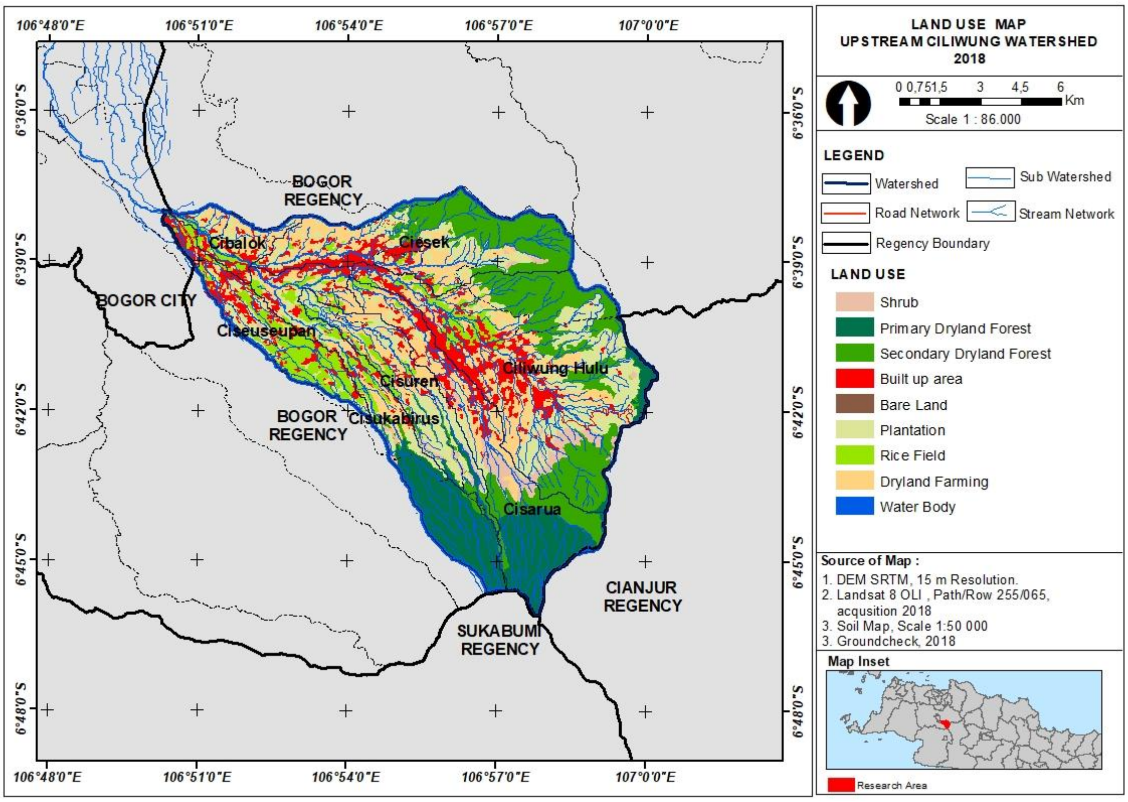

Figure 4. Land use map of the Upstream of Ciliwung Watershed in the year 2018.

Extensive decrease during the period of 2008-2018 was occurred in the land use of shrubs, secondary dryland forests, plantations, rice fields and dryland farming, of 125.82, 103.69, 24.30, 257.36 and 620.61 Ha respectively. This condition was in lined with the conversion of vegetation areas into built up area which is increasing in the Puncak area - Bogor. The results of the land use change analysis in the upstream of Ciliwung watershed is shown in Table 1, meanwhile the percentage of land use change is shown in Figure 5.

Table 1

The upstream of Ciliwung Watershed land use area in the 2008–2018 period

No	*Land use*	*Area (Ha)*		
		2008	*2018*	*Changes*
1	Shrub	577.20	451.38	-125.82
2	Primary dry land forest	1,853.23	1,996.02	142.79
3	Secondary dry land forest	3,002.35	2,898.66	-103.69
4	Built up area	1,903.41	3,085.96	1,182.55
5	Bare land	0.55	23.99	23.44
6	Plantation	2,999.15	2,757.85	-241.30
7	Rice field	1,321.55	1,064.19	-257.36
8	Dry land farming	2,912.61	2292,00	-620.61
9	Water body	47.57	47.57	0.00
	Total area (Ha)	14,617.62	14,617.62	

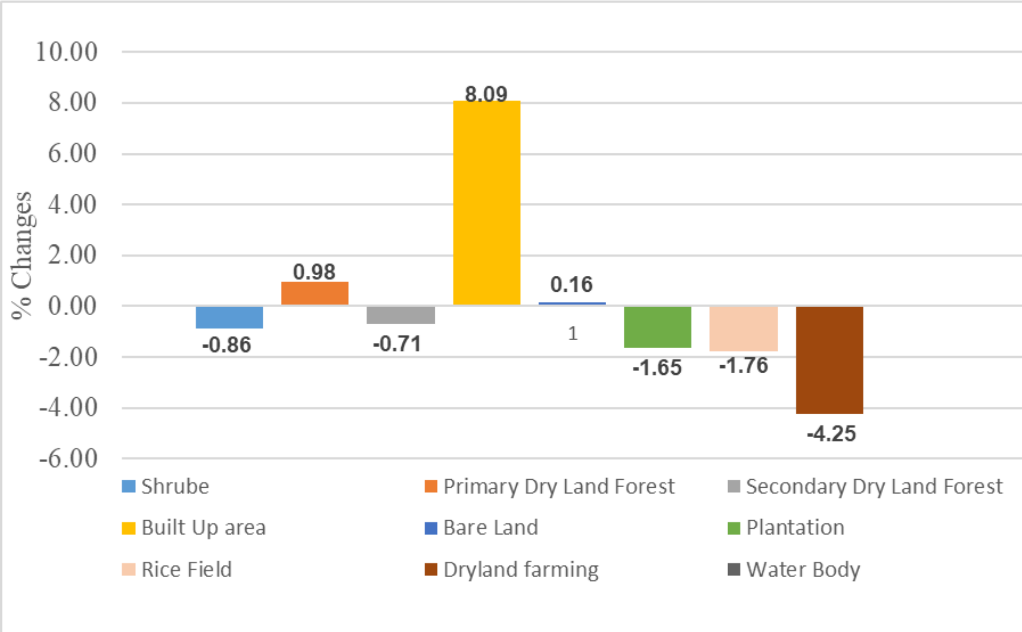

Figure 5. Land use change percentage during period of 2008–2018.

Impact of land use changes on the hydrological response. Specifically, the dynamics of land use change will have an impact on the hydrological response in a watershed area. The dynamics of hydrological characteristics show the performance of a watershed in ensuring the fulfillment of water needs. Hydrological responses assessed due to land use changes include surface runoff, CN, run off coefficient (C), River Regime Coefficient and annual flow coefficient. The results of the analysis of land use changes to the hydrological response in the upstream of Ciliwung watershed are presented in Table 2.

Table 2

Hydrological response in the upstream of Ciliwung watershed in the year 2008 and 2018

Year	*Rainfall*	*Surface runoff*	*Qmax*	*Qmin*	*CN*	*C*	*River regime coefficient*	*Annual flow coefficient*
	(mm/year)		*(m^3/second)*					
2008	3993	578.42	54.80	4.50	56.66	0.16	12.18	0.31
2018	3841	1,361.25	85.60	1.50	75.12	0.37	57.07	0.49

Qmax = Maximum discharge, Qmin = Minimum discharge, CN = Curve number, C = Runoff coefficient.

The existence of vegetation in an area will be closely related to the CN and surface runoff. The higher proportion of vegetation in an area will have an impact on the decrease in CN value and surface runoff. This indicates that the amount of rainfall received by a soil will be absorbed more than turning in surface runoff. During the period of 2008-2018, the value of the CN has increased from 56.6 to 75.12, this indicates a decrease in the vegetated area that has been converted to build up area in the upstream of Ciliwung watershed area. Distribution map of CN in 2008 and 2018 is shown in Figure 6 and 7.

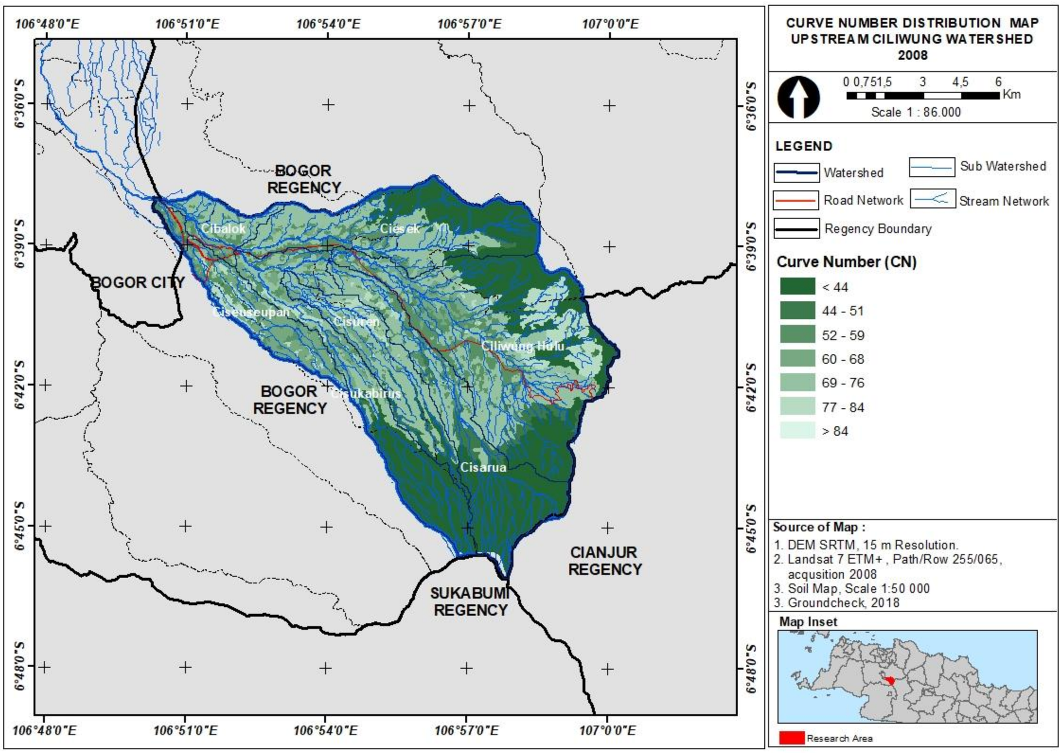

Figure 6. Curve number distribution map at upstream of Ciliwung watershed in year 2008.

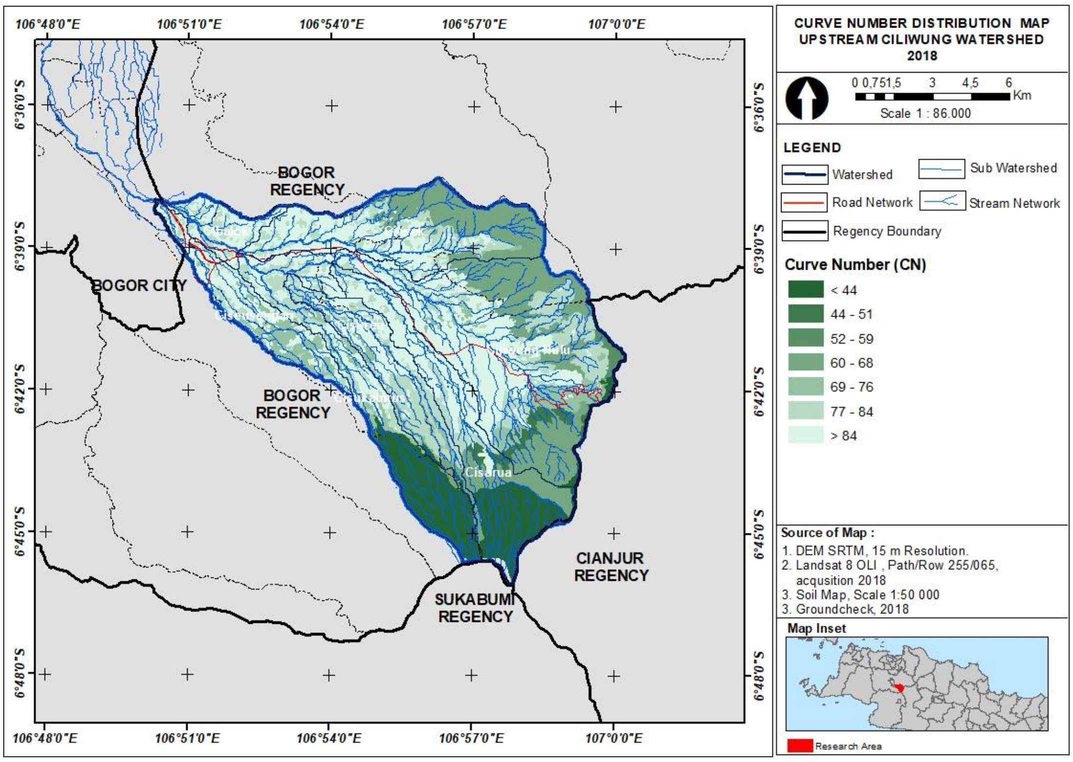

Figure 7. Curve number distribution map at upstream of Ciliwung watershed in year 2018.

The impact of increasing the CN will have an impact on increasing surface runoff. An increase in surface runoff from 578.42 mm/year in 2008 to 1,361.25 mm/year in 2018 took place. This condition is due to the reduced vegetation area, so that more rainfall that falls to the surface was channeled into surface runoff. The distribution of surface runoff in 2008 and 2018 is shown in Figure 8 and 9.

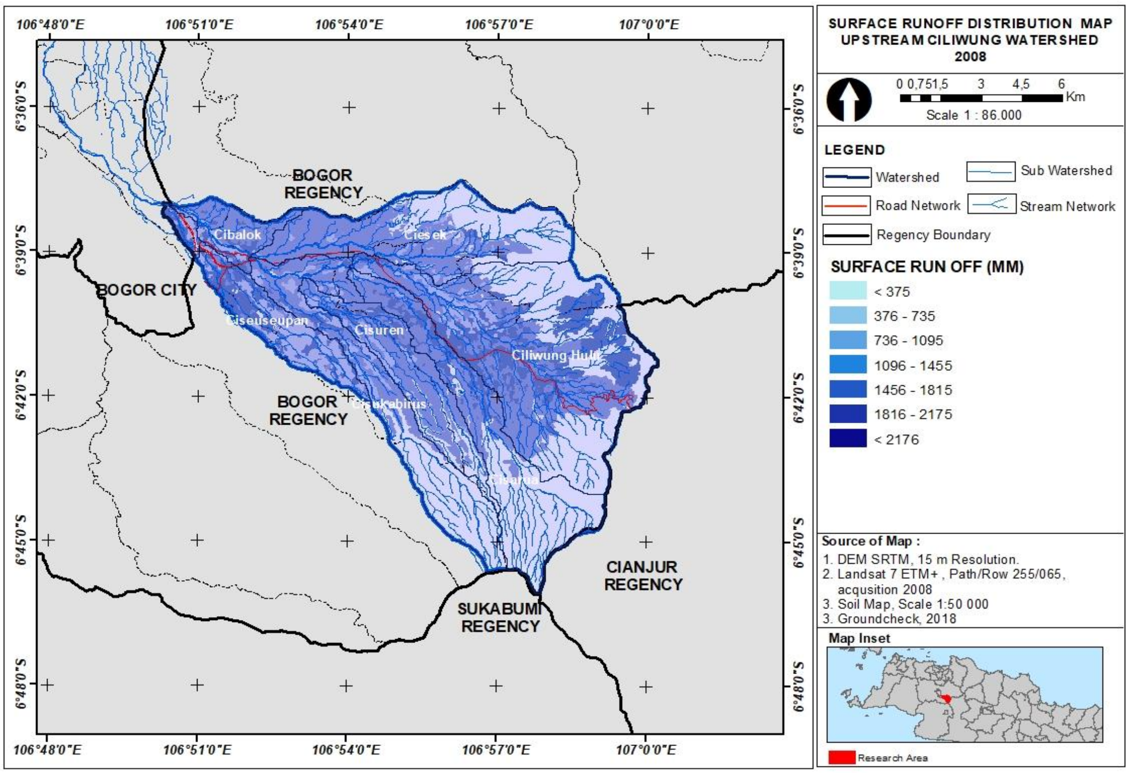

Figure 8. Surface runoff distribution map at upstream of Ciliwung watershed in year 2008.

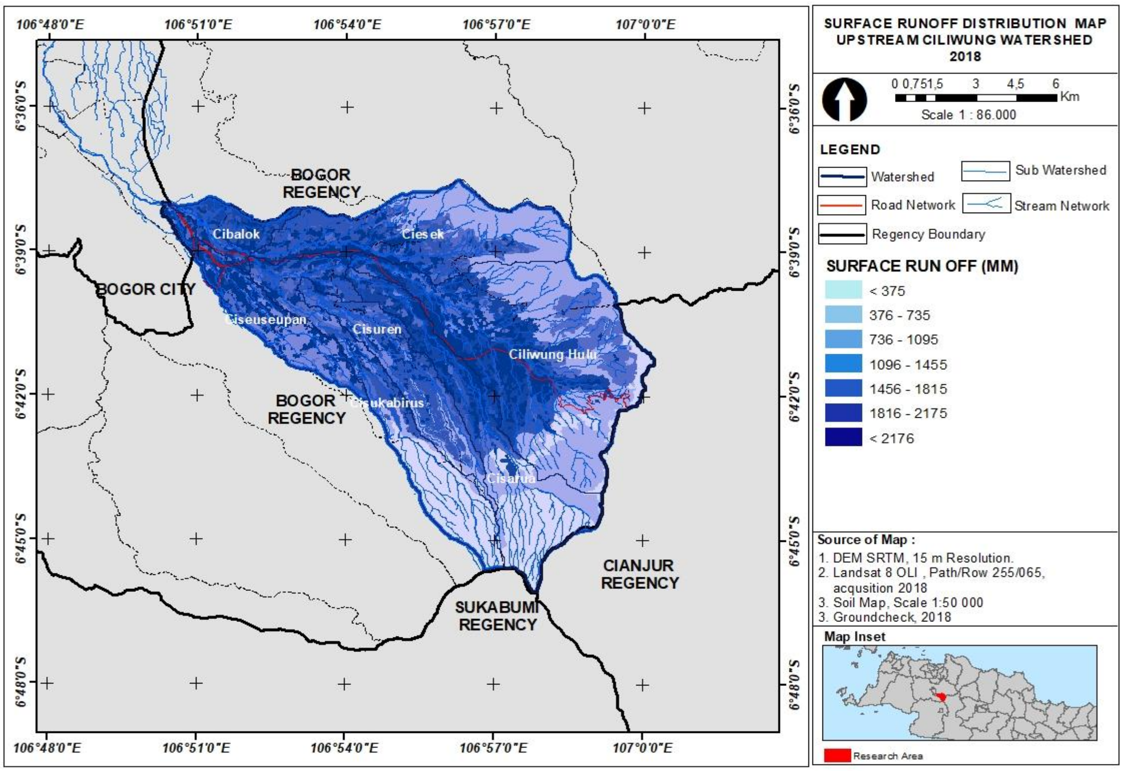

Figure 9. Surface runoff distribution map at upstream of Ciliwung watershed in year 2018.

Figures 10 and 11, shows the River Regime Coefficient Distribution Map in the upstream of Ciliwung watershed. River Regime Coefficient is the ratio between maximum discharge (Qmax) and minimum discharge (Qmin) in a watershed. A high River Regime Coefficient value indicates that the range of high surface runoff values in the rainy season, whereas in the dry season the water flow that occurs is very small or indicates drought.

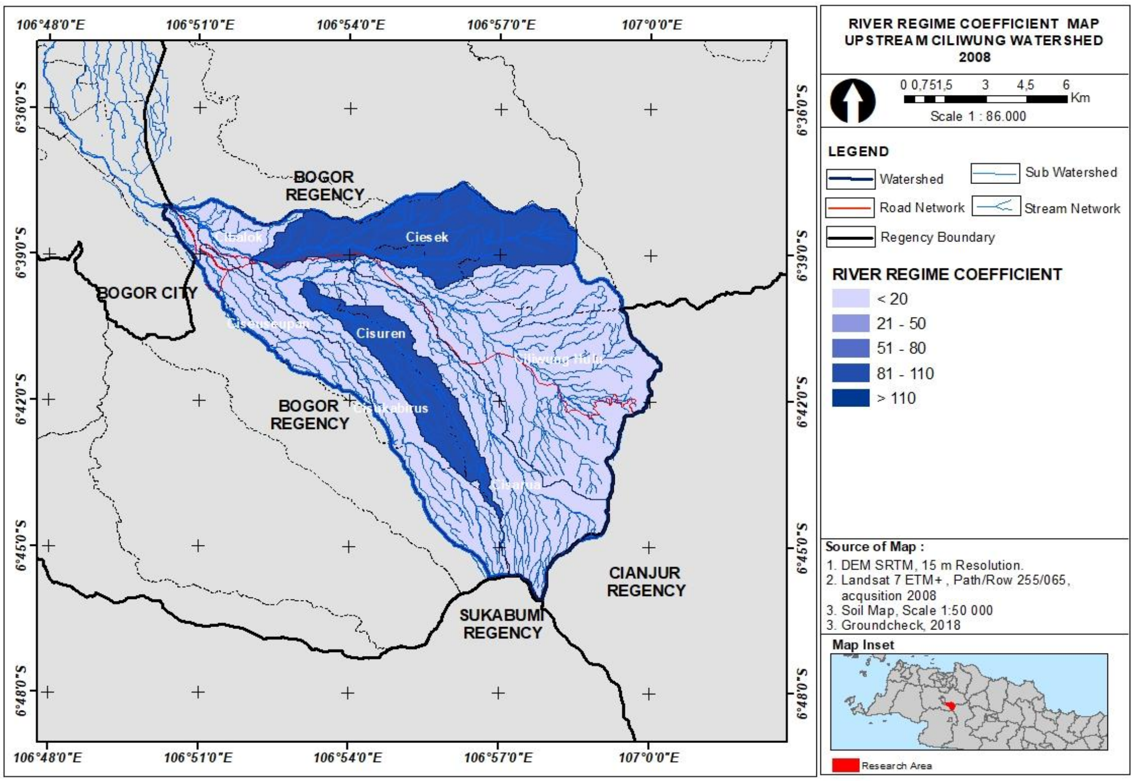

Figure 10. River regime coefficient map at upstream of Ciliwung watershed in year 2008.

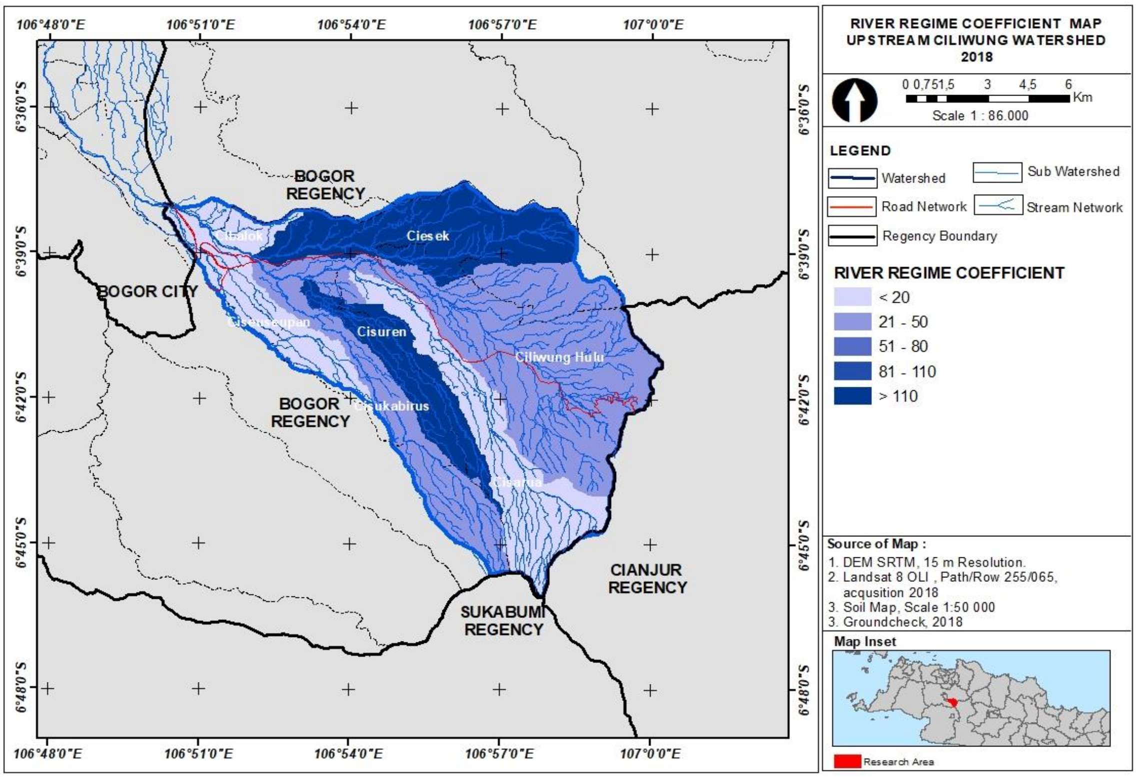

Figure 11. River regime coefficient map at upstream of Ciliwung watershed in year 2018.

Indirectly, this condition shows that the absorption capacity of the land in the watershed is less able to hold and store falling rainwater and runoff, many of which continue to enter the river and are discharged into the sea so that the availability of water in the watershed during the dry season is low. Based on the distribution map of River Regime Coefficient as a result of SWAT modeling, an increase in River Regime Coefficient value from 12.18 in the year 2008 to 57.07 in the year 2018 took place. This condition illustrates that water absorption in the upstream of Ciliwung watershed is decreasing. This condition was in line with the reduction in vegetation area, increasing CN value and increasing surface runoff during the period of 2008-2018.

The Annual Flow Coefficient is the ratio between the thickness of the annual flow (Q, mm) and the thickness of the annual rainfall (P, mm) in the watershed or what percentage of rainfall becomes the surface runoff in the watershed. The greater the value of the Annual Flow Coefficient indicates that most of the rainfall will be surface runoff rather than stored into ground water.

Based on the distribution map of the Annual Flow Coefficient in Figures 12 and 13, there is an increase in the value of the Annual Flow Coefficient in the upper Ciliwung watershed from 0.31 in 2008 to 0.49 in 2018. This condition indicates the percentage of the amount of rainfall falling in the upper Ciliwung watershed becomes more surface runoff rather than being stored water in the soil. This condition is also in line with the reduction of vegetation area which decreases the value of CN, increases the surface flow and increases the value of the coefficient of the diving river regime in the 2008-2018 period.

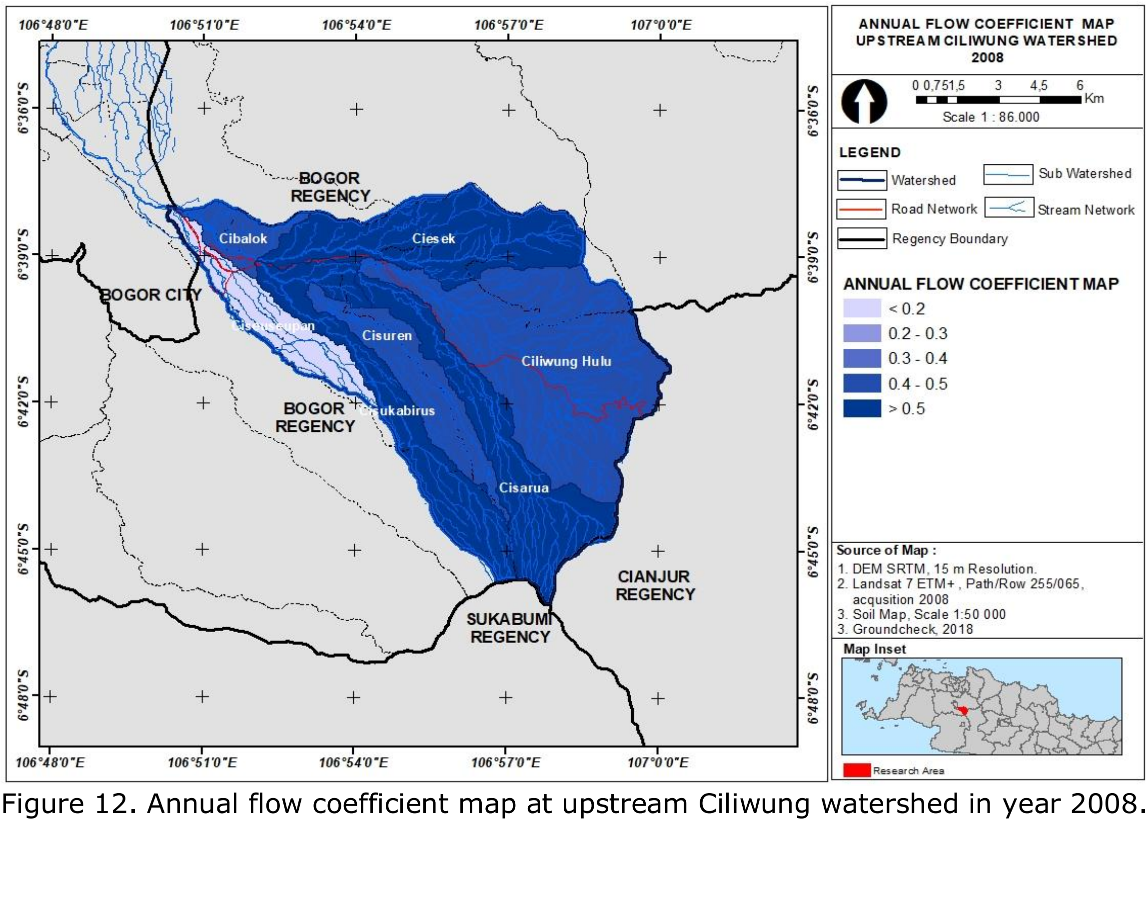

Figure 12. Annual flow coefficient map at upstream Ciliwung watershed in year 2008.

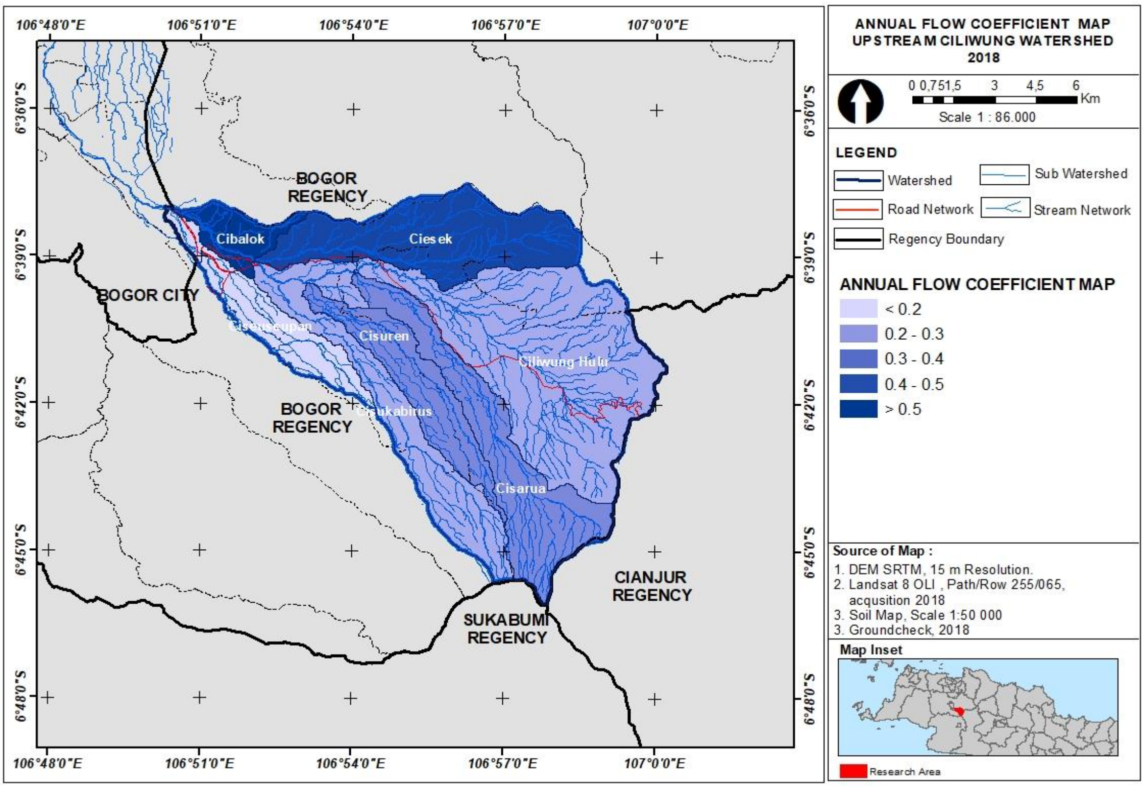

Figure 13. Annual flow coefficient map at upstream Ciliwung watershed in year 2018.

Conclusions. During the period of 2008-2018 in the upstream of Ciliwung watershed there has been an increase built up area by 8.09% (1,182.55 Ha). The dynamics of land use change that occurred had an impact on the hydrological response in the upstream of Ciliwung watershed. The SWAT model that was built was able to give good results and was able to describe the hydrological response resulting from land use changes in the upstream of Ciliwung watershed. The increase of built up area in 2018 had an impact on increasing CN values, surface runoff, river regime coefficients and annual flow coefficients, with 75.12, 1,361.25 mm/year, 57.07 and 0.49 respectively.

Acknowledgements. The authors would like to gratefully acknowledge support of: (1) Research and Social Service, Ministry of Ristekdikti, for funding this this research which is a part of Doctoral Dissertation Skim based on MoU with LPPM of Ibn Khaldun University; (2) Ibn Khaldun University, Bogor Regency, West Java Indonesia; (3) watershed and protected forest management agency of Citarum-Ciliwung, Ministry of Environment and Forestry.

References

Ali M., Hadi S., Sulistyantara B., 2016 Study on land cover change of Ciliwung downstream watershed with spatial dynamic approach. Procedia-Social and Behavioral Sciences 227:52-59.
Anand J., Gosain A. K., Khosa R., 2018 Prediction of land use changes based on Land Change Modeler and attribution of changes in the water balance of Ganga basin to land use change using the SWAT model. Science of the Total Environment 644:503-519.
Congalton R. G., 2001 Accuracy assessment and validation of remotely sensed and other spatial information. International Journal of Wildland Fire 10(4):321-328.
Dewi I. K., 2015 Evaluation of land use change in the upstream of Ciliwung watershed to ensure sustainability of water resources. Asian Journal of Water, Environment and Pollution 12(1):11-19.

Indriastuti D., 2016 Analysis of runoff due to the change in land use at the watershed of upstream Ciliwung. Journal of the Civil Engineering Forum 2(1):19-26.
Lee D., Han J. H., Park M. J., Engel B. A., Kim J., Lim K. J., Jang W. S., 2019 Development of advanced web-based SWAT LUC system considering yearly land use changes and recession curve characteristics. Ecological engineering 128:39-47.
Mubarok Z., Murtilaksono K., Wahjunie E. D., 2015 Response of land use change on hydrological characteristics of Way Betung Watershed-Lampung. Jurnal Penelitian Kehutanan Wallacea 4(1):1-10.
Osei M. A., Amekudzi L. K., Wemegah D. D., Preko K., Gyawu E. S., Obiri D. K., 2019 The impact of climate and land-use changes on the hydrological processes of Owabi catchment from SWAT analysis. Journal of Hydrology: Regional Studies 25 (100620). https://doi.org/10.1016/j.ejrh.2019.100620.
Ruspendi D., Hadi S., Rusdiana O., 2016 [Study of land cover change in the upstream of Ciliwung River Basin with a dynamic spatial approach]. Jurnal Lanskap Indonesia 5(2):1-5. [In Indonesian].
Yustika R. D., Tarigan S. D., Hidayat Y., Sudadi U., 2012 Simulation of land management in Hulu Ciliwung use SWAT Model. Informatika Pertanian 21(2):71–79.
*** SRTM, 2019 DEM SRTM with 30x30 m spatial resolution coveraging the upstream of Ciliwung Watershed. Available at: http://srtm.csi.cgiar.org/srtmdata/ Accessed: August, 2019.
*** USGS, 2019 Landsat Imagery 8 OLI coveraging the upstream of Ciliwung Watershed in the year 2018. Available at: http://glovis.usgs.gov/ Accessed: August, 2019.

Received: 12 July 2019. Accepted: 20 August 2019. Published online: 29 August 2019.
Authors:
Erwin Hermawan, Graduate School of IPB University, Study Program of Natural Resources and Environmental Management, Indonesia, West Java, 16680 Bogor, e-mail: rwien.gfm@gmail.com
Santun Risma Pandapotan Sitorus, IPB University, Faculty of Agriculture, Department of Soil Science and Land Resources, Indonesia, West Java, 16680 Bogor, e-mail: santun_rps@ipb.ac.id
Surya Darma Tarigan, IPB University, Faculty of Agriculture, Department of Soil Science and Land Resources, Indonesia, West Java, 16680 Bogor, e-mail: surya.tarigan@yahoo.com
Marimin, IPB University, Faculty of Agricultural Technology, Department of Agricultural Industrial Technology, Indonesia, West Java, 16680 Bogor, e-mail: marimin@ipb.ac.id

How to cite this article:
Hermawan E., Sitorus S. R. P., Tarigan S. D., Marimin, 2019 Spatial dynamics of land use change to hydrological response in the upstream of Ciliwung Watershed, West Java Province, Indonesia. AES Bioflux 11(2):122-132.