

Assessing the Influence of Land-Use Changes on Water Quality Using Remote Sensing and GIS: A Study in Cirata Reservoir, Indonesia

Sunardi Sunardi^{1,2,3*}, Ilyas Nursamsi^{1,6}, Moh. Dede³, Amalia Paramitha¹, Mochamad Candra Wirawan Arief^{3,4}, Miranti Ariyani⁵, Prihadi Santoso¹

¹Department of Biology, Faculty of Mathematic and Natural Sciences, Universitas Padjadjaran, Sumedang 45363, Indonesia

²Postgraduate School, Universitas Padjadjaran, Bandung 40132, Indonesia

³Center for Environment and Sustainability Science, Universitas Padjadjaran, Bandung 40132, Indonesia

⁴Department of Fisheries, Faculty of Fisheries and Marine Science, Universitas Padjadjaran, Sumedang 45363, Indonesia

⁵Research Unit for Clean Technology, Indonesian Institute of Sciences, Bandung, 40135 Indonesia

⁶School of Earth and Environmental Science, Faculty of Science, The University of Queensland, Brisbane 4072, Australia

*Corresponding Author e-mail: sunardi@unpad.ac.id

Abstract

Environmental Changes in a round of reservoirs have dramatic influences on the sedimentation and deterioration of water quality. A significant land-use change in the Cibalagung sub-watershed has an impact on the water quality in the Cirata reservoir. In this study, we used remote sensing and GIS to investigate the influence of land-use changes on water quality in the Cibalagung sub-watershed, Cirata reservoir in 2004–2014. We use Knowledge-Based Classification (KBC) and Fuzzy Logic (FL) to determine the land-use classification. The influence of land-use changes on Total Suspended Solids (TSS), as the main parameter of water quality, was determined by path analysis. This study indicated that 92.50 % of land-use changes through increasing mixed plantations, cropland, settlements, and grassland could affect the TSS content in the reservoir. Decreasing vegetated land had a simultaneous effect to reduce the water quality.

Keywords

Cirata reservoir, GIS, Land-Use Changes, Remote Sensing, TSS.

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1. INTRODUCTION

A reservoir serves multiple functions, such as hydro-energy, irrigation, flood control, water resource, river ecological indicator, transportation, recreation, agriculture, and aquaculture activities (Simonovic, 1992; Raje and Mujumdar, 2010; Varol, 2020). However, a variety of problems such as sedimentation, flooding, water pollution, water allocation, and debris in reservoir systems (George et al., 2017) can threaten the sustainability of the reservoir functions. Water resource management and development planning, therefore, are required to estimate the sustainability of reservoirs and ensure economic feasibility, environmental standards, and adequate socio-economic opportunities for the local communities (Chen and Tsai, 2017). Sedimentation is one of the complex problems in the context of reservoir management. This problem is associated with water availability as a provisioning system, sustainable development which deals with watershed degradation, floods system, and dam infrastructure (Annandale, 1987; Li et al., 2008). Sedi-

mentation has been used as an indicator of water pollution in reservoirs. A few studies on reservoir sedimentation have been carried out in many countries. In China, it is caused by hydrological morphometric and lack of environmental management (Jiang and Fu, 1998; Li et al., 2011). Meanwhile in Europe, especially in France, Spain, and Italy, the controlled sediment flushing triggers reservoir sedimentation which damages the freshwater ecosystem from contaminants (Muñoz et al., 2006; Espa et al., 2016; Lepage et al., 2020). Without proper environmental management, reservoir sedimentation is a common problem for dams in Japan, Taiwan, and the United States (Graf et al., 2010; Chen and Tsai, 2017; Nukazawa et al., 2020).

Sedimentation is strongly influenced by the surrounding environment or landscape conditions. Land-use changes in watershed areas have a significant impact on the reservoir by reducing the water quality and dissolved oxygen; increasing the sedimentation, and disturbing primary productivity by increasing nutrients loading into the stream water flow (Erol and Randhir, 2013). Similarly, the environmental quality around

the reservoir can also affect the water quality and dynamics of the watershed flow (Ho et al., 2017). Cirata reservoir was built in Citarum River Basin in 1984, serving as a hydropower plant for the Java–Bali region as well as for irrigation and aquaculture (PJB BPWC, 2019). At present, the ecosystem around the Cirata Reservoir is continuously degrading due to complex anthropogenic activities within the reservoir and around the river basin, which in turn leads to water quality deterioration and affects the social and economic resilience of the local communities (Parikesit et al., 2005; Sunardi et al., 2020). Cibalagung is in the most critical condition due to the high pressure of human activities, the river brings many high loads of suspended material (216.61 kg/day) into Cirata Reservoir after the Cisokan River (Kartamihardja and Krismono, 2016).

Numerous studies have been conducted to illustrate the land-use and land cover dynamics in the watershed area and its impact on the sedimentation rate in the tropical reservoir using GIS-based analysis (Welde and Gebremariam, 2017; Abdulkareem et al., 2019; Razad et al., 2020). However, knowledge on land-use changes and dynamics as the determining factors of the water quality of tropical reservoirs, particularly at the level of sub-watershed, is still limited. Few studies have been conducted to investigate the impacts of land-use changes in the Upper Citarum and Cimanuk watershed in West Java (Firdaus et al., 2013; Siswanto and Francés, 2019) and Batang Merao watershed in West Sumatra (Ridwansyah et al., 2020), but none were performed on a sub-watershed scale. An accurate analysis of the relevant aspects needs to be carried out to provide an advanced system of preventative and reservoir conservation actions. For such reasons, the objectives of the study were to investigate the land-use changes and to further determine the direct and indirect effect of its changes to TSS level in the Cirata Reservoir. TSS is the main parameter of water quality, it is related to critical land, soil erosion, flood, and river-coastal sedimentation which bring many social-economic problems in the watershed (Dede et al., 2019; Widiawaty et al., 2021).

2. RESEARCH METHODS

2.1 Study Site

The Cibalagung sub-watershed is located in the southwest part of the Cirata catchment (Figure 1). The sub-watershed connects to the Cirata through the Cibalagung River, which is part of the Cianjur Regency, West Java, Indonesia. The Cibalagung sub-watershed has a total area of around 45 km² with the range of flow discharge rate of about 0.80-21.14 m³/s and TDS concentration of around 75.00-148.33 mg/L (Wahyudiana, 2019) The characteristics of the sediment are clay (3.87-28.33 %), fine-coarse sand (70.20-71.50 %), and gravels (0.17-25.93 %) (Moelyo and Januar, 2012).

2.2 Data Analysis

Land-use changes were analyzed by classifying a series of remote sensing imagery of Landsat-7 ETM+ (2004, 2009, and 2014) using Knowledge-Based Classification (KBC) and Fuzzy Logic (FL) in QGIS 2.4 and GRASS GIS. KBC and

FL techniques for quantification of pixel membership were frequently used in land-use changes studies (Al Fugara et al., 2009; Mousavi et al., 2019). Remote sensing-based analysis was employed to estimate and interpret images from Landsat data visually and digitally to produce a multi-temporal land-use map, including the vegetation cover conditions (Widiawaty, 2019). In addition, remote sensing imageries were widely used in various fields of research, such as urban studies (Zhang et al., 2014; Dede et al., 2021), rural and forest ecosystems (Mancino et al., 2020), dams, and river basins (Hassani et al., 2015; Gounaridis et al., 2014; Zaines et al., 2019), also coastal and marine ecosystems (El-Askary et al., 2014; Nguyen et al., 2020; Widiawaty and Nandi, 2020). In this study, the image was classified into seven land-use categories according to the Indonesia Ministry of National Land and Land-use and SNI 7645:2010 (Indonesian National Standard) on land-use mapping, which covers dryland forest (DF), mixed plantations (MP), cropland (CL), grasslands (GL), settlements (SM), open field (OF), and water bodies (WB).

The overall accuracy was obtained from the comparison between the total number of pixels that are classified correctly in all land-use classes with the total number of pixels from the sample obtained from observations. The accuracy assessment (error matrix) contains the producer's accuracy, user's accuracy, and overall accuracy, which were estimated using Equations (1-3) below. Further evaluation of classification results was carried out by the Kappa formula (Congalton, 1991; Ben-David, 2008; Ismail et al., 2020), and purposively tested via fieldwork in 50 randomly selected locations for each land-use class for supplementary data.

$$\text{Producer's accuracy} = \frac{X_{kk}}{X_{k+}} \times 100\% \quad (1)$$

$$\text{User's accuracy} = \frac{X_{kk}}{X_{+k}} \times 100\% \quad (2)$$

$$\text{Overall accuracy} = \frac{\sum X_{kk}}{N} \times 100\% \quad (3)$$

where X_{kk} is the number of pixels classified correctly in each category, X_{k+} is the number of pixels in each training set of each category, X_{+k} is the number of pixels classified in each category, $\sum X_{kk}$ is the number of pixels classified correctly in all categories, and N is a number of reference pixels.

To find out the importance and significance impact values of land-use changes to the changes in the value of Total Suspended Solids (TSS) concentration in the respective year, we use statistical method through the path analysis with additional trimming (Teas et al., 1979; Cramer et al., 1999) (Figure 2). TSS concentration data from the year 2004 to 2014 was obtained from PT Java Bali Powerplant (PT PJB) report. TSS was measured at the intake point of Cibalagung river to Cirata

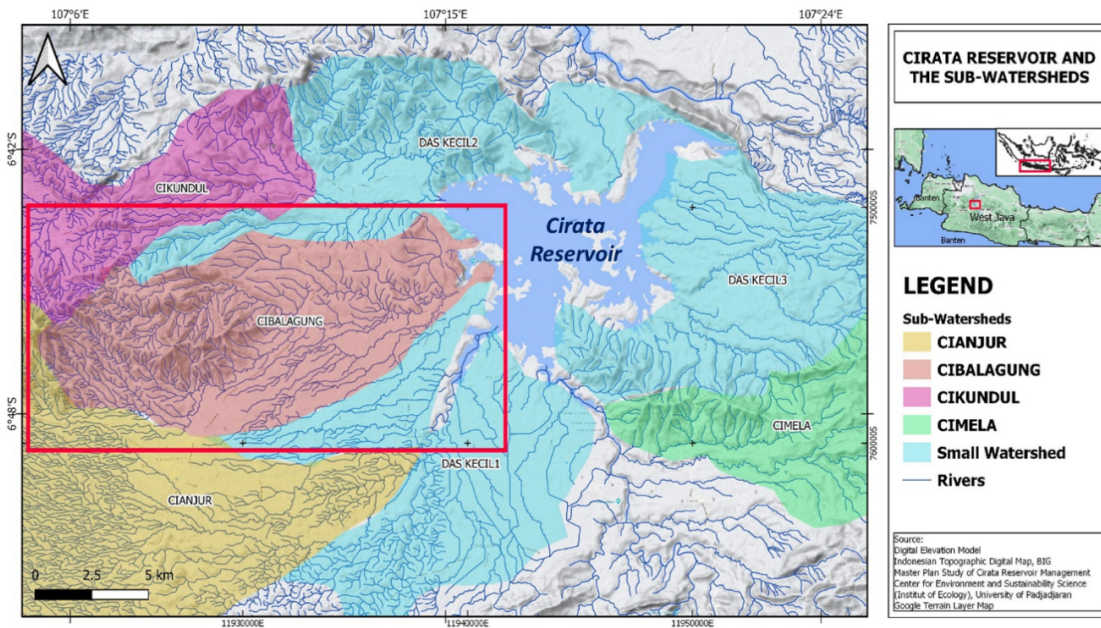


Figure 1. Cibalong Sub-Watershed is Located in The West of Cirata Reservoir.

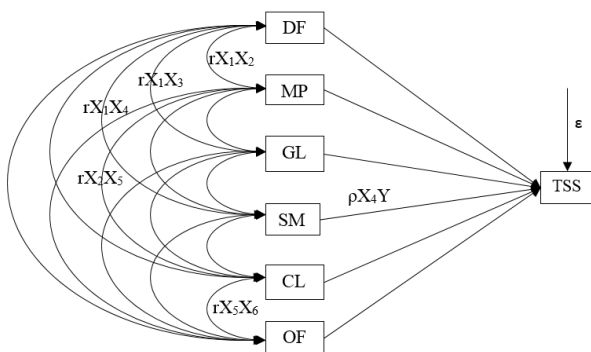


Figure 2. Interaction Between Land-Use and TSS.

Reservoir (estuary). Based on a dynamic model, TSS was increased to 21.62 % from 2004-2014, this level will increase to 82.76 % in 2045 (Widiyati, 2011). All of these land-use classes were analyzed through correlation and linear regression analysis with the coefficient of linear structural equations representing the causal relationship directly or indirectly to the changes in TSS concentration (Chen et al., 2015; Wang et al., 2015). Path analysis was designed to estimate the direct relationships among the stimuli (land-use category changes) and the response (TSS changes), while also estimating the indirect effect of stimulus interactions onto the response (Imen et al., 2015). We arranged conceivable paths that linked each land-use category to the response, as well as among the stimulus to illustrate its direct and indirect impact. The direct impact value of each land cover change towards TSS dynamics was retrieved from the β coefficient values. Meanwhile, the indirect impacts of a certain land cover changes correlated to changes in other

land cover types were calculated via the following Equation (4).

$$IE_{X_i} \rightarrow Y \text{ (Via } X_j) = ((\rho_{X_i Y}) \times (r_{X_i X_j}) \times (\rho_{X_j Y})) \quad (4)$$

where IE_{X_i} is the indirect effect of land-use class i via land-use class j , Y changes in TSS, $\rho_{X_i Y}$ is a direct effect of land-use class i to the TSS changes, and $r_{X_i X_j}$ is a correlation between land-use classes.

3. RESULTS AND DISCUSSION

3.1 Land-Use Changes

The land-use classification result was validated using a matrix accuracy test and we obtained a high degree of mapping accuracy (Table 1). The result showed that the overall accuracy of all land-use classes was 91.14 % with a Kappa index value of 0.89. This kappa index indicates the possibility of avoiding errors in maps production of around 89.50 %. This level of accuracy is well above the classification accuracy standard in land-use mapping derived from remote sensing data, which should be as minimum as 80 % (Widiawaty et al., 2020a). In this study, the highest producer's accuracy was obtained for dryland forest (96.34 %) and the lowest was for water bodies (83.82 %). Meanwhile, the highest user accuracy was obtained for mixed plantations (97.75 %), and the lowest was for the open field class (72.10 %). The highest accuracy obtained ensures that the most appeared land-use class on the map have been well characterized (Giri, 2012), while the accuracy value obtained below the standard limit shows the inaccuracy of land-use classification due to the error in translating the land-use classes with similar spectral signatures.

Furthermore, the reliability of the land-use classification was assessed by comparing the kappa index value and the over-

Table 1. Confusion Matrix of Accuracy Classification in 2014

Reference class	Classification of class*							Row total	Producer's accuracy (%)
	DF	MP	CL	PR	DF	MP	CL		
Dryland forest (DF)	158	1	0	5	0	0	0	164	96.3
Mixed plantations (MP)	6	87	8	0	0	0	0	101	86.1
Cropland (CL)	5	0	137	0	0	0	5	147	93.1
Grassland (GL)	0	1	0	92	0	0	3	96	95.8
Settlements (SM)	0	0	7	0	86	15	0	102	84.3
Open field (OF)	0	0	0	0	7	83	0	90	92.2
Dryland forest (DF)	0	0	0	0	0	4	57	68	83.8
Total of column	171	89	155	103	93	115	65	Overall accuracy 91.14	
User's accuracy (%)	92.4	97.8	88.4	89.3	92.5	72.2	87.7	Kappa 0.895	

all accuracy (Congalton and Green, 2019). Since the kappa index value was lower than the overall accuracy obtained, the land-use classification based on Landsat-7 ETM+ in 2014 imagery had good accuracy and was deemed acceptable for further analysis. Land-use classes during the 2004–2014 period were dominated by dryland forest (Table 2), which covered more than 30 % of the Cibalagung sub-watershed. This study also shows that, while the dryland forest decreased due to the land-use conversion, all the other types of land use found in the Cibalagung sub-watershed increased in size during the period. Overall, for one decade, the dryland forest decreased by about 1077.78 ha (-19.65 %). However, the grassland area increased up to 57.96 ha (+3.45 %). Along with the grassland, the other types of land use, such as mixed plantations, cropland, and settlements also increased in size by about 3.99 %, 23.32 %, and 49.86 %, respectively. An extreme change of dryland forest area to grassland was occurred due to logging activities, which were then followed by the growth of grasses and reeds until they formed grassland.

The majority of land-use changes were occurred by converting the dry forest area into grassland and mixed plantations (Figure 3). This condition was exacerbated by the development of massive settlements and the road network along the northwest, east, and northeast parts where the dry forest was located previously. Furthermore, the existence of cropland which dominated the center area in the southern part of the sub-watershed continued by the mixed plantations expanding from the southern part to the northeast part. Most of them were located along with the river network which probably leads to the increase of sedimentation rate in the river (Siswanto and Francés, 2019).

3.2 Influence of Land-Use Changes on TSS

The Path analysis with the Trimming method showed that there were two exogenous variables with $\alpha > 0.05$, i.e., the dryland forest and open field (see Table 3) that have no significant effect on the changes in TSS value. Thereby, both of those variables were excluded from the subsequent Path analysis, the

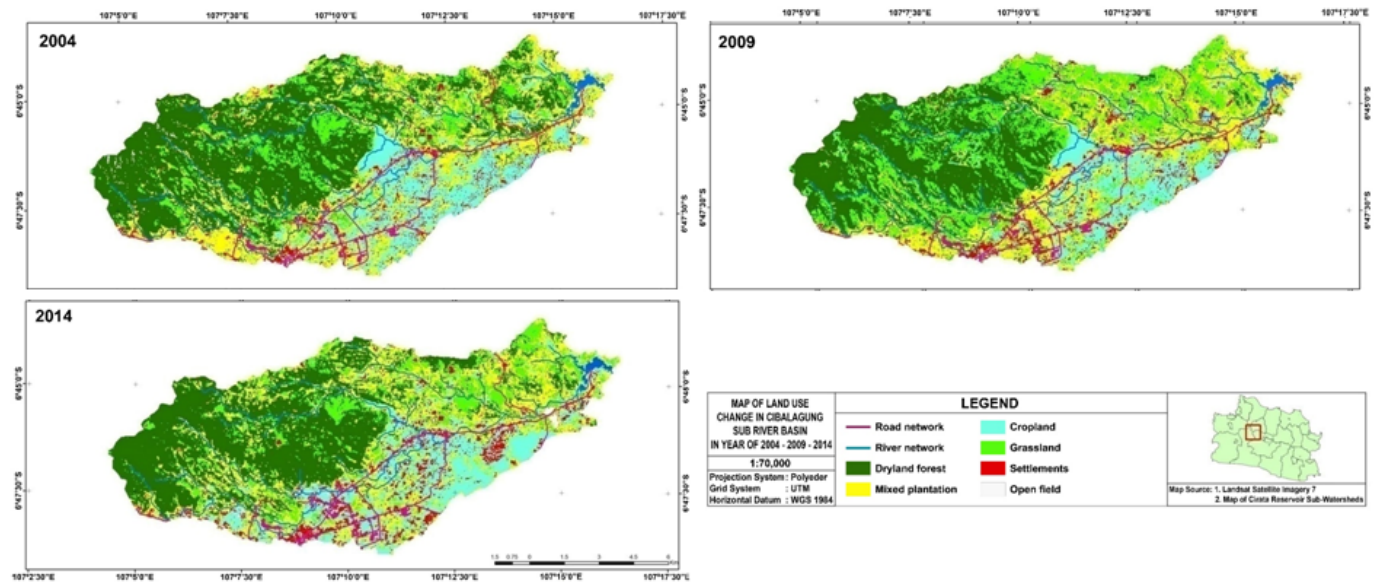
remaining mixed plantations (MP), cropland (CL), grassland (GL), and settlements (SM) classes were then included for the second path analysis calculation (see Figure 4). In the Partial correlation analysis (Figure 4), each of the land-use class' interrelation was assessed and shows both positive and negative relations to each other. Mixed plantations (MP) or cropland (CL) with settlement (SM) and cropland (CL) with settlement (SM) had a strong positive relationship to the changes in TSS values, with coefficient values of 0.78, 0.71, and 0.99, respectively. While, the relation between grassland (GL) with both mixed plantations (MP) and cropland (CL) were negative, with coefficient values of -0.72 and -0.12, respectively. There was no significant correlation between grassland (GL) with settlements (SM). While the simultaneous correlation coefficient for overall groups was 0.64 showing a fair interaction among land-use classes (Figure 4) (Setiawan et al., 2019). The direct effects of each land-use class were shown via direct arrow path from the land-use class to the TSS showing that the highest direct effect to the TSS was from mixed plantations (0.45) while grassland had the lowest direct effect (0.05).

Analysis of correlation between land-use changes and the TSS dynamic changes at the reservoir was obtained through correlation and linear regression analysis, with the coefficient of linear structural equations, representing the causal relationship directly or indirectly to the changes in TSS concentration (Table 4). TSS concentration or water turbidity level is one of the main parameters for measuring water quality which has an important role in the formation of the physical landscape and ecological regulatory systems (Widiawaty et al., 2020b). The types and spatial patterns of land-use/land cover in the watershed have different effects on the TSS content in the river (Shi et al., 2017). We found that land-use classes that contributed to significant changes in TSS were mixed plantations, cropland, grassland, and settlements, representing a total effect of 92.50 %.

Between 2004 and 2014, the increase of mixed plantations, settlements, and cropland was driven by logging and land clearing activities in the dryland forest which had a fairly strong

Table 2. Land-Use Area in The Three Periods

Land-use	2004		2009		2014	
	ha	%	ha	%	ha	%
Dryland forest (DF)	5,483.33	41.79	3,980.97	30.34	4,406.10	33.58
Mixed plantations (MP)	3,077.73	23.46	2,999.43	22.86	3,200.76	24.39
Cropland (CL)	2,238.03	17.06	2,408.24	18.36	2,759.95	21.05
Grassland (GL)	1,679.58	12.8	2,872.52	21.89	1,737.54	13.24
Settlements (SM)	633.33	4.83	767.34	5.85	949.14	7.23
Open field (OF)	0	0	92.5	0.7	67.4	0.51

**Figure 3.** Land-Use Changes in Cibalagung Sub-Watershed.**Table 3.** Significance of Test Results of Exogenous Variables

Land-use	β -coefficient	Significance value
Dryland forest (DF)	0.0006	0.93
Mixed plantations (MP)	0.2859	0
Cropland (CL)	0.0788	0
Grassland (GL)	-0.0326	0
Settlements (SM)	0.1209	0
Open field (OF)	-0.0022	0.98

positive effect on TSS content. The presence of vegetation along the riparian zone particularly in the lower catchment zone will eventually protect discharges of the pollutants to the river stream (Zaimes et al., 2011). We also found that TSS content was largely affected by the land-use change from the mixed plantations by 49.50 %, i.e. 40.40 % directly and 9.10 % indirectly. The indirect effect explains that about 9.10 % of changes in TSS value were due to the changes in mixed plantations correlated with changes in other land-use classes. The vegetation coverage in the mixed plantations can reduce

erosion rate, as one of the ecosystem services provided by vegetated land. TSS content was also slightly affected by the change of settlements (about 23.7%), i.e. 15.4% directly and 5.9% indirectly. Settlements area increases the water discharge due to lower absorption ability of land surface caused by asphalt or cement (Widiawaty and Dede, 2018), then eventually increase the sediment runoff when flowing across the bare land (Arsyad, 2009). Therefore, 49.86% increase in the settlement area, in the period of 2004-2014, had a positive effect on the fluctuation of TSS content by 23.70 %.

TSS content was also affected by the increase of cropland by 15.10 %, i.e. 10.20 % directly and 4.80 % indirectly. Cropland is believed to have a small erosion rate due to the existence of terraces and rice fields that holds water and soils, soil loss in cropland can increase erosion mainly due to poor land management. Particles from the cropland dilute in the water that flows during soil puddling and weeding, and further, they pollute the surrounding environment. The increase in TSS content in the reservoir was attributed also to the change of grassland by 6.50 %, i.e. 5.0 % directly and 1.50 % indirectly. The increased area

Table 4. Total Effect Value to The TSS Content

Land-use	Direct effect (DE)	Indirect effect (IE)				Total (IE)	Total effect (DE + IE)	
		MP	CL	GL	SM		Total	%
MP	0.4	0	0.03	0.01	0.04	0.09	0.49	49.58
CL	0.1	0.03	0	0	0.01	0.05	0.15	15.1
GL	0.05	0.01	0	0	0	0.01	0.06	6.5
SM	0.15	0.04	0.015	0	0	0.06	0.24	23.7
Total effect	0.71					0.21	0.92	92.5
	71.20%					21.30%		

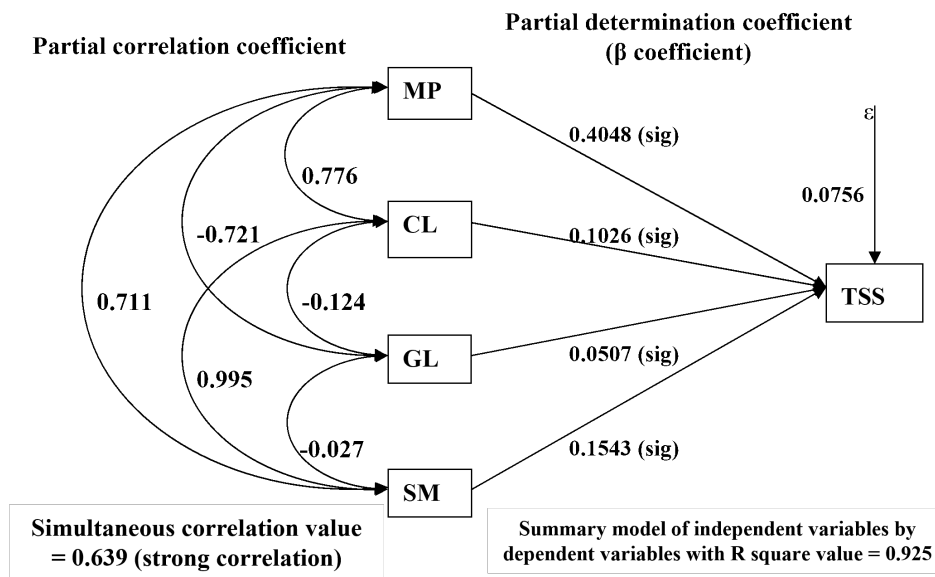


Figure 4. Path Analysis Structural Model of Land-Use on TSS in Cibalagung Sub-Watershed.

of grassland was allegedly due to the clearing activity of the dryland forest that changed to grassland. However then, there was a decrease in grassland which was due to land changes activities for mixed plantations, cropland, and settlements. Grassland area is an area that is dominated by various types of undergrowth, grass, thicket, and reeds that can withstand the surface water flow and soil particles to be discharged to the river. This result was somehow similar to the pattern found in other studies located in the tropical catchment, where the conversion of grass and shrubland for agricultural purposes has increased the volume of sediment yields (Welde and Gebremariam, 2017). The grassland is observed to have a regulatory effect on the erosion rate (Abdulkareem et al., 2019).

Overall, the dynamics of land-use changes that occurred in the Cibalagung sub-watershed had a fairly strong effect on the dynamics of TSS, by 92.50 %, i.e. 71.20 % directly and 21.30 % indirectly. Nevertheless, the path coefficient outside the model had an error coefficient (ϵ value) of 0.075 or 7.50 %, indicating that the unidentified variables may remarkably contribute to the dynamics of TSS content. The dryland forest

and open field were expected to have a significant influence on the dynamics of TSS in river waters, even though they were excluded from the analysis. Dryland forest as an area with plant cover from various strata can provide great rainwater retain. The vegetation roots are useful as water storage pockets that can reduce the rate of erosion and hold off the surface water flow that brings soil sediment. Meanwhile, open field is the biggest contributor to river water sediments as it makes surface water easily dissolve the sediment, and flow the soil particles into rivers. Such conditions are happening in all parts of river catchment as a result of land conversion activities, especially in mixed plantations (Sutono et al., 2002). However, due to the small size of open land, during the period of study, such an effect is minuscule to be detected.

4. CONCLUSIONS

The model presented in this study illustrates the interrelationships of land-use changes in Cibalagung sub-watershed dynamics affecting water quality in the reservoir. Land-use changes in the Cibalagung sub-watershed in the period of 2004-2014

showed a decrease in dryland forest by 1077.78 ha, and an increase in mixed plantations by 123.03 ha; cropland, by 521.92 ha; grassland, by 57.96 ha; settlements, by 315.81 ha; and open field, by 67.4 ha. Directly and indirectly, an increase of mixed plantations, cropland, settlements, and grassland contributed to the rise of TSS content in the estuary by 49.50 %, 15.10 %, 23.70 %, and 6.50 %, respectively. Overall, the four land-uses contributed to the TSS content in the Cibalugung River waters by 92.50 %, and the other 7.50 % comes from factors outside of the model. This study states that conservation efforts through vegetative methods are more effective in controlling the rate of soil release and increasing TSS in the Cirata Reservoir. The government and stakeholders need to reforest critical lands accompanied by technical efforts such as terracing, installing groins/gabions, and regular monitoring of water quality.

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