JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 6 No 2 2022

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Efforts to Reduce River Water Discharge through Land Use Control (Case Study: Upstream Ciliwung Watershed, Indonesia)

Shamira Nathania[1], Endrawati Fatimah[2]*, Benny B. Suharto[3]

[1,2,3] Urban and Regional Planning Department, Faculty of Landscape Architecture and Environmental Technology, Trisakti University, 11440, Indonesia

Corresponding Author e-mail*: endrawati@trisakti.ac.id

Received: October 11, 2022
Accepted: November 11, 2022
Published: November 11, 2022

Abstract

Land-use change is the main cause of high runoff compared to other factors. The type of land use also plays a role in determining the amount of runoff that occurs. The Upstream Ciliwung watershed is blamed as the main causes of the flood disaster in Jakarta, the capital city. The land use in the upper stream has changed and causes increasing of run off to be higher than the capacity of river to drain it. This study aims to explore the land use changes of the Upstream Ciliwung Watershed from 1996 to 2016 and their consequences on the stream run off. Furthermore, the study also recommends the efforts needed to reduce river water discharge. The land use changes are identified by using spatial analysis method. The calculation of run off uses the rational method. Average rainfall data for every ten years is calculated by use of Gumbell distribution formula. The study shows that in the period 1996 – 2016, there was a change in land use in the upstream Ciliwung watershed. The area that continues to decline includes primary forest, open land, paddy fields, shrubs, and mixed gardens, all of which are categorized as undeveloped areas. The runoff discharge from 1996 – 2016 has increased from 278.77 to 465.57 mm/second that indicate runoff discharge is already in the Standby I position. Efforts that need to be made to reduce runoff water flow in the Ciliwung watershed are: 1) consistently develop and control land use change in the area based on the Jabodetabekpunjur Spatial Planning 2) consistently apply the building coverage ratio (BCR) regulation; 3) construct engineering and technology approach such as build infiltration wells in settlement, 4) forest rehabilitation and 5) conducting law enforcement.

Keywords: Ciliwung Watersheh; Land Use; Water Discharge

1. Introduction

Land use is a form of activity utilizing the land to meet certain needs. Land-use change is an increase in land use from one side of use to another at a certain time. Land-use change is defined as a change from one type of land use to another. Land conversion can be permanent or temporary. If technically irrigated agricultural land is turned into housing or industry, the conversion of this land function is permanent [Asdak, 2004). Land use has a close relationship with the hydrological cycle. Land use change is one of the main contributing factors affecting discharge in watershed (Konkul *et al.,* 2014; Waiyasusri *et al.,* 2016; Chotpantarat *et al.,* 2018). Each type of land use has specific capacity of infiltration. Then, land use change might increase or decrease in infiltration and, in turn, a decrease or an increase in the rate and volume of surface runoff (Chotpantarat, *et al.,* 2018; Klongvessa, *et al.,* 2017).

Ciliwung watershed is one of watershed in Java Island, Indonesia. This watershed is popular because Jakarta, the capital city, is in the downstream. During rainy season, Jakarta almost always experiences floods which are mostly suspected come from the Ciliwung river. In the last ten years, floods in Jakarta tend to get worse. The uncontrolled land use change in the upstream watershed is blamed as the main cause of the flood. The upstream Ciliwung watershed is covered around 15,225.13 hectares. Based on the Spatial Plan Regulation, the upstream area is mostly for conservation area (2654,90 hectares) and rural settlements which characterize as very low (class B5) – low density (class B4) settlement (Presidential

Regulation Number 60 of 2020 on Spatial Planning for Jakarta. Bogor. Depok. Tangerang. Bekasi. Puncak and Cianjur (Jabodektabek-Punjur))

This study aims to identify the land use changes in the upstream Ciliwung watershed and to calculate the water discharges from 1996 to 2016. Water discharge is the volume of water flowing through a river cross section per unit time. Extreme water discharge indicates that the river will be prone to overflow. So water discharge may become of flood's indicators (Hasanah *et al.,* 2013). Based on the water discharge calculation, some recommendations are given to reduce the discharge or runoff through land use control.

2. Methodology

This research method used is descriptive quantitative research, which is one type of research that aims to describe systematically, factually, and accurately the facts and characteristics of a particular population or try to describe the phenomenon in detail (Sugiyono, 2009). The analysis methods in this research use spatial analysis with super imposed technique and mathematical analysis using rational method. The data needed in this research is time-series data to find out changes in phenomena that occur during 1996 – 2016 and mostly is secondary data collecting from government institutions (Zuma *et al.,* 2017). The overlay technique will later translate the resulting map into a table to see the influence of the variables determined by changes in runoff water discharge in this study area.

To find out the maximum runoff water discharge, first needs to estimate maximum rainfall intensity that represent rainfall data for one period (10 years). The formula used in this analysis is Gumbel distribution by using monthly rain fall for one period. The rainfall results from the calculation, then are used to calculate the runoff water discharge using the Rational Method. The formulas use in this study are follow:

1. Gumbel distribution is used to calculate the possibility of maximum rainfall in 10 years period (Suripin, 2004.; Bhagat, 2017). The equation of Gumbel distribution method as follows:

$$R_{24} = \bar{X} + \frac{S_X}{S_n}\left(Y_t \_ Y_n\right)$$

Where:
R24 = The maximum daily rainfall 24 hours (mm/24 hours)
X = Average rainfall (mm)
Sx = Deviation Standard
Yn = Reduced mean

2. Mononobe equation is used to calculate the intensity of rainfall in mm per hour based on the maximum daily rainfall 24 hours calculated with Gumbel distribution equation. The Mononobe equation as follows (Suripin, 2004 .; Bhagat, 2017).

$$I = \frac{R24}{24}\left(\frac{24}{t}\right)^{2/3}$$

Where:
I = Rainfall Intensity (mm/hours)
R24 = The maximum daily rainfall (24 hours) (mm)
t = Rain Duration (24 hours)

3. Rational Method is used to calculate the runoff water discharge (Dunne. 2018)

Q=C.I A
Q = Maximum surface runoff rate (m3/s)
C = Surface runoff Coefficient
I = rainfall intensity (mm/hours)
A = Total Area (ha)
The value of C depends on the land cover, as shown in Table 1

Table 1. Surface runoff Coefficient (C) based on Land Cover

No	Use/Cover Land	Score C
1	Primary Forest	0.01
2	Secondary Forest	0.05
3	Mixed agriculture	0.5
4	Field	0.5
5	Plantation	0.5
6	Bush	0.3
7	Ricefield	0.2
8	Pavement	0.7
9	Open Space	0.95
10	Settlement	0.9

Source: Dunne&Leopold, 1978 (Dunne, 2018)

3. Result and Discussion

The analysis of land use changes in the Upper Ciliwung uses data for the year of 1996, 2006, and 2016, as shown in Tabel 1. The data show that generally unbuild land use areas, that are primary forest, open field, rice field, bush, and mixed agriculture, tend to be continuously decrease. On the other side, built-up area in the form of settlement seems to be increasing significantly.

Table 2. Land Use of the Upstream Ciliwung Watershed in the 1996, 2006 and 2016

No	Land use	1996		2006		2016		Land Use Change 1996-2016 (ha)
		Hectare	%	Hectare	%	Hectare	%	
1	Primary Forest	547.95	3.60	547.95	3.60	518.46	3.41	(29.49)
2	Secondary Forest	2.408.98	15.82	1,560.91	10.25	2,811.54	18.47	402.56
3	Open Field	20.36	0.13	20.36	0.13	0.59	0.00	(19.77)
4	Ricefield	7,671.23	50.39	6,849.02	44.98	520.22	3.42	(7,151.01)
5	Bush	100.32	0.66	100.32	0.66	29.85	0.20	(70.47)
6	Mixed agriculture	2873.91	18.88	3,706.72	24.35	2,097.89	13.78	(776.02)
7	Plantation	545.77	3.58	545.77	3.58	1,035.67	6.80	489.90
8	Field/Dryland farming	694.79	4.56	694.79	4.56	5,952.72	39.10	5,257.93
9	Settlement	361.82	2.38	1,199.29	7.88	2,258.19	14.83	1,896.37
	Total Land Use	15,225.13	100.00	15,225.13	100.00	15,225.13	100.00	

Table 2 also shows that the most change in area is the land for rice field. It decreases more than 7000 ha and almost extinct. The rice field area is very possible to turn into settlement area or use for dry land farming. Primary forest that should be conserved also decreased. During 1996 – 2006, the area of primary forest had been maintained, but since 2006 the area tends to decrease. It can be seen from Figure 1, that the primary forest seems to change into secondary forest and bush. That means the forest has decrease in quality as a water catchment area because it is cultivated.

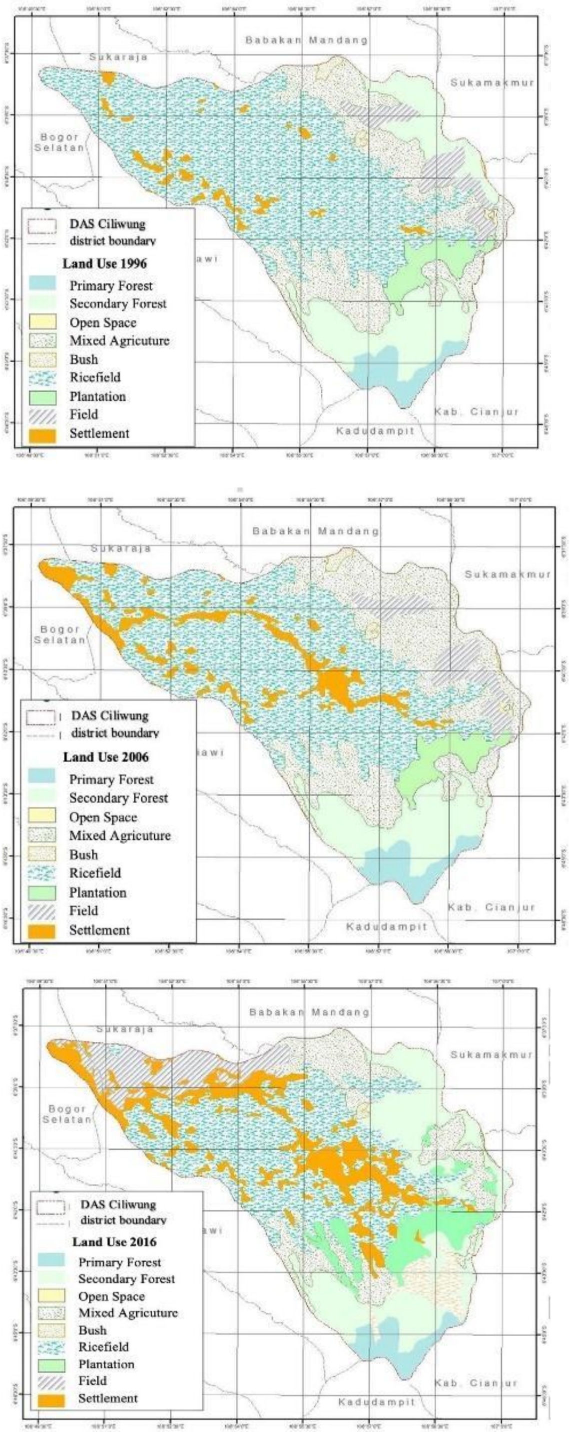

Figure 1. Land Use of The Upperstream Ciliwung Watershed in 1996, 2006 and 2016

Figure 1 also shows that very intensive land use change from undeveloped land to settlements occurs in the middle of the catchment area parallel to the river and located along and around the main road. During 2006 -2016, in the northern part, close to the middle stream watershed, there is also a massive change in paddy fields. Most of the rice fields turned into dry land. It is estimated that this change is a temporary change before it become the settlements and/or other use of built-up land.

As mentioned before, the land use changes have a close relationship with the proportion of volume of water absorbed by the soil and the volume of water that flows into surface water. By using the rational method, Table 4 shows the result of calculations of runoff water discharge based the land use data in 1996, 2006 and 2016 shown in Table 3. The value of maximum rainfall intensity uses in this study is calculated using Gumbel distribution methods and monthly rainfall data from 1996 – 2016. The calculation result shows that the maximum rainfall intensity is 24.52 mm/hour which is then used as the value of “I” in the rational method formula. The value of “C” in the rational formula, that is the surface runoff coefficient, is based on the C value for each land use as shown in table 1. The result of Runoff Water Discharge calculations for 1996, 2006 and 2016 is demonstrated in Table 3

Table 3. Runoff Water Discharge Values in m^3/sec in the years of 1996, 2006 and 2016

Land Use	C	1996	2006	2016
Primary Forest	0.01	0.37	0.37	0.35
Secondary Forest	0.05	8.20	5.32	9.58
Open Space	0.95	1.32	1.32	0.04
Rice field	0.2	104.51	93.31	7.09
Bush	0.3	2.05	2.05	0.61
Mixed agriculture	0.5	97.88	126.24	71.45
Plantation	0.5	18.59	18.59	35.27
Field	0.5	23.66	23.66	202.74
Settlement	0.9	22.18	73.52	138.44
Total Runoff water Discharge		278.77	344.38	465.57

The total runoff calculated in this study is the maximum possible runoff because the rainfall intensity value used is maximum based on rainfall time series data from 1996 – 2016. The total runoff value of the upstream Ciliwung watershed is an indicator that can be used to predict whether Jakarta, the downstream part of the watershed, will be flooded or not. BPBD (Regional Disaster Management Agency) Jakarta Province uses the Katulampa Weir Warning Level Criteria to estimate the occurrence of flood disasters. The Katulampa Weir is part of the flood early warning system of Ciliwung River (Farika *et al*., 2018). The weir is located in the boundary upstream and middle stream Ciliwung Watershed. The total runoff water discharge from the upstream can be estimated by observing the water level in the weir. For example, if the water level measurement in the weir shows that the water level is 80 cm, it means that water discharge from upstream is around 90.05 m3/sec. Ciliwung discharge in Katulampa Weir be known with water level reading which will be converted using rating curve. Table 5 shows the Katulampa Weir Warning Level Criteria.

Tabel 4. Katulampa Weir Warning Level Criteria

Warning Level (Alert)	Water Level Limit (cm)	Discharge Limit (m3/sec)
I	200	441.98
II	150	276.25
III	80	90.05
IV	0	0

Source: Farika, N, D. Sutjiningsih and E. Anggraheni, 2018 (Farika N. et.al 2018).

Warning Level (alert) I, with a water level of 200 cm and a discharge of 441.98 m3/sec, means that about 9 to 12 hours later, it is almost certain that there will be flooding in the Jakarta city. The maximum water discharges based on the condition of land uses in 1996, 2006 and 2016, then, can be classified using the Katulampa Weir Warning Level Criteria.

Table 5. Classification of Warning Level

Years	Calculated runoff water discharge (m3/Second)	Warning Level/Alert
1996	278.77	Alert II (276 sd 441 m3/dt)
2006	344.38	Alert II (276 sd 441 m3/dt)
2016	465.7	Alert I (>441 m3/dt)

Table 5 shows that with the condition of land uses in upstream Ciliwung watershed as in 2016, Jakarta would be flooding if it rains with intensity 24.52 mm per hour and it lasts for 24 hours. There for, this study tries to find recommendations to reduce the water discharge from more than 441 m3/sec to be in the Warning Level II. The recommendation is formulated based on the Jabodetabekpunjur Spatial Plan and at the same time, the study can show whether the land use plan, if implemented consistently, has considered the water discharge limit or not.

Based on the Jabodetabekpunjur Spatial Plan, the upstream Ciliwung watershed is comprised 2 (two) main categories of land uses, that are protected area (L) and settlement area (B). The settlements in the study area are classified into 5 (five) types of settlement zone. The land use plan of the upstream Ciliwung watershed can be seen in Table 6 and Figure 2.

Table 6 Land Use Plan of The Upstream Ciliwung Watershed based on President Regulation Number 60 of 2020

Land Use	Zone Code	Area (ha)	Percentage of total area (%)	Spatial Development Guidelines
Protected Area	L3	2654.90	17.44	Conservation area that can be in the forms of nature reservation areas or national parks
Settlement Area	B1	1432.96	9.41	High density settlement area, and high intensity urban centre
	B2	1035.31	6.80	Medium density settlement area and medium intensity urban centre
	B3	5814.84	38.20	Low – Medium density settlement area, agro-industrial area, tourism area, military zone area
	B4	4280.52	28.11	Low density settlement area, plantation area, agro-industrial area, agriculture area, tourism area dan production forest
	B5	6.58	0.04	Agricultural area
	Total	15225.12	100	

Source: President Regulation Number 60 of 2020 on the Jabodetabekpunjur Spatial Planning (Presidential Regulation Number 60 of 2020 on Spatial Planning for Jakarta. Bogor. Depok. Tangerang. Bekasi. Puncak and Cianjur (Jabodektabek-Punjur)).

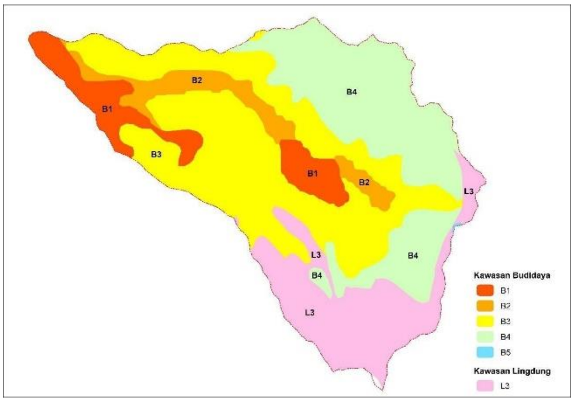

Figure 2. Land Use Plan of The Upstream Ciliwung Watershed

(**Source:** remapped based on President Regulation No 60 of 2020 on the Jabodetabekpunjur Spatial Planning)

It can be seen from the table and the figure, most dominant land use in the upstream Ciliwung watershed is settlement area classified as low to medium (B3 and B4). Those two zones of settlement cover around 66.31%. The protected area that covers 17.44% also is relatively dominant among other land uses. This land use planning shows that the upstream Ciliwung as a part of the whole watershed area tends to have a specific function as water catchment area that should infiltrated rain waters as much as possible. It means that the planning has considered the importance of the area in the context of hydrological cycle.

It also can be proven by calculating the runoff water discharge use by using the land use plan as shown in Tabel 7. The result shows that the value of Q, runoff water discharge, is estimated as 377.97 m3/second. Based on the warning level criteria (refer to Table 5), the planned runoff water discharge is below the limit of Warning Level I. That means that the flood disaster in Jakarta, the downstream area, would not occur or at least if there is a flood, it is not caused by overflowing water from the upper area.

Table 7. Runoff Water Discharge of the Upstream Ciliwung Watershed use the Land Use Plan

No.	Zone	Area (Ha)	C	I (mm/hours)	Q(m3/second)
1	B1	1432.96	0.9	24.52	87.85
2	B2	1035.31	0.6	24.52	42.31
3	B3	5814.84	0.4	24.52	158.43
4	B4	4280.52	0.3	24.52	87.47
5	B5	6.58	0.2	24.52	0.09
6	L3	2654.90	0.01	24.52	1.81
	Total	15225.12			377.97

Considering that the results of calculating runoff water discharge using the land use plan indicate a relatively safe level for flooding in Jakarta, the recommendations proposed in this study will assume that the regulation of the Jabodetabekpunjur Spatial Plan is implemented consistently. Tabel 8 shows the comparison between the 2016 land uses and the land use plan including their runoff water discharges. Zone B1 that covers 1432,92 hectare is in a good condition since Q existing stands lower than Q as it is plan. Zone

B1, as mentioned before, is permitted to develop as high-density settlements. However, the development must pay to attention that upper zone of watershed has function as a water catchment area and has an important role as flood control for the lower zone (Handayani IGAKR. *et al.,* 2017.;Sudia *et al.,* 2021). With that consideration, the recommendations for Zone B1 are the area can still be developed, but it should be restrictedly. Some specifics guidelines for settlement development are applying Low Building Coefficient (BCR) standard and equipped with infiltration wells. Constructing infiltration wells in every individual or communal plot is recommended because infiltration wells have functions to reducing surface stream to minimize and prevent flood and inundation as well as to maintaining and increasing groundwater-surface height (Hirijanto *et al.,* 2021).

The Q existing in Zone B2 has exceed what it should be even though not too much. The recommendations for settlement area in Zone B2 are similar with these recommended in Zone B1 but as far as possible no expansion. The field or yard area seems to contribute the high volume of surface runoff. Therefore, the recommended farming method in this area is to apply agroforestry techniques or practices. As the FAO affirms that the definition of “agroforestry that is a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence” (Santoro, et.al 2020) . The agroforestry practices have many benefits to the farmers in following ways (Hirijanto *et al.,* 2021 .; Alao, 2013):

a. Consistent restoration of the fertility status of the soil
b. A variety of products
c. Prevention of wind and water erosion by trees acting as wind break and intercepting the raindrop impact on the soil respectively.
d. Improving the micro-climate effect
e. Restoration of water table to an absorbable level for crops use.
f. Increased income opportunities and economic stability
g. Reduce cost for establishing plantation
h. Increased ability to manage for sustained yield.
i. Hence, the advantages of agroforestry cover the social, economic, and environmental benefits to the farmers.

Table 8. Comparison between the existing land uses and the Jabodetabekpunjur land use plan and its implication to the Q value

BASED ON THE SPATIAL PLAN				BASED ON THE EXISTING CONDITION					Comparison and its Implication
Zone	Area (Ha)	C	Q plan (m^3/sec)	Land	Area (Ha)	C	Q existing (m^3/sec)		
B1	1432.96	0.90	87.85	Field	291.82	0.50	9.94	62.02	Q existing < Q plan Settlement can be further developed but should be restrictedly such as with low Building Coefficient Ratio (BCR) and
				Settlement	766.19	0.90	46.97		
				Ricefield	374.95	0.20	5.11		
B2	1035.31	0.60	42.31	Field	310.56	0.50	10.58	48.21	Q existing > Q plan The value of C should decrease. Settlement development must apply low BCR and equipped with infiltration wells. Field or yard is cultivated by using agroforestry concept
				Settlement	581.98	0.90	35.68		
				Ricefield	142.77	0.20	1.95		
B3	5814.84	0.40	158.43	Secondary Forest	200.81	0.05	0.68	215.26	Q existing > Q plan The value of C should decrease. Settlement development must apply low Building Coefficient Ratio and equipped with infiltration wells. Applying agroforestry concept.
				Mixed agriculture	277.82	0.50	9.46		
				Field	4108.07	0.50	139.91		
				Plantation	369.92	0.50	12.60		
				Settlement	858.22	0.90	52.61		
B4	4280.52	0.30	87.47	Secondary Forest	1475.05	0.05	5.02	101.57	Q existing > Q plan Applying agroforestry concept.
				Mixed agriculture	1282.91	0.50	43.69		
				Field	900.27	0.50	30.66		
				Plantation	540.64	0.50	18.41		
				Settlement	51.80	0.90	3.18		
				Bush	29.78	0.30	0.61		
B5	6.58	0.30	0.22	Mixed agriculture	1.07	0.50	0.04	0.17	Q existing ≈ Q plan The condition should be maintained
				Plantation	3.01	0.50	0.10		
				Rice field	2.50	0.20	0.03		
L3	2654.90	0.01	1.81	Primary Forest	518.46	0.01	0.35	38.33	Q existing > Q plan The L3 must be rehabilitated to its planned use and function such as by conducting reforestation
				Secondary Forest	1135.68	0.05	3.87		
				Mixed agriculture	536.07	0.50	18.26		
				Plantation	122.10	0.50	4.16		
				Field	342.00	0.50	11.65		
				Open land	0.59	0.95	0.04		
	16226.11		**378.10**	**TOTAL**	**16226.11**			**486.57**	

As shown in Table 8, Zone B3 seems to tend to develop very intensively and uncontrollably as well as deviations from the Spatial Planning Regulation. Zone B3 is planned to be low – Medium density settlement area. agro-industrial area. tourism area. military zone area (refer to Table 7). Same as the Zone B3, the value of Q Zone B4 existing also exceeds the Q plan. The recommendations for the settlement areas are that the settlement should be maintain as low density settlement and completed with infiltration wells. The agricultural uses are dominantly in Zone B3 and B4 either in the form of field or yard, mixed agricultural and plantation. Again, the cultivations in these areas must be planted with perennial crop or by applying the agroforestry concept. The tree planting must be close to the secondary forest characteristics in terms of its density and variety of crop. So, the value of C can be decrease, which means the capacity of infiltration can be increase significantly.

The Q value of Zone L3 is also higher that it should be. Different with other zones, Zone L3 as the protected area is forced to be rehabilitated. From table 8, it can be seen some areas of L3 are occupied for agricultural purposes which have lower infiltration capacity than forests have. Hence, the recommendation for Zone L3 is conducting the forestation programmes to increase the quality of its function as protected area.

4. Conclusion

In the period 1996 – 2016. there was a change in land use in the upstream Ciliwung watershed. The area of land use that continues to decline includes primary forest. open land. rice fields. and mixed agriculture. all of which are categorized as undeveloped areas. Consequently. the runoff discharge from 1996 – 2016 has increased from 278.77 mm/sec to 465.57 mm/second. Most of the undeveloped land has been converted into residential use. and fields. By using the maximum assumption of rain intensity (I) equal to 24.52 mm/hour. the runoff discharge in 2016 is already in the warning level I. This means that the runoff discharge from the upstream Ciliwung watershed will cause flooding in the downstream (Jakarta). This study alsp proposes some recommendations for reducing runoff water flow in the upstream Ciliwung watershed that are the Jabodetabekpunjur Spatial Planning as regulated in The President Regulation Number 60 of 2020 must consistently implemented and became the legal basis for any determination letters. Settlement development may still have the permission to be developed in the upper stream. though it is recommended to implement low BCR zoning regulation. infiltration wells. and to locate the development in zone where the Q existing is lower than Q plan. Finally, the upstream Ciliwung watershed only develop it is necessary to apply the basic building coefficient ratio (BCR) that have been regulated in the Jabodetabekpunjur RTR and it is necessary to apply engineering technology such as infiltration wells. Finally. it is highly recommended to maintain the function of the upstream Ciliwung watershed as a water catchment area. Therefore. it is very necessary to increase I nfiltration capacity as well as controlling runoff volume through restoring protected functions in conservation areas. applying the concept of agroforestry on agricultural land and conducting law enforcement. This study concludes that law enforcement related to land use is very important and must be properly implemented to prevent or mitigate flood disasters in downstream areas.

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