Journal of Ecohumanism
2025
Volume: 4, No: 3, pp. 70 – 86
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i3.6255

Synthesis on the Impact of Land Cover Conversion towards Water Quantity and Quality

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Abstract:

This research intends to establish a policy on watershed management based on the land use recommendation and an analysis of land cover conversion to per-urban location towards water quality and discharge which many sub-watersheds in Indonesia are in critical condition due to the frequent event of flooding, drought, and landslide. It is further worsened by the changes of land cover in the watershed that causes to increase in surface runoff which also affects the water quality in the watershed. Watershed condition can be restored by management if the correct implementation and regulation is effective. Out of 458 watersheds in Indonesia, 60 of them were very critical, 222 were critical, and the remaining 176 were in endangered condition. One of the critical watersheds is Ciliwung watershed. Furthermore, public participation is a key in managing watershed. The methodology consists of collecting the primary data as a benchmark for simulation by using SWAT; the regression model is used for covering the water quality while the water discharge analysis is performed through hydrological simulation. Then socio-economic survey is conducted to evaluate public willingness and capacity to participate in the watershed management. The result of simulation shows that sediment and nitrate is positively affected by water discharge while phosphate is negatively affected by it. The conversion of forest into agriculture significantly increases the nitrate and sediment production in while phosphate is not really affected. Meanwhile, in the watershed overall, surface runoff, nitrate, and phosphate are increasing drastically. The result of survey shows that most people that are living in the watershed do not have the funding or yard to participate in the watershed management. This result is a recommendation which reduces the agriculture land use by 10% and allocating it for water management.

Keywords: *water quality, discharge, SWAT analysis, land cover, public participation.*

Introduction

Currently many areas in Indonesia are in a very critical condition due to the frequent event of flooding (Adhikari, 2013), drought, and landslide. One of the factors that trigger this natural disaster is the increase of surface water runoff (College of Resources and Environmental Sciences, 2014). The volume of the surface runoff has tight correlation with the environment conditions of a watershed. Watersheds in Indonesia undergo an environmental damage each year. In 2013, out of 458 watersheds in Indonesia, 60 of them were in a very critical condition, 222 in critical condition, and the remaining 176 is in critical potential due to changes in watershed land use. According to Government Regulation No.37 Year 2012 about watershed management, watershed condition has been categorized into (1) maintained watershed where the watershed condition is still good and (2) watershed where the condition needs to be restored due to degradation. Currently, the amount of critical watershed in Indonesia is increasing and according to *Rencana Pembangunan Jangka Menengah* (RPJMN) years 2015-2019, government has set 15 watersheds out of 108 critical watersheds as a restoration priority. These watersheds are Citarum, Ciliwung, Cisadane, Serayu, Solo, Brantas, Kapuas, Siak, Musi, Asahan Toba, Jenebarang, Moyo, Way Sekampung, and Limboto (KLHK, 2018). Ciliwung river, as a strategic river that flows through West Java and Jakarta, is categorized as priority watershed out of the 15 watersheds. High population growth in Ciliwung watershed causes more than 50% of the watershed's area to be covered by settlement (Pramono, et al., 2016). Other than that, this matter is worsened by land conversion that is not accompanied by soil and water conservation effort (Asmaranto et. al, 2024) as well as implementation of development direction in addressing natural resources issue national guideline that's not very clear. Conversion of land into agriculture, moor, settlements, and industrial activities contribute to changes in geomorphology, hydrological processes, soil characteristics, and water quality in local or regional scale (Wan et. al, 2014).

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There are 2 factors that affect the surface runoff volume, meteorological and physical factor on the area. One of the physical factors that is highly affecting the surface runoff is land cover. In vegetation dense area rainfall will be retained on the vegetation and infiltrate to soil through it so the runoff is minimum. On the other hand, when the surface is impervious rainfall that supposed to infiltrate will instead flow over causing increase runoff (Laoh, 2002). Surface runoff is one of the key factors (Tama et. al, 2023) in supporting water resource management activities. Other than that, land cover conversion affects watershed water quality (Tikno, 2002). The effect of land use (Juwono et.al, 2019; Penington and Radeloff, 2014.) towards water quality is highly correlated with watershed management (Departemen Kehutanan dan perkebunan (Dephutbun), 1998).

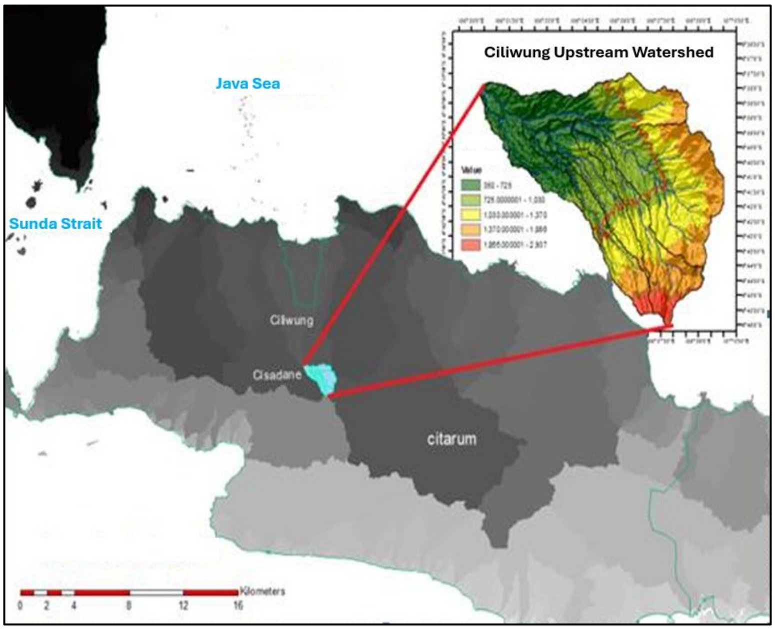

Figure 1. Upstream Ciliwung Watershed Location

Source: Samsudin, (2016)

Furthermore, the conversion of land cover cause a decrease in water quality by increasing sediment, nitrate, and phosphor leechate from soil. Due to land cover conversion, rainfall are not absorbed into soil and increase the runoff. The excess runoff then will transport sediment and kontaminant from the soil. Kontaminant leechate hen is tworsened by usage of nitrate base fertilizer where it will increase nitrate composition in water body (Laoh, 2002; Ward, et. al, 2018; Shuman, 2003). To reduce the impact of sediment and contaminant leechate, it is important to restore the land cover in Ciliwung Upstream watershed to its optimum condition. Space management policy is an important aspect to remedy the watershed condition, thou it is mandatory full public participation for its to be optimum. Thus the recommendation for water conservation policy will be based on public survey willingness in managing their living environment and aiding government to create water conservation. It is imprtant to anlayze the impact land cover conversion gave towards water quality and quantitiy as well as a recommendation on how to remedy it with public participation.

Methodology

This research is conducted in the upstream part of Ciliwung Watershed by utilizing SWAT as a material simulation tool that affects the water quality and discharge. The continuous discharge simulation uses FJ Mock model and the flood discharge uses SCS-CN model. The simulation result for water discharge and rainfall is calibrated with the result of field measurements and the calibration result is checked with NSE and R^2. Water quality is simulated by using SWAT and the result of multi-variable regression is used to

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determine the correlation between land cover conversion with water quality, while land cover conversion correlation with water volume is conducted by using the surface runoff simulation.

Data that is required in this research are as follows:

- Topographical map with the scale of 1:25.000 that includes Ciliwung Upstream Watershed (BIG)
- Ciliwung Upstream Watershed River map the scale of 1:25.000 (BIG)
- Land use map (BBWS Ciliwung Cisadane) from years 2000, 2005, 2011 & 2017
- Daily rainfall data from 3 rainfall stations on the years 2000 - 2019 (BMKG and BBWS Ciliwung Cisadane)
- Climate data on the years 2000 – 2019 (BMKG and BBWS Ciliwung Cisadane)
- AWLR discharge records in watershed on the years 1998 – 2019 (Katulampa)
- Water quality data (primary and secondary).
- Public survey on the watershed management willingness.

Results and Discussion

This research is conducted by simulating the impact of land cover conversion towards water quality and volume by using SWAT. The research initiated by collecting the sample of primary data for water quality and quantity to conduct the NSE and R^2 value of the simulation. Data sampling is collected in 13 locations throughout the Ciliwung Upstream Watershed. Data that was taken included the quality and discharge of water. The sampling location was taken in the location and it is presented in Table 1.

Table 1. Primary data collection location

No	Sub-watershed	Location Number	Name of location	coordinate LS	coordinate BT	Village/District/City
1	Ciliwung Hulu 1	1	Behind Stall	06°42'15.56"	106°58'57.75"	Tugu Selatan
2	Ciliwung Hulu 2	2	River Across Road	06°41'53.60"	106°59'08"	Tugu Utara
3	Ciliwung Hulu 3	3	Indomaret Intersection	06°41'45.47"	106°58'10.96"	Tugu Selatan
4	Ciliwung Hulu 4	4	Indomaret	06°41'45.8"	106°58'10"	Tugu Selatan
5	Ciliwung Hulu 5	5	Arab Villa	06°41'15.5"	106°57'28.9"	Tugu Selatan
6	Ciliwung Hulu 6	6	Buena Vista	06°40'42.1"	106°56'39.2"	Batulayang, Cisarua
7	Ciliwung Hulu 7	7	Sirnarasa Street	06°40'0.5"	106°55'58.3"	Jogjogan
8	Cisarua	8	Kopo Street	06°40'23.6"	106°55'25.7"	Kopo
9	Cisuren	9	End Point of Lembah Nendeut Street	06°40'15.00"	106°53'53.1"	Sukakarya

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No	Sub-watershed	Location Number	Name of location	coordinate LS	coordinate BT	Village/District/City
10	Cisukabirus	10	Lembah Nendeut Street	06°39'52.70"	106°52'39.9"	Gadog
11	Ciesek	11	Luthfi Villa	06°39'05"	106°52'03.6"	Pasir Angin
12	Cibalok	12	Chicken Shed	06°38'32"	106°51'15.6"	Pasir Angin
13	Ciseuseupan	13	Seuseupan Bridge	06°38'47.2"	106°50'39"	Sindangsari

Source: Sutjiningsih, 2018

The primary data collection for water quantity and quality with quality index of WQI, Habitat, and FBI is presented in Table 2. Data collection was performed between May until August.

Table 2. Sample Collection Result for Water Quality and Quantity

No	Sub-Watershed	Sampling Location	Sampling Time	Discharge	WQI	Habitat	FBI
1	Ciliwung Hulu 1	Behind Stall	May & July	0.09	72.5	2.56	5.16
2	Ciliwung Hulu 2	River Across Road	May	0.27	68.0	2.44	4.50
3	Ciliwung Hulu 3	Indomaret Intersection	July	0.65	78.0	2.13	6.04
4	Ciliwung Hulu 4	Indomaret	May & July	0.33	72.5	1.75	6.72
5	Ciliwung Hulu 5	Arab Villa	May & July	1.18	72.5	2.38	3.13
6	Ciliwung Hulu 6	Buena Vista	May & July	0.69	73.5	1.88	5.18
7	Ciliwung Hulu 7	Sirnarasa Street	August	0.37	70.0	2.38	5.77
8	Cisarua	Kopo Street	August	0.80	79.0	1.69	7.61
9	Cisuren	End Point of Lembah Nendeut Street	August	1.34	78.0	2.38	5.04
10	Cisukabirus	Lembah Nendeut Street	August	0.65	77.0	2.88	4.24
11	Ciesek	Luthfi Villa	May & July	15.79	70.5	2.31	5.14
12	Cibalok	Chicken Shed	May & July	0.27	70.0	2.56	4.93
13	Ciseuseupan	Seuseupan Bridge	May & July	0.84	69.5	1.56	5.21

Source: Sutjiningsih, 2018

The conversion of land cover is compared for every ten years since 1990. The forest is seen a decrease in land cover every year since 1990 while land for agriculture and settlement keep increasing. The changes of land cover every 10 years can be seen in the figure below.

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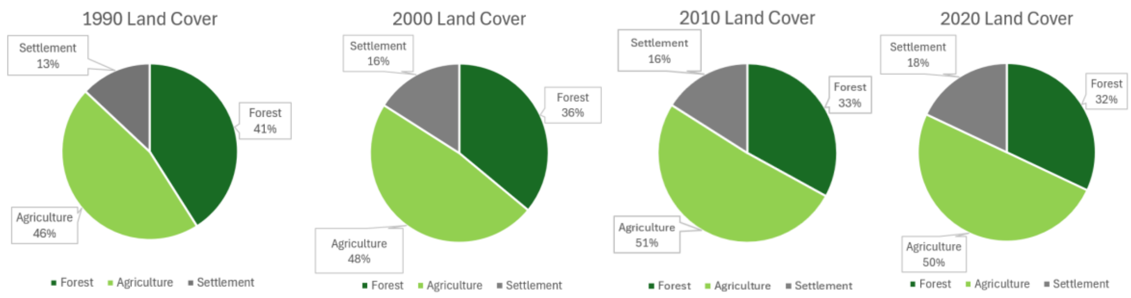

Figure 2. Land Covers Conversion Years 1990-2020

Source: own study

This research is conducted with the deterministic method and is represented by 2 largest watersheds where one of them is mostly covered with agriculture and the other one covered with forest and agriculture. Based on the condition, sub-watershed-8 and 15 is the most suitable watershed for this analysis. Therefore, the quality and quantity analysis with SWAT is based on the sub-watershed-8 and 15. Detail of the sub-watershed in Ciliwung Upstream watershed can be seen on the figure below.

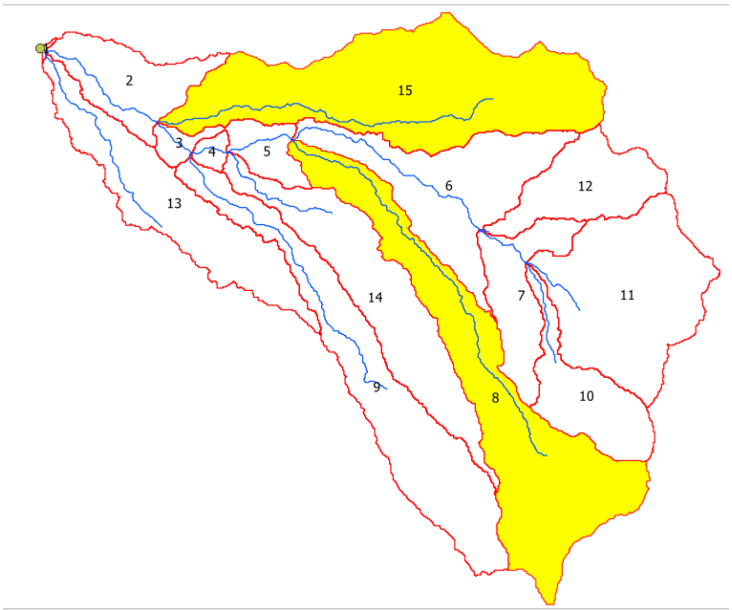

Figure 3. Ciliwung Upstream Sub-Watershed Detail

Source: own study

The validation and calibration between the observed rainfall intensity and the observed discharge at Katulampa shows a good correlation within each other. The validation of rainfall is performed by examining the trend of the discharge at katulampa with the rainfall data at Gadog and Perk Gunung rainfall station. The trend between the rainfall and discharge at Katulampa shows a similar trend which indicates good correlation between rainfall and discharge.

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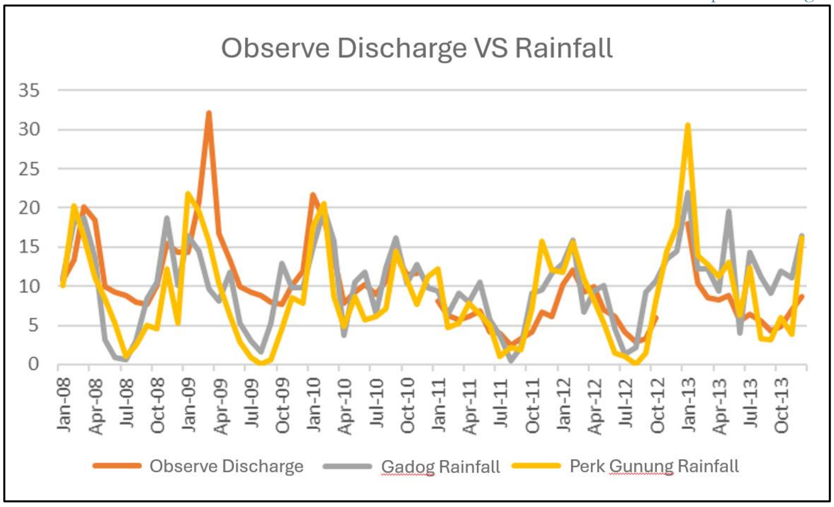

Figure 4. Discharge Correlation at Katulama Water Gate with Rainfall Intensity at Rainfall Station

Source: own study

The calibration between simulation and observed discharge is compared with R^2 and NSE method. The correlation value is 0.66 which indicates good corelation between both data. But, NSE value is -1 which indicates some error in the simulation model.

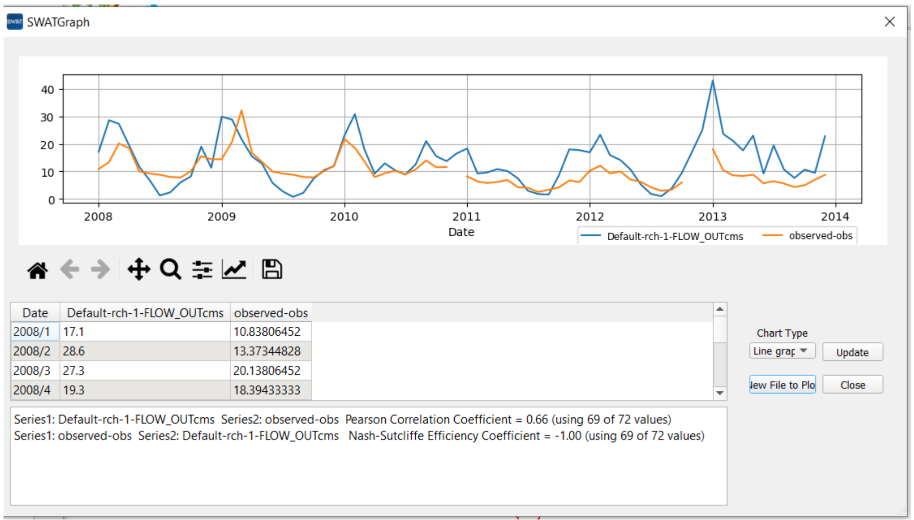

Figure 5. SWAT Simulation Calibration with Observed Discharge

Source: own study

Water quality analysis is performed by simulating the land cover due to the meteorological condition. The results of SWAT simulation are discharge, sedimentation, NO_3, NH_4, Phosphor, and DO for river. The result from SWAT simulation shows high output when the river colour is res and low output when the colour is green for sedimentation and contamination. As for water discharge indicates that the darker the blue causes the higher the discharge. Each component simulation result can be seen in Figure 5 – 10 and Table 3.

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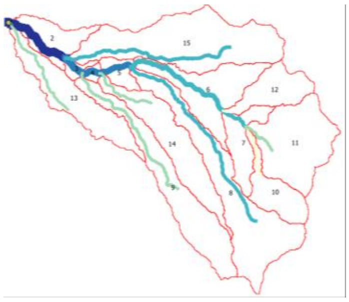

Figure 6. Discharge

Source: own study

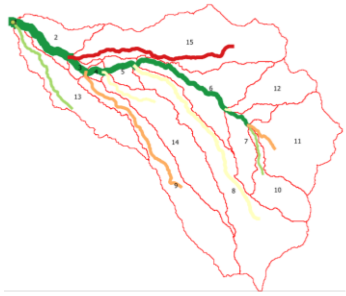

Figure 7. Sediment

Source: own study

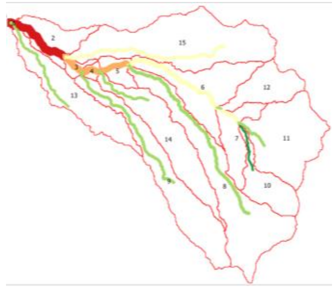

Figure 8. NO_3

Source: own study

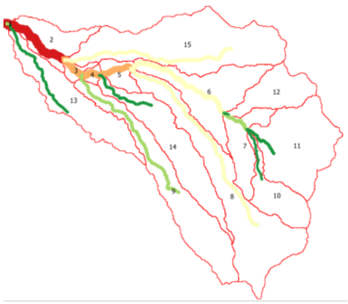

Figure 9. NH_4

Source: own study

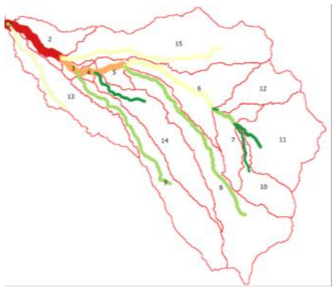

Figure 10. Phosphor

Source: own study

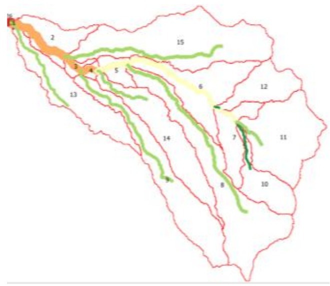

Figure 11. DO

Source: own study

Tabel 3. Output of River Due to the SWAT Simulation

Sub-watershed	Discharge (m^3/s)	Sediment (ton/month)	NO_3 (kg)	NH_4 (kg)	P (kg)	DO (kg)
8	1.459-4.236	505423-979604	1330-5552	24-77	15-42	1849-5279
15	1.459-4.236	129443-2300078	5552-14907	24 – 77	42-138	1849-5279

Source: own study

The result of watershed simulation by SWAT are percolation, surface runoff, baseflow, surface sediment, nitrogen, and phosphor on the sub-watershed surface. The simulation result displays small value with cream on percolation, surface runoff, and baseflow while high value is shown with blue. As for sediment, nitrogen, and phosphor, small value displayed by green and high value with red. Sub-watershed simulation result can be seen in Figure 11-17 and detailed result in Table 4.

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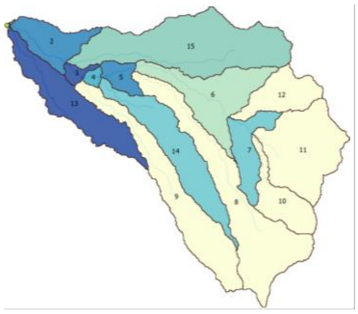

Figure 12. Percolation

Source: own study

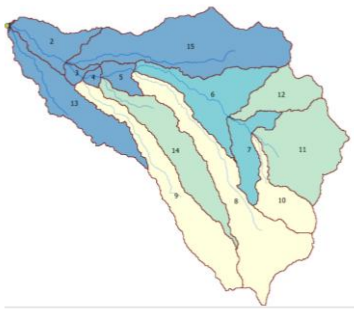

Figure 13. Surface runoff

Source: own study

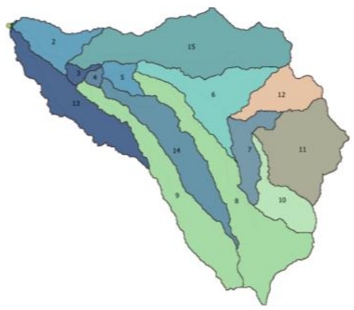

Figure 14. Baseflow

Source: own study

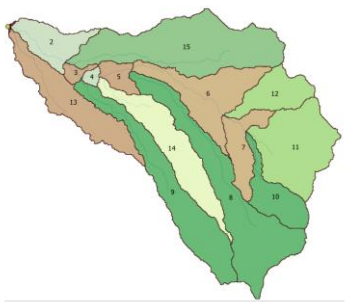

Figure 15. Sediement

Source: own study

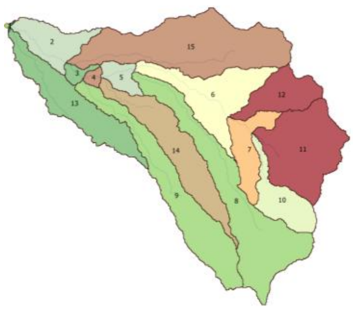

Figure 16. Nitrogen

Source: own study

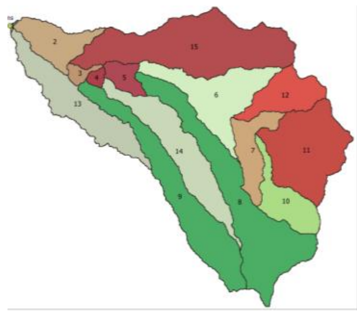

Figure 17. Phosphor

Source: own study

Tabel 4. Output sub-watershed Due to the SWAT Simulation

Sub-DAS	Percolation (mm)	Runoff (mm)	Baseflow (mm)	Sediment (kg/ha)	Nitrogen (kg/ha)	Phosphor (kg/ha)
8	49-56	101-105	45-52	0.3	3.3-4.3	0.7
15	56-73	128-169	52-68	0.34-0.4	4.7-5.4	1

Source: own study

The correlation of land use with surface runoff discharge performed by hydrological simulation and water quality simulation utilize MANOVA, friedman analysis, and regresion analysis. The result of correlation anaylsis of land cover conversion based on the Figure 2 with meteorological condition can be seen in Table 5.

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Table 5. Surface Runoff as the Result of Land Cover Conversion

Year	Sub-ws-8 discharge (m^3/s)	Sub-ws-15 discharge (m^3/s)
1990	42.8	49.2
2000	53	61.1
2010	55.7	64.1
2020	60.6	69.6

Source: own study

The correlation analysis between land cover conversion with water quality is performed by using three methods of analysis. MANOVA shows that phosphate is the only variable that highly affected by land cover conversion with a significant value of 0.027 and the coefficient of determination is 33.1%.

Tabel 6. MANOVA Analysis Result

Dependent Variabel	Type III Sum of Squares	df	Average	F value	p-value
Debit	1.059[a]	5	.212	.000	1.000
Fosfat	2938.959[b]	5	587.792	2.971	.027
Sedimen	10.135[c]	5	2.027	.001	1.000
Nitrat	15958.788[d]	5	3191.758	.263	.930

a. R Squared = 0.000 (Adjusted R Squared = -0.167)
b. R Squared = 0.331 (Adjusted R Squared = 0.220)
c. R Squared = 0.000 (Adjusted R Squared = -0.166)
d. R Squared = 0.042 (Adjusted R Squared = -0.118)

Source: own study

Friedman analysis is an analysis to determine the similarity of treatment effects on groups/populations. Different with MANOVA result, Friedman analysis result shows a few impacts of land cover conversion to phosphate, nitrate, and sedimentation.

Table 7. Friedman Analysis

Dependent Variable	Friedman (p-value)	Explanation
Debit	8,631 (0,125)	Unreal
Fosfat	243,94 (0,000)	Real
Sedimen	69,89 (0,000)	Real
Nitrat	268,784 (0,000)	Real

Source: own study

The regression analysis was performed with the value of $\alpha = 0,05$. The parameter notation for each parameters are:

H_{01}: No effect of discharge to phosphate

H_{11}: Signifficant effect of discharge to phosphate

H_{02}: No effect of discharge to sediment

H_{12}: Signifficant effect of discharge to sediment

H_{03}: No effect of discharge to nitrate

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H_{13}: Signifficant effect of discharge to nitrate

Table 8. Regression Analysis Result

Model	B	Std. Error	t	p value.
Constant	2.4035	.204	11.792	.000
Nitrat	.000011	.00000245	4.678	.000
Phosphate	-.0003	0	-1.067	.3
Sediment	.0009	.0000224	39.655	.000

Source: own study

From the table above, it is shown that the significant value is less than 0.05 which indicates the significant of all parameters. R-square value as high as 0.983 indicates that all parameters are affected by discharge. This regard also supported by the fact that t value shows phosphate have negative impact on discharge while sediment and nitrate have positive impact to discharge by the function

$$Discharge = 2.4035 + 0.000011 * Nitrate - 0.0003 * Phosphate + 0.0009 * Sediment$$

$$\left(m^3/_s\right) \quad \left(m^3/_s\right) \quad \left(\frac{kg * m^3}{second * kg}\right) \quad \left(\frac{kg * m^3}{second * kg}\right) \quad \left(\frac{kg * m^3}{second * kg}\right)$$

Explanation of function above is as follows:

- Every increase in 1 phosphate unit will reduce the discharge unit in 0.003 with the other variables stay constant.
- Every increase in 1 sediment unit will reduce the discharge unit in 0.003 with the other variables stay constant.
- Every increase in 1 nitrate unit will reduce the discharge unit in 0.003 with the other variables stay constant.

The effect of land cover conversion is the increase in sediment and contaminant in water body. The result from 1990 – 2030 can be seen in the diagram below.

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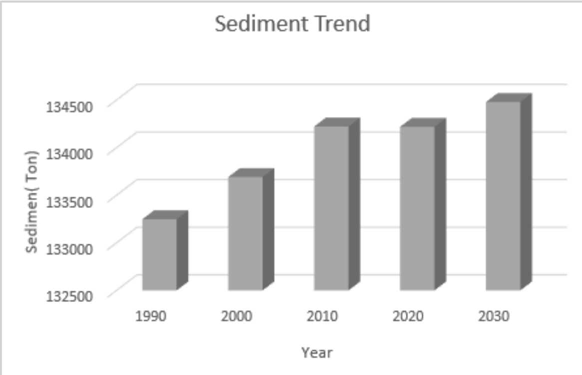

Figure 18. Sediment Trend

Source: own study

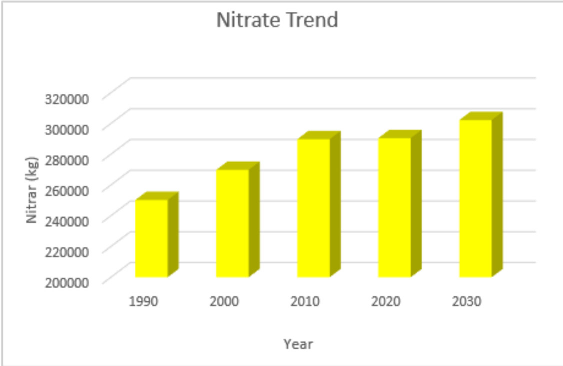

Figure 19. Nitrate Trend

Source: own study

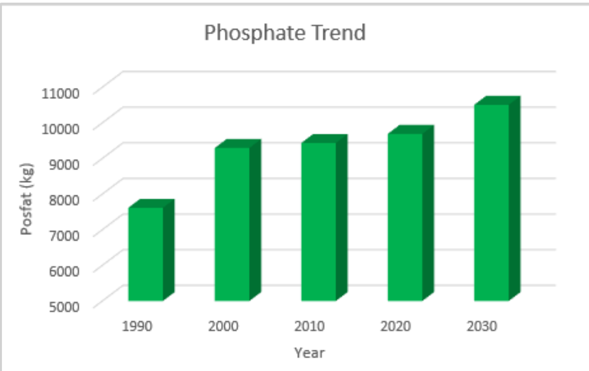

Figure 20. Phosphate Trend

Source: own study

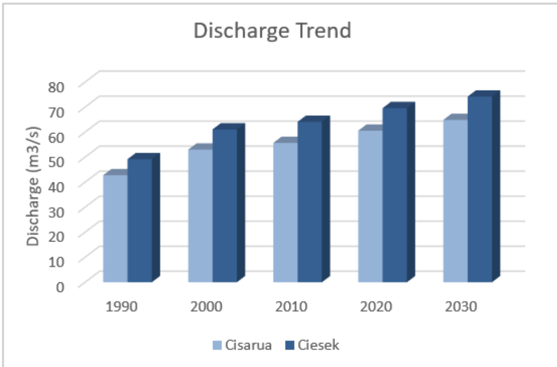

Figure 21. Discharge Trend

Source: own study

Due to the ever-increasing trend of discharge, sediment, and contaminant, it is important to recommend a watershed management policy. The recommendations come from the public participation willingness in managing their watersheds. From their willingness, then it can be simulated the possible land cover conversion to the better. The research initiated by performing a survey to public regarding their basic personal information, their willingness to contribute as an individual and as a community, and their current action in preserving the environment (Figure 22).

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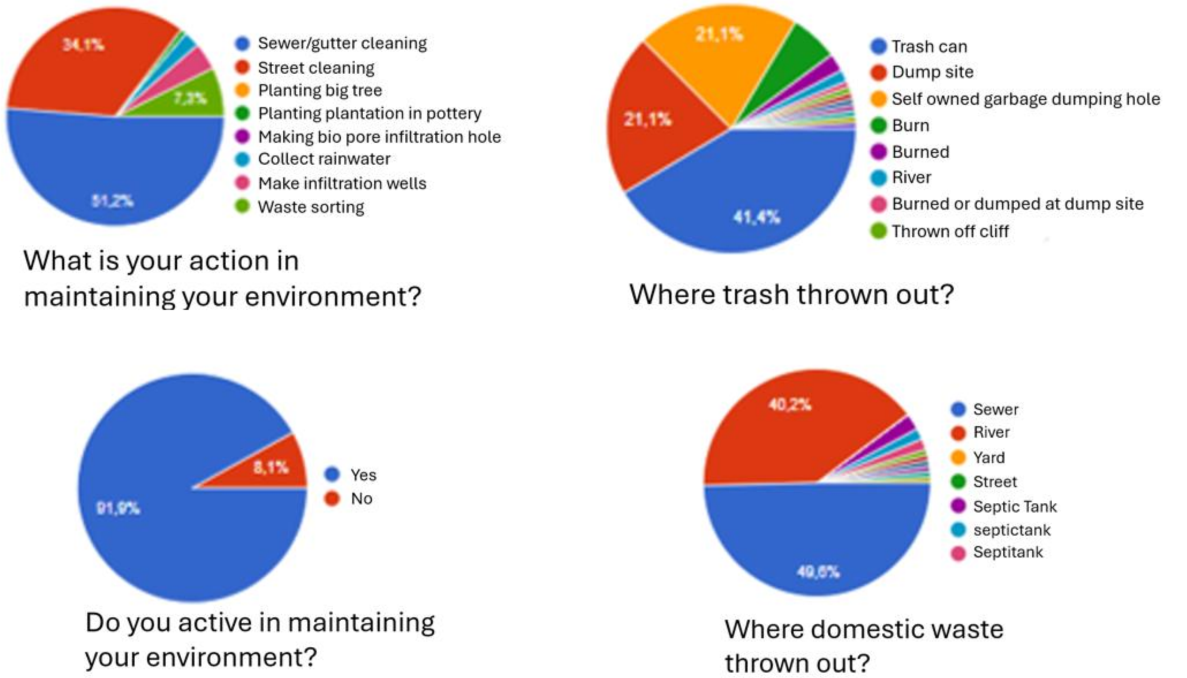

Figure 22. Public participation in managing drainage

Source: own study

This survey portrays the participation of public in maintaining drainage in their living environment. This shows how 91.9% of people in the watershed still maintain the environment despite their action in disposing waste which is not environment friendly.

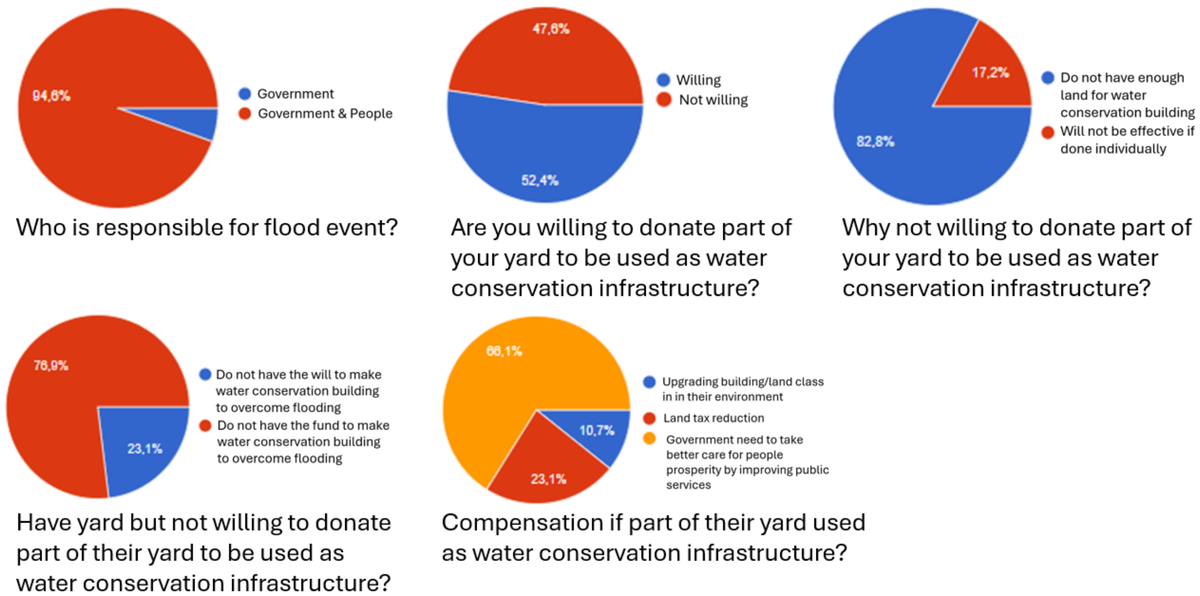

Figure 23. Public Willingness in Contributing Independently

Source: own study

When the public were given the option to participate in environemnt management by donating part of their yard for water conservation, 47.6% are not willing to donate their land. It is due to the majority of them

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does not have yard that can be used for water conservation while the other is will not be effective enough if it was done individually. For the other who have yard but not willing for it to be used, majortiy of them does not have the fund to construct water conservation infrastructure while the other just does not want to.

Then people were asked to rank the alternative for water conservation from the most attractive to the least attractive. The most attractive alternative is when they only recieve the water conservasion infrastructure without doing any works (85 repondents), the next attractive is the aid in form of workforce and materials in form of fund (82 respondents), and the third is compensation for land that is used as water conservation in the form of funds (79 repondents). However, the least attractive alternative is in the form of tax relaxation (41 respondents) and when they were only given the design specification of the infrastructure (18 respondents).

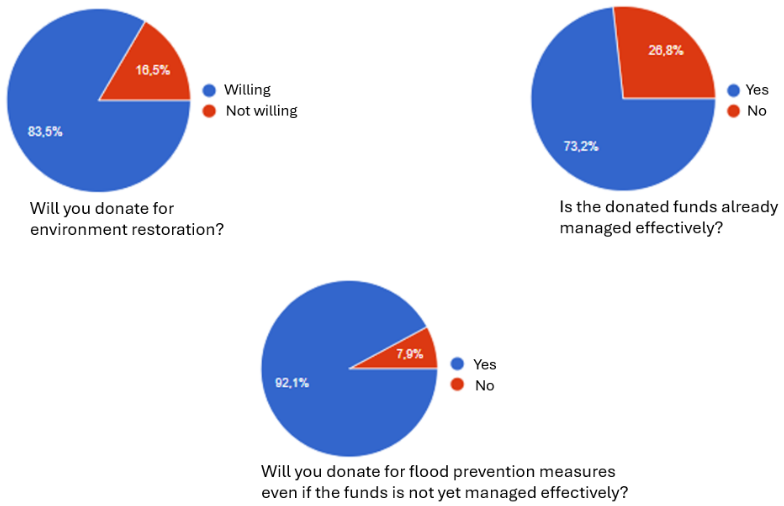

Figure 24. Public Willingness in Contributing on Community

Source: own study

But the different result in the participation willingness is shown when the environment management effort is done through the communal work instead individually. When the public were asked for their participation willingness by donating fund to manage their living environmnet, 83.5% of them were willing to donate funds for the effort. Unfortunately, more than 25% of repondents still think that the donated fund have not been effectively used. Despite of it, 92.1% state that they were not reluctant to donate their private funds to overcome flooding.

Based on the public survey, then a simple recommendaiton for water friendly land usage is developed. The reccomendation is by converting yard and agriculture area into water conservation infrastructures. These water conservation infrastructures have the similar impact as forest thus it is included as forest for the simulation in SWAT. The optimation reduces the agriculture land cover from 51% into 41% and increases the forest land cover from 32% into 40% (Figure 25 and 26).

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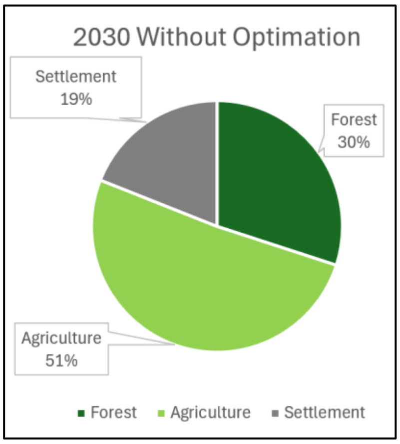

Figure 25. Land cover withour optimation

Source: own study

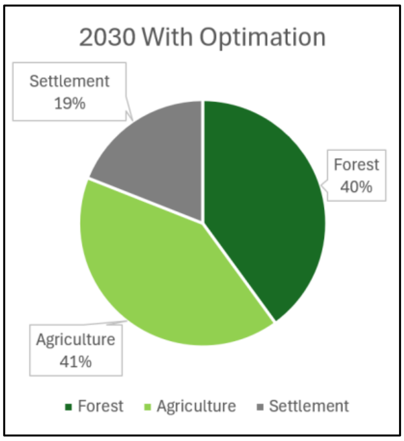

Figure 26. Land cover with **optimation**

Source: own study

The result of the simulation shows a decrease based on land cover conversion in sediment and nitrate in the sub-watershed while phosphate on the other hand saw a decrease, though it is not very significant. Comparison of the result for discharge, sediment, and contamination is aligned with the CN value. Despite of that, there are the other factors that affect discharge and phosphate thus the effect is not as prominent and the same as sediment and nitrate. We can see that despite the CN reduced is still higher than that is in 1990 and lower than 200, the nitrate and sediment saw a massive decrease in value reducing below 1990 level. On the other hand, phosphate only saw a minor decrease and discharge decrease to a comparable level in 2010 (Figure 27-30).

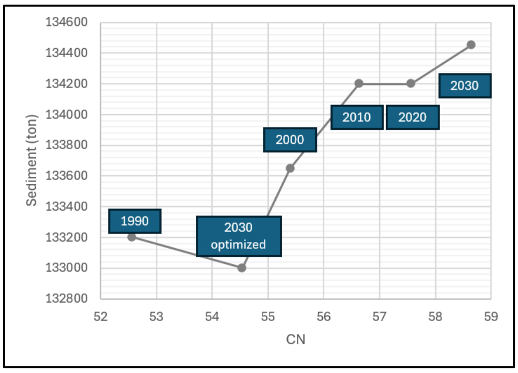

Figure 27. Sedimen-CN Correlation

Source: own study

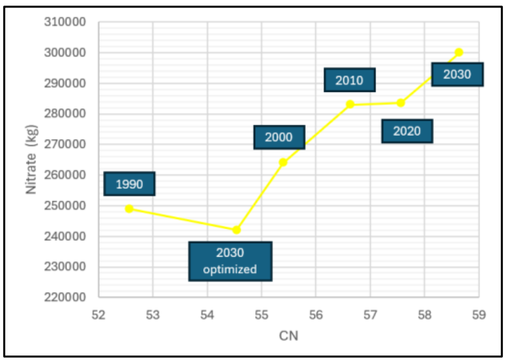

Figure 28. Nitrat-CN Correlation

Source: own study

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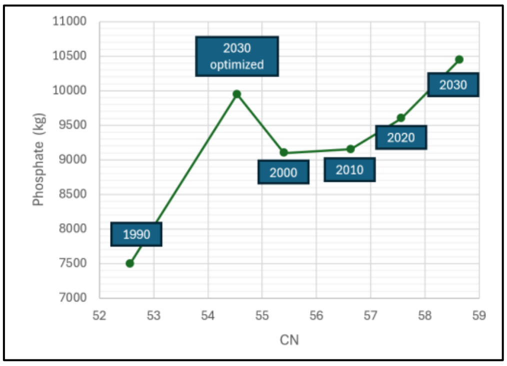

Figure 29. Phosphate-CN Correlation

Source: own study

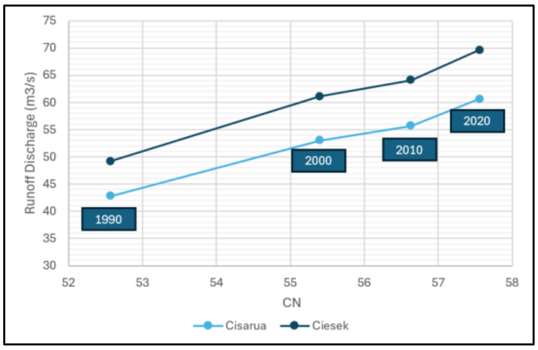

Figure 30. Discharge-CN Corelation

Source: own study

The result aligns where phosphate does not positively affect the land cover conversion. Although sediment is reduced only by around 1400 tons which is lower than in 1990. Nitrate saw a decrease of almost 60000 kg or around 19% lower than the value in 1990. While phosphate saw a 5% decrease or around 250 kg, the value is still higher compared to even 2020. Discharge saw a decrease of around 13% for both sub-Watershed (Figure 31-34).

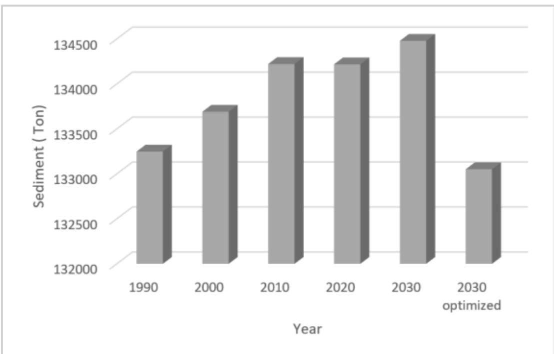

Figure 31. Sedimen Optimized Trend

Source: own study

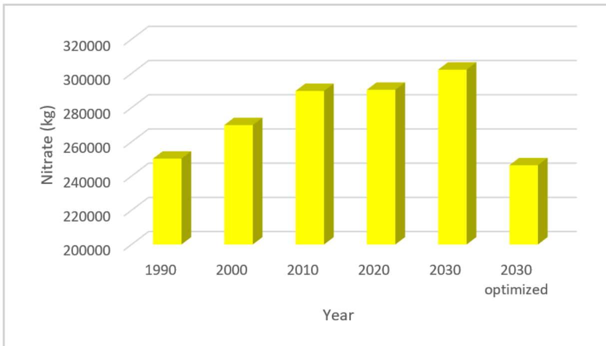

Figure 32. Nitrat Optimized Trend

Source: own study

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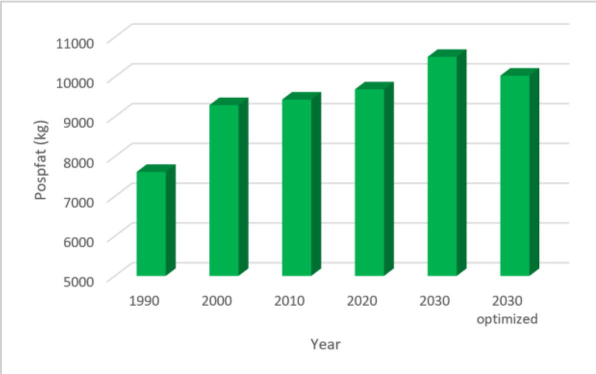

Figure 33. Phosphate Optimized Trend

Source: own study

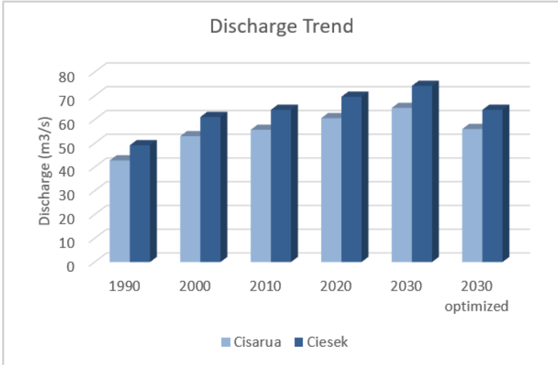

Figure 34. Discharge Optimized Trend

Source: own study

Conclusion

Based on the analysis, it was founded that land cover conversion from forest to agriculture significantly increases the discharge, nitrate levels and sedimentation in rivers, while phosphate levels only slightly increased. Meanwhile, in the watershed overall, surface runoff, nitrate, and phosphate are increasing drastically, whereas sediment slightly increases. Despite these changes, the river discharge is on the normal condition, base flow, and percolation tends to remain unchanged. The public participation willingness can improve the watershed land cover condition by converting the land use for agriculture back into forest or some land cover that has the similar impact with forest of up to 10%. Restoring 10% of the land to water-friendly spaces (forests) can significantly reduce sedimentation and nitrate contamination by 1% and 19% respectively where both value is less than the value in 1990. Phosphate levels is also decreasing, though not significantly and the value is still higher than the value in 2020. Therefore, the sustainability of the Ciliwung Hulu watershed can be achieved by managing land use to maintain 40% of the watershed area as water-friendly zones.

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