

Research Article

Structural modelling of riparian tree diversity and ecosystem degradation roles in determining the water quality of springs and its drains in East Java

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Received 18 June 2020, Accepted 8 August 2020

Abstract: This research was aimed to study the role of riparian trees and ecosystem degradation to determine water quality in some springs and its channels located in East Java. The research was held in some selected degraded springs in Kediri, Pasuruan, Malang, and the Meru Betiri National Park located in Jember, as a reference site. In each spring, three sites including upstream, midstream, and downstream were observed. The field observation consisted of several steps such as land use quality at river land side, geographical conditions, riparian tree diversity and water quality, quality of springs physical condition, and its channels. Riparian trees role to determine the water quality was analyzed by applying Partial Least Square analysis with Smart PLS software. Structural modelling of the interaction of riparian trees diversity with some determining variables of water quality revealed that there was an important role of riparian diversity quality towards water quality. The value of predictive relevance (Q^2) was 99.11% and the model could be accepted. The riparian trees diversity and geographical conditions directly influenced the water colour and its turbidity. The quality of land use at several water bodies did not directly influence the water colour and its turbidity. Therefore, water colour and its transparency at channels were directly influenced by riparian width, ecosystem degradation shown by naturalness index, hemeroby index, environmental services index, and the slope of landside.

Keywords: *degraded spring, riparian vegetation, water quality*

To cite this article: Semiun, C.G., Retnaningdyah, C. and Arisoesilaningsih, E. 2020. Structural modelling of riparian tree diversity and ecosystem degradation roles in determining the water quality of springs and its drains in East Java. *J. Degrade. Min. Land Manage.* 8(1): 2431-2438, DOI: 10.15243/jdmlm. 2020.081.2431.

Introduction

A riparian zone is an interface between land and a river or stream. It is also an ecological transition zone of material, energy, and information exchange between land and water ecosystems, which has the dual features of water and land (Fu et al., 2015). Riparian areas serve many ecological functions including natural filtering of runoff pollutants, detaining or retaining runoff and flood flows, providing stream temperature control, and serving as wildlife habitats (Weilert et al., 2018). The composition of the riparian ecosystem

consists of biotic and abiotic components. Biotic components are vegetation, animals, and microorganism. According to Richardson et al. (2007), riparian vegetation fulfils or influences various important ecological functions in relation to aquatic habitats, including the provision of food, moderation of stream water temperature via evapotranspiration and shading, providing a buffer zone that filters sediments and controls nutrients, and stabilization of stream banks. It also provides a corridor for the movement of biota and serves many important roles for humans. Among biotic

components of the riparian vegetation, trees show a significant role of ecological service in nature. The riparian tree is an important factor to determine the water quality of springs and its drains. (Semiun and Lengur, 2018). High tree riparian cover is associated with high levels of dissolved oxygen in rivers, and low levels of sediment and sand (Luke et al., 2018). Spring is groundwater that appears to the land surface and naturally becomes clean water resources for the people. However, springs become susceptible to anthropogenic activities such as sloping agricultural land, residents living near water resources, livestock grazing, and trapping that will change the quality of vegetation and water (Semiun et al., 2013). Land use involving degradation of riparian vegetation will directly affect the decrease of water infiltration and increasing runoff. This condition becomes more severe by the invasion of exotic species. Therefore it decreases riparian vegetation quality in nature (Castro-Diez and Alonso, 2017). This relation shows a link between riparian trees and water quality in springs. The riparian trees have important roles in maintaining water quality in springs such as; (1) evaporating water (transpiration); (2) absorbing water into the ground; (3) reducing the kinetic power of raindrops; (4) increase the capacity of the land; (5) to store water in the soil; (6) reducing runoff and (7) reducing soil erosion (Nugroho et al., 2019).

Currently, well-conserved springs can only be found in areas far from human activities and show a high diversity of natural vegetation. Therefore, it is necessary to gather information about the contribution of riparian tree diversity to water quality in some springs and channels in East Java so that the information can provide appropriate recommendations in conserving and managing tree diversity in degraded springs.

Materials and Methods

Field survey and data collection

This research was conducted in selected springs of some districts in East Java Province, i.e. Meru Betiri National Park (MBNP), Jember (Blok Aren and Andongrejo), Kediri (Plosolor, Klaten, Jengkol, Tempurejo, Bendo, Jarak, and Bangkok), Pasuruan (Cowek and Semut), and Malang (Lawang, Karang Ploso, and Coban Rondo). These springs were chosen because of variations in the surrounding land use conditions which include forests, settlements, rice fields, and ecotourism. MBNP was chosen as a reference site to be compared with other research location areas. It is because MBNP is still natural and has a high biodiversity, among which is the wealth of flora

with various types of plants and as a fauna habitat. Later, the data obtained were analyzed in the Laboratory of Ecology and Animal Diversity, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang.

This descriptive research held with three replications was carried out using the purposive sampling. The physical condition of riparian tree vegetation in the four research locations was identified by observing geography, quality of land use, and the width of the riparian zone (border). The geography observation included slope, altitude, latitude, and longitude. It was aimed to record the spatial variation of the diversity of riparian tree and water quality in water springs and its channels. Observation of the land use quality was determined by the assessment of degraded environmental services based on environmental service index, naturalness index, and hemeroby index. Furthermore, riparian trees observation was carried out from the upstream edge to the downstream edge with a length of 10m, and the width adjusted to the specific location conditions.

Water quality was determined by recording some physical-chemical variables (such as pH, conductivity, brightness, and colour). Water pH measurements were carried out using a pH meter, conductivity measurements with conductivity meters, water brightness, colour measurements were carried out visually in each observation plot, and physical conditions of the water body (current velocity, depth, width, discharge, and substrate). Flow velocity measurements were carried out using a float that drifts following the flow of water with a length of one to two meters, and its time was recorded with a stopwatch. Measurement of the depth and width of water bodies was carried out directly on each observation plot using a meter. The calculation of water discharge was done by using the formula $D = V \times A$ (D = Water discharge; V = Speed current; A = Cross-sectional area of water channel)

The distance between springs and its channels observed were Blok Aren (1.06 km), AndongRejo (0.4 km), Plosolor (2.52 km), Tempurejo (0.07 km), Bendo (1.7 km), Cowek (5.5 km), Lawang (1.72 km), Karang (1.3 km) and Coban Rondo (1.09 km). All measurements were conducted simultaneously on all sites at each observation station.

Data analysis

The data obtained in this study were vegetation quality, physical-chemical variable of water quality, physical conditions of water bodies, land use quality, and geographic conditions of springs and channels. The profile of tree vegetation

diversity at each observation station refers to the study of Semiun et al. (2013). The observation of land use quality to determine environmental services was based on the environmental services index (Pagiola et al., 2004), naturalness index (Machado, 2004), and hemeroby index (Kim et al., 2002). The environmental services index described the quality of habitat, the naturalness index described the naturalness of habitat, while the hemeroby index described the anthropogenic impact on habitat.

The contribution of tree vegetation and ecosystem degradation to the improvement of water quality was determined by a multivariate analysis using the structural modelling of Partial Least Square with open source software Smart PLS. The steps in PLS were; designing a structural model (inner model), and a measurement model (outer model), constructing a path diagram, converting path diagrams to system equations, estimating path coefficients, loading and weight, evaluating goodness of fit, and testing hypotheses (re-sampling bootstrapping). The statistical test was performed using t-test with $\alpha = 5\%$. If the p-value is ≤ 0.05 , then the model will be significant. A significant outer model showed the valid indicators, and then the inner model showed significant variables.

Results and Discussion

In assessing habitat quality for riparian vegetation, vegetation quality indices included naturalness index, hemeroby index, and index of environmental services. The locations of the study showed variable naturalness index, hemeroby

index, and environmental services (Figure 1). The naturalness index ranged from 2-8, while the hemeroby index ranged from 2-4. The naturalness index of MBNP reached 8 (sub natural system or natural, with irrelevant change) which was characterized mainly by no fragmentation of the forest. Meanwhile, the hemeroby index of MBNP reached 2 (β - mesohemerobic or small disturbances) characterized mainly by low disturbances on vegetation and input of waste into water bodies. This indicated that the quality of the habitat was still very good with very little intervention from humans.

On the contrary, riparian tree vegetation that was highly degraded, especially in the irrigation canal, had a value of semi-transformed system, and hemeroby 4 (euhemerobic or large disturbance). This was influenced by tree replacement by shrubs or only herbs that were routinely pruned. It generally only had a width of 0.5-3.0 m and became rice fields/fields/borders of irrigation waterways as found in BA3, Je, Se, L2, L4, K2, K3, and CR3. Hemeroby values were reversed to the value of naturalness and environmental services. The higher the value of naturalness, the lower the hemeroby value (Figure 1). Li et al. (2018) in their study revealed that water quality significantly influenced by landscape changes in the riparian zone, as a result of massive human activities in the undeveloped riparian zone. Moreover, this result showed that there was a positive correlation between the width of the riparian zone and water quality (Figure 2). Another finding was human activities correlated positively to degraded water quality where the higher human activities than the higher degraded water quality.

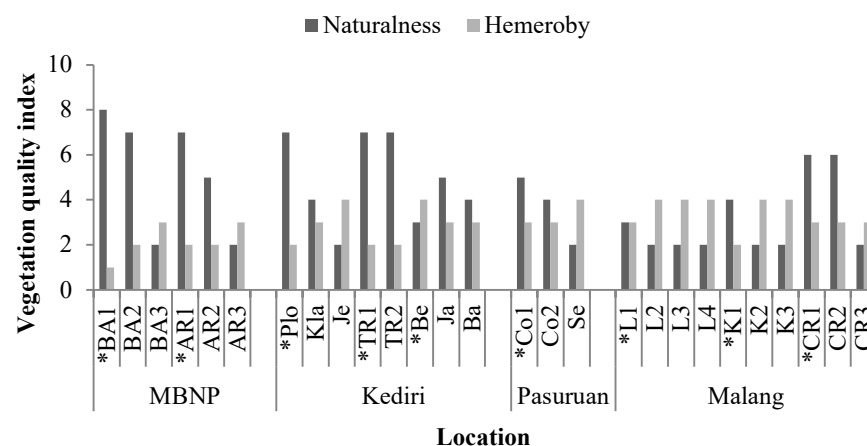


Figure 1. Riparian ecosystem quality based on naturalness index and hemeroby index in some springs in East Java. BA = Blok Aren; AR = Andongrejo; Plo = Plosolor; Kla = Klaten; Je = Jengkol; Be = Bendo; TR = Tempurejo; Ja = Jarak; Ba = Bangkok; Be = Bendo; Co = Cowek; Se = Semut; L = Lawang; K = Karangan; CR = Coban Rondo.

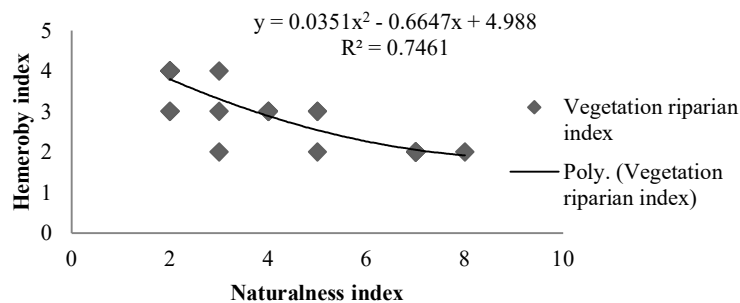


Figure 2. The relationship between naturalness index and hemeroby index. BA = Blok Aren; AR = Andongrejo; Plo = Plosolor; Kla = Klaten; Je = Jengkol; Be = Bendo; TR = Tempurejo; Ja = Jarak; Ba = Bangkok; Be = Bendo; Co = Cowek; Se = Semut; L = Lawang; K = Karangan; CR = Coban Rondo.

The index of environmental services in springs and its drains found in this study varied (Figure 3). The highest environmental services index was found in BA1 and BA2, while the lowest was found in locations of highly degraded springs with scarce riparian vegetation, such as in Je, Se, L3, L4, K2, and K3; therefore, its habitat quality was low. The existence of trees would improve the quality of habitat because trees tap roots could penetrate deeply into the soil and showed a high potential increasing infiltration, reducing surface runoff, and preventing landslides in hilly areas. Nugroho and Riyanto (2018) in their research asserted that the low tree species diversity in river zone decreased zone protection or conservation; as a result, the river becomes hampered. This is in line with research conducted by Cornejo-Denman et al. (2018) that focused on the influence of anthropogenic disturbance on the San Miguel Mexico river. The result revealed that a high anthropogenic disturbance zone had a lower diversity of shrubs and riparian trees compared to a low anthropogenic disturbance zone. This affects photosynthesis activity that becomes lower along with the increasing of human activity.

The Environmental Service Index of land use around springs and its channels was found to be varied (Figure 2). MBNP showed a better land-use quality compared to the three other locations (Kediri, Pasuruan, and Malang). This was related to a minimum level of human activities and the success of the national park conservation program in the jungle zone. In contrast, the low quality of land use index is found generally in degraded spring channels. This degradation is related to anthropogenic intervention in land use such as settlements, rice fields, and fields. On the contrary, the naturalness index of land use of Blok Aren (BA) 'Zona Rimba' MBNP reached 8 (subnatural system or natural and irrelevant change) which was characterized mainly by no forest fragmentation.

Meanwhile, the hemeroby index was 0 (A hemerobic or no disturbance) which indicated the absence of human activity to the spring. Therefore, the habitat for riparian vegetation was still relatively natural. This influenced ecological services by riparian vegetation on springs and its channels such as stabilizing stream banks, storing nutrients, providing shade to stream banks, maintaining moisture in riparian soils, and improving water quality (Mligo, 2017).

Based on the literature study, a theoretical model for determining the quality of water in springs and channels was designed in several districts of East Java. The latent variable (ellipse form) was composed of one or more indicators depicted in a rectangular shape. The variable was connected with an interaction arrow. Geographic variables affected the quality of land use and water quality, the quality of land use affected the diversity of riparian tree vegetation, the physical condition, and water quality. The physical condition of the water body affected the water quality and riparian trees diversity, which in turn, it influenced water quality in the springs and its channels. The theoretical model showing the role of riparian tree diversity in water quality is shown in Figure 4.

Indicators such as g1, l1, l2, f1, f2, f4, d1, d3, d4, d6, a1, and a2 showed not significantly different in test ($P > 0.05$). So, those indicators were excluded from the model. Furthermore, an evaluation of the initial PLS model was carried out by excluding insignificant indicators of the latent variable. The results of model re-evaluation revealed that g2 (slope of the channel border), l3 (index of environmental services), f3 (width of water body), f5 (substrate), d2 (riparian width), d5 (index of naturalness), d7 (Environmental service index), a3 (water brightness), and a4 (water colour) were significant ($p\text{-value} < 0.05$) in forming each variable.

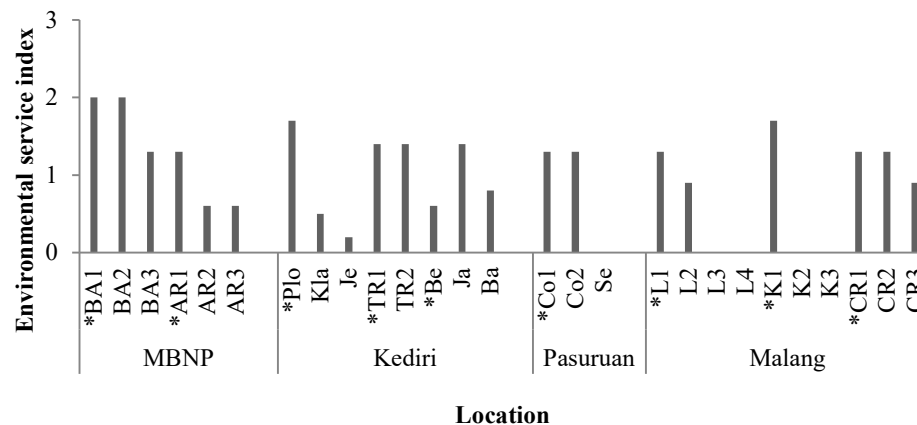


Figure 3. Spatial variation of environmental services index in several riparian located in several regencies in East Java. BA = Blok Aren; AR = Andongrejo; Plo = Plosolor; Kla = Klaten; Je = Jengkol; Be = Bendo; TR = Tempurejo; Ja = Jarak; Ba = Bangkok; Be = Bendo; Co = Cowek; Se = Semut; L = Lawang; K = Karangan; CR = Coban Rondo.

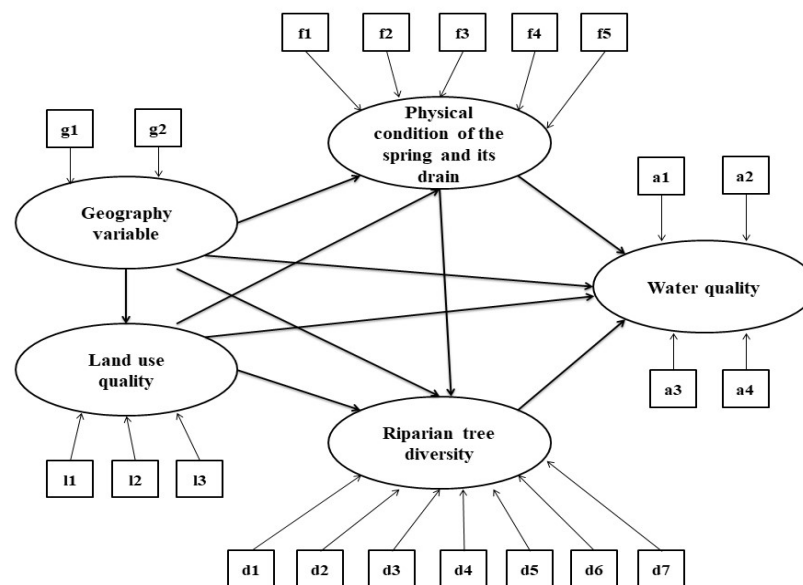


Figure 4. Theoretical model design of riparian tree diversity role on water quality quality. g1 = altitude, g2 = slope, l1 = naturalness index, l2 = hemeroby index, l3 = environmental service index, d1 = richness index, d2 = riparian width, d3 = stratification, d4 = rate of endemism, d5 = naturalness index, d6 = hemeroby index, d7 = environmental service index, f1 = water velocity, f2 = depth, f3 = width, f4 = discharge, f5 = substrate, a1 = pH, a2 = electric conductivity, a3 = transparency, a4 = color

The predictive-relevance Q2 value was 99.11% and more than 80%, so the model was feasible to be used. The information contained in the 99.11% data could be explained by the final PLS model, while the remaining 0.89% was explained by other variables (which were not included in the model). The final PLS model shown in Figure 5 revealed

that the geographic variable (slope of the border) and variable of riparian vegetation (riparian width, naturalness index, and environmental services) showed a direct influence to the water quality, while the quality of land use (environmental services) showed an indirect effect. This model was developed based on field observations on

springs and its channels with a radius of 0.07 to 5.5 km from springs. Therefore, the model was only relevant for explaining phenomena at this limited radius. Water quality of the channel at this radius still depended on the water quality of spring (Table 1), while the quality of land use contributed less significantly and negatively correlated with water quality. Apparently, in the radius of more than 5.5 km, the channel water quality would be more positively influenced by land use quality. This was in accordance with the research of Demirci et al.

(2006) who reported that water quality tended to decrease along with the land use service quality around the river. Therefore, to clarify the riparian role in the spring channel, the model was improved by separating the water quality of the spring and its channel into two different variables.

Tree vegetation quality provided a greater influence on water quality compared to geographic profiles. The tree vegetation diversity quality showed a significant effect on the water quality profile with a coefficient of 0.591.

Table 1. Data of water quality and physical condition of the springs.

Location	Sub location	a1	a2	a3	a4	f1	f2	f3	f4	f5
MBNP	BA 1*	7.9	200.1	3	4	0.29	0.15	2.71	329.15	4
Jember	BA 2	7.6	314.7	3	4	0.33	0.18	3.05	96.25	4
	BA 3	7.7	202.7	2	3	0.61	0.29	1.10	179.62	1
	AR 1*	7.7	113.0	3	4	0.27	0.13	0.83	33.21	3
	AR 2	7.7	113.0	3	4	0.27	0.13	0.83	33.21	3
	AR 3	7.6	239.7	3	4	0.11	0.07	1.00	8.64	3
Kediri	Plo*	7.5	367.0	3	4	0.50	0.07	3.58	95.68	3
	Kla	7.6	335.0	3	4	0.37	0.15	2.03	118.42	3
	Je	7.4	353.0	2	3	0.51	0.17	0.86	67.79	1
	TR 1*	6.9	278.7	3	4	0.55	0.06	2.61	87.95	3
	TR 2	7.4	251.7	3	4	0.62	0.11	4.45	302.99	3
	Be*	7.1	400.3	3	4	0.39	0.02	1.75	17.53	2
	Ja	7.0	310.0	3	4	0.80	0.12	3.60	307.46	2
	Ba	7.3	419.0	3	4	0.20	0.27	2.59	77.72	2
	Co 1*	6.5	221.3	3	4	0.30	0.10	0.87	27.95	3
	Co 2	7.3	223.0	2	4	0.62	0.12	2.33	164.39	3
Pasuruan	Se	7.8	302.0	2	2	0.51	0.14	0.76	49.10	1
	L 1*	7.4	279.3	3	4	0.38	0.19	0.74	27.77	2
	L 2	8.1	190.6	3	4	0.43	0.24	0.45	222.84	2
	L 3	8.4	175.3	2	2	0.43	0.07	1.06	42.20	2
	L 4	8.6	223.3	2	2	0.19	0.16	0.04	35.55	1
Malang	K 1*	7.6	143.6	3	4	0.45	0.08	0.71	26.50	2
	K 2	8.4	135.4	3	4	0.48	0.13	0.99	90.44	2
	K 3	8.6	189.8	2	3	0.36	0.12	1.01	1.01	2
	CR 1*	8.6	53.5	3	4	0.20	0.28	3.40	190.4	3
	CR 2	8.8	54.0	3	4	0.40	0.32	1.20	153.6	3
	CR 3	8.3	142.6	3	3	0.35	0.26	0.99	0	2

Note : BA = Blok Aren; AR = Andongrejo; Plo = Plosolor; Kla = Klaten; Je = Jengkol; Be = Bendo; TR = Tempurejo; Ja = Jarak; Ba = Bangkok; Be = Bendo; Co = Cowek; Se = Semut; L = Lawang; K = Karangan; CR = Coban Rondo; a1 = pH, a2 = electric conductivity, a3 = transparency (4=colourless; 3 = light brown; 2 = brown; 1 = dark brown), a4 = colour (3 = clear; 2 = slightly turbid; 1 = turbid), f1 = water velocity, f2 = depth, f3 = width, f4 = discharget, f5= substrate (4 = large stone; 3 = large gravel; 2 = gravel; 1 = sand/mud)

The geographic profile affected the water quality and the land use quality with coefficients of 0.491 (on the steep border there was recorded a better water quality), and 0.729 (at the steep border there were higher environmental services). The researchers observed the riparian tree vegetation at an altitude that less than 1200 m above sea level. However, the researchers also observed the

riparian tree vegetation at an altitude of 1,290 m above sea level (Coban Rondo). Almost all springs have borders with a steep slope to sheer slope with a level of 25-55° (47-119%), while the channels have borders varying from flat, gentle, slightly steep, steep, very steep to steep. The level of the border slope also determines the quality of habitat, the steeper, the smaller the quality value of its

habitat. This is due to the steep slope of the intensity of nutrient leaching by the runoff of the rainwater is getting higher, so that the nutrient content left in the soil layer is getting less. River slopes play an important role in the development of aquatic and terrestrial ecosystems because of its specific hydrological, hydrochemical, and ecological conditions. River slopes act as a buffer between the water and the surrounding terrain (Yifeng et al., 2017). According to Dewi et al. (2012) on the steeper slope, the higher runoff speed inhibited the infiltration process and increased erosion. Around the springs with very steep slopes, higher species diversity of riparian trees was grown.

The presence of tree species improved habitat quality due to its capabilities to stabilize the slope area. Research conducted by Ali et al. (2012) showed that trees in slope areas had an important role in maintaining hydrological and mechanical soil stability. Riparian trees increased the soil strength by reducing its water content, and even evapotranspiration by plants reduced the weight of soil mass. The surrounding land use quality

showed a significant effect on the riparian tree diversity profile with a coefficient of 0.706 (the higher the environmental services, the better the tree quality). The physical condition of spring and its channel influenced the diversity profile of riparian tree vegetation with a coefficient of 0.347 (in springs that the substrate dominated by large stones, it was found a better riparian tree quality). Nearly all springs and channels observed during the study were surrounded by riparian vegetation that had been partially converted, degraded, or affected by human activities. Riparian tree vegetation in BA was still natural. The land use around the springs and their channels include forests, settlements, rice fields, gardens, and also tourist attractions were still low. The location that alike forests were also found in Plosolor and Tempurejo with higher degradation rates compared to MBNP. Ding et al. (2013) revealed that there was a negative correlation between land use and riparian quality. Riparian quality decreased along with the increasing of anthropogenic activity where the role of riparian as a buffer to remedy polluted materials also decreased.

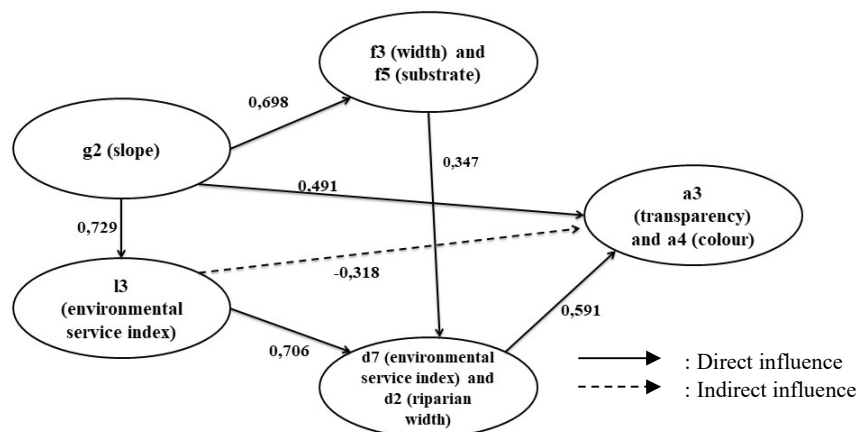


Figure 5. The revised PLS model of riparian tree diversity interaction with some determining variables of water quality.

In addition to the direct interaction, there was a negative indirect effect between the quality of land use and water quality through riparian tree diversity. This indirect effect coefficient was -0.318, the higher land use quality; the lower water quality would be if the riparian tree diversity was also getting lower. It is in line with research done by Yurigui et al. (2019) who revealed that the high vegetation fragmentation in the riparian zone was caused by human activities, i.e. farms, paddies, and urban areas. Yurigui et al. (2019) also argued that human activities had impacted on degraded water quality, but it had negatively impacted on the existence of biotic components such as diatom,

macroinvertebrate, and fish in the river. Increasing anthropogenic pressure in the river areas quickly eliminated natural riparian vegetation (Shah et al., 2015). Therefore, river water quality was low due to the absence of ecological services needed to control the movement of sediments and nutrients in the water body. Riparian trees developed strong roots that were important in maintaining riverbank stability and preventing erosion by reinforcing soil, providing root tensile forces, and root distributions. Besides the roots showed a hydrological function by filtering dissolved nitrogen, phosphorus, and various pollutants that move along the slope so that water quality becomes better (Ward et al., 2002).

Conclusion

The riparian tree diversity and geographical conditions directly influenced water quality, especially on water colour and its turbidity. Whereas, the quality of land use of some water bodies did not directly influence water colour and its turbidity. Therefore, water colour and channels transparencies were directly influenced by riparian width. Ecosystem degradation was shown by naturalness index, hemeroby index, environmental services index, and the slope of riverbank.

Acknowledgements

This research was fully funded by Grant I-MHERE Biology Department, Brawijaya University. Special thanks are due to Mr. Budi and Mr. Topan for their assistance during the fieldwork in Meru Betiri National Park.

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