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The impact of Land use Change on Water Pollution Index of Kali Madiun Sub-watershed

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Abstract. Land use change is one of the effects of population growth and increased human activities. Land use change that overlooked the rule of ecosystem sustainability has a propensity to adversely affect the environment, including the decline of water quality. Kali Madiun is a sub-watershed of Bengawan Solo Watershed that allegedly endured the impacts of land use change. This study aimed to investigate the impacts of land use change on the water quality index of Kali Madiun Sub-watershed. Land use change analysis was done by overlay analysis of spatial data including the maps of land use in 2010 and 2015. Samples were the surface water in the upper, middle and lower part of Kali Madiun Sub-Watershed. Water quality analysis was carried out by comparing the results of water quality parameter assessment based on Government Regulation No. 82 of 2001, while water quality index was figured out by an assessment based on the Decree of the Minister of Environment No. 115 of 2003. The results indicated that during the five years observation, there were land use changes in the upper, middle and lower part of Kali Madiun Sub-watershed. Several parameters increased in 2010 to 2015, namely: TDS, BOD, COD, nitrate, detergents, oils and greases. Pollution index shifted from slightly polluted in 2010 into moderately polluted in 2015. We propose a strategy to solve these problems by the involvement of stakeholders and the participation of local community in managing both domestic and industrial wastes. Also, it should be supported by palpable regulations related to land conversion. Furthermore, it is expected that the effort will reduce the potential of pollution and improve the water quality.

Keywords: Pollution Index, land use change, Kali Madiun Sub-Watershed.

Abstrak. *Perubahan penggunaan lahan merupakan salah satu akibat dari meningkatnya jumlah penduduk dan aktivitas yang dilakukan. Alih fungsi lahan yang kurang mengindahkan kaidah kelestarian akan berdampak negatif terhadap lingkungan, salah satunya adalah menurunnya kualitas air. Salah satu Sub DAS yang mengalami perubahan penggunaan lahan adalah Sub DAS Kali Madiun yang merupakan bagian dari DAS Bengawan Solo. Penelitian ini bertujuan mengetahui dampak perubahan penggunaan lahan terhadap indeks pencemaran kualitas air di Sub DAS Kali Madiun. Analisis perubahan penggunaan lahan dilakukan dengan overlay peta penggunaan lahan tahun 2010 dan tahun 2015. Sampel air yang diamati adalah air permukaan yang berada pada 3 titik yaitu hulu, tengah dan hilir. Analisis kualitas air dilakukan dengan membandingkan hasil pengukuran parameter kualitas air dengan Peraturan Pemerintah (PP) No. 82 tahun , sedangkan Indeks Pencemaran air diketahui dengan melakukan penghitungan berdasarkan Keputusan Menteri Negara Lingkungan Hidup No. 115 tahun 2003. Hasil penelitian menunjukkan bahwa selama 5 tahun pengamatan, terdapat perubahan penggunaan lahan, baik di bagian hulu, tengah maupun hilir. Terdapat beberapa paremeter yang mengalami peningkatan dari tahun 2010 ke tahun 2015 diantaranya TDS, BOD, COD, nitrit, detergen, serta minyak dan lemak. Indeks Pencemaran diketahui mengamai peningkatan dari kelas tercemar ringan pada tahun 2010 menjadi tercemar sedang pada tahun 2015. Untuk mengatasi masalah tersebut diperlukan strategi melalui kerjasama antar stakeholders dan partisipasi masyarakat dalam mengelola limbah domestik dan industri. Hal tersebut perlu didukung dengan peraturan*

atau regulasi yang jelas terkait alih fungsi lahan, dan diharapkan dapat membantu menurunkan potensi pencemaran serta meningkatkan kualitas air.

Kata Kunci: *Indeks Pencemaran,perubahan penggunaan lahan, Sub DAS Kali Madiun.*

1. Introduction

Watershed is an area of land which is a unity with the river and its tributaries that serve to accommodate, store, and drain water originating from rainfall to the lake or the sea naturally. It is bordered by topographical boundary and on the ocean, by the water area that is still affected by terrestrial activities (Setneg RI, 2012). Watershed is an ecosystem where there are a variety of natural resource components which interact each other. One of the natural resources in the watershed are land resources. Land is the physical environment that consists of climate, soil, relief, water, and vegetation as well as above ground objects and has influence on land use (Arsyad, 2000).

The condition of land in watershed is degraded as the consequence of over intensive and exploitative land utilisation. Moreover, the level of population growth is linear to the higher level of marginal land area, thus, watershed's carrying capacity is declined (Kementerian Kehutanan, 2009). Land use change is defined as a shifting or change of a function of land into other functions, whether temporary or permanent, due to the dynamic within a society (Winoto *et al*., 1996). Similar to a study by Hanjani *et al*. (2015), land use change is a form of human intervention on the environment to fulfil human's life requirements, both material and spiritual. Rapid population growth is essentially proportional to the need for land (Brueckner, 2000). However, land use that neglects the sustainability rule will only adversely affect quality of life regarding the environment. According to Lambin *et al.* (2001), land use that ignores the environmental rules will cause land degradation such as erosion, sedimentation, floods, landslides, and other damages of natural resources. It shows that land use change is a form of land exploitation. This land exploitation for settlement, industry, and other land functions, gives further burden on land in addition to the potential of pollution and environmental degradation. Other case based on Ramlan *et al.* (2015), the increase of population leads to an increase of land use for agricultural sectors. As a result, the amount of land for preservation zones significantly decreases because of the continuous increase of land change for agricultural activities. The change of land use has effects on society, particularly in the dry season where soil water availability is limited.

One of the indicators of appropriate watershed management is the sustainability of the quantity, quality, and continuity of watershed's water resources. Surya *et al.* (2014) emphasised the population growth in a watershed area will affect land use and will ultimately influence the hydrological system of a watershed. Likewise, Rahman *et al.* (2014) asserted that conversion and proportion of land use would significantly affect the water quality. Water pollution is a consequence of land conversion that gives less attention to the aspects of environmental sustainability. The more activities are undertaken by humans, the higher amount of wastes is generated by those activities. Those wastes will cause a decline in surface water quality and disrupt the ecosystem of water body (Pasisingi *et al*., 2014). Water quality and quantity is one of the most important requirements in the health and live of all living beings (Krisnawati *et al*., 2015). The decline in water quality is a condition where water cannot be utilised in accordance with the status of water quality (Ali *et al*., 2013).

Extended area for settlement in a watershed area, both in the upper, middle, lower part, will escalate the potential for water pollution due to generated domestic wastes. Uncontrolled land use change in the upstream will eventually affect the water quality of the midstream and downstream. Similarly, Suswati and Wibisono (2013) in a study claimed that the population growth causes surface water pollution, particularly on river water due to limited sanitary and domestic wastes management. The shortage of domestic waste management

and prevailing human behaviour indirectly disposing of both organic and inorganic wastes as well as solid and liquid wastes into water bodies, have increased water pollution level and degraded the water quality.

Kali Madiun Sub-watershed is part of the Bengawan Solo Watershed that endured land use change from time to time. The conversions might result in the shift of surface water quality, therefore, it was important to determine the surface water quality, thus, the community and policy makers could initiate appropriate actions in order to maintain and improve the water quality in the area. This study aimed to investigate the impacts of land use change on water quality and pollution index in Kali Madiun Sub-watershed.

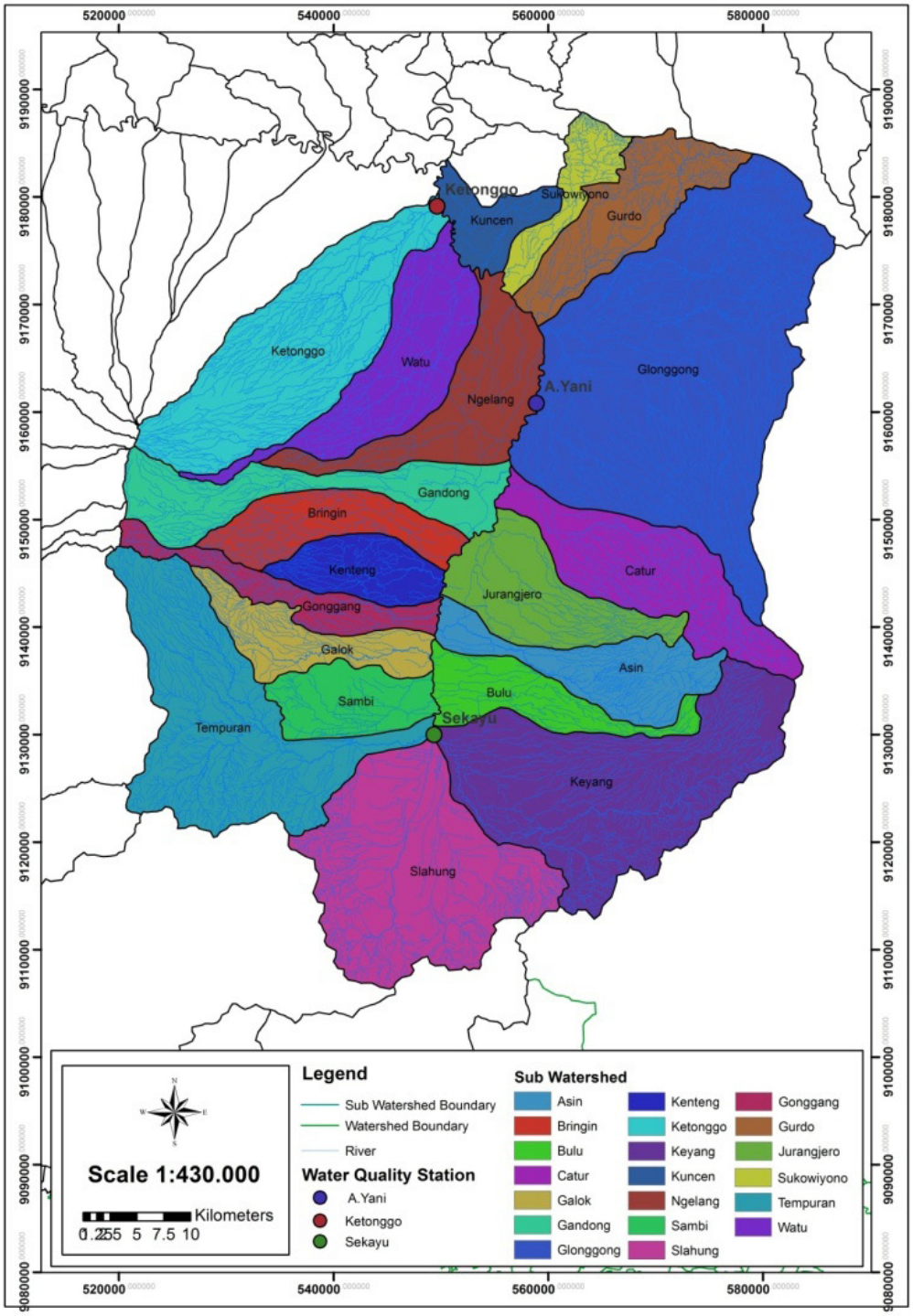

Figure 1. Map of Location in Kali Madiun Sub-Watershed

2. Research Method

a. Study Areva

This study was carried out in 2016 in Kali Madiun subwatershed, which is part of the Bengawan Solo Watershed. The total area of Kali Madiun Sub-watershed is approximately 371591.54 ha. Geographically, Solo watershed lies between 7°21′ – 8°50′ S and 110°10′-110°26′ E. Administratively, Kali Madiun Sub-watershed includes 11 districts, namely, Bojonegoro, Karanganyar, Madiun City, Madiun, Magetan, Ngawi, Pacitan, Ponorogo, Trenggalek, and Wonogiri. The topographic boundaries of Kali Madiun Sub-Watershed are, North: Ngale Sub-watershed and Padas Sub-watershed, East: BrantasWatershed, South: Pringombo Watershed and Grindulu Watershed, West: Samin Sub-watershed and Mungkung Sub-watershed. Total area of potential critical to very critical in Kali Madiun Sub-watershed was 30.88% (BPDAS Solo, 2012). The types of soil that dominate the area are Mediterranean, grumosol, alluvial, and litosol. Study area can be observed in Figure 1.

b. Materials and Tools

Materials used in this study consisted of the maps of Kali Madiun Sub-watershed, RBI map scale 1:25000, Landsat 7 imagery of 2010 and Landsat 8 imagery of 2015 with Path/Row 119/65, Coordinates of sample collection area, monthly water quality data in 2010 and 2015 were carried out in the three sections of river, namely in Sekayu station, A Yani station, and Ketonggo station in the upper, middle, and lower part of Kali Madiun Sub-Watershed (Figure 1) and daily precipitation of 15 stations in 2010 and 2015 obtained from *Balai Besar Wilayah Sungai Bengawan Solo*.

c. Research Procedure

Analysis of land use change was done by overlay technique on spatial data analysis result, including the maps of land use in 2010 and 2015. Band combination used three wavelengths performed by basic colours of red, green, and blue. This research used composite colour for Landsat ETM 7+ image as the combination of band 5 4 3, while the band combination for Landsat 8 image was band 6 5 4. Image interpretation and classification were conducted by using supervised classification. Land use change on the map of land use spatial analysis was done by combining three waves that displayed basic colours of red, green and blue.The results generated from this analysis were the type, width, and pattern of land use change in Kali Madiun Sub-watershed.

Water quality analysis was conducted in the dry season by an assumption that the concentration of pollutants would be higher because there is no leaching of rainwater. The starts of the dry season and rainy season of the observed years were determined by rainfall data analysis based on BMKG criteria. The period was considered as the rainy season when the rainfall was ≥50 mm and considered as the dry season when the rainfall was □50 mm.The results of the water quality analysis in each observed seasons were assessed based on Government Regulation No. 82 of 2001 on Management of Water Quality and Control over Water Pollution on Pollution in Class I, II, III, and IV to find out the limiting factors. Water pollution index at each section was calculated based on the Decree of the Minister of Environment No. 115 of 2003 on Guidelines for Determination of Water Quality Status by using a formula as follows:

$$PIj = \sqrt{\frac{(Ci/Lij)_M^2 + (Ci/Lij)_R^2}{2}} \qquad (1)$$

where:

Lij = Concentration of water quality parameter based on the water quality standard for a designation (j).

Ci = Concentration of water quality parameter resulted from survey.

PIj = Pollution Index for a designation (j).

$(Ci/Lij)_M$ = Maximum value of Ci/Lij.

$(Ci/Lij)_R$ = Average value of Ci/Lij.

Evaluation of water Pollution Index was based on the result of calculation, which was classified into four classes (Table 1).

Table 1. Criteria of Water Quality Pollution Index.

Score	Class
0 ≤ PIj ≤ 1.0	Good (complying standard quality)
1.0 ≤ PIj ≤ 5.0	Slightly polluted
5.0 ≤ PIj ≤ 10	Moderately polluted
PIj > 10	Heavily polluted

Source: Decree of the Minister of Environment No. 115 of 2003.

3. Results and Discussion

a. Land use change based on total Area

Based on the results of the analysis, there were several land use changes in the watershed area in 2010 to 2015. The specific land use change in the upper, middle, and lower of Kali Madiun Sub-watershed is presented in Table 2.

Table 2. Land use change in the area of Kali Madiun Sub-watershed in 2010-2015.

No	Function	Land Use	Year				Conversion	
			2010		2015			
			Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
A	Upper							
		Freshwater	306.94	0.08	306.94	0.08	0.00	0.00
		Shrub	6066.47	1.63	6030.78	1.62	-35.69	-0.01
		Forest	6833.84	1.84	6833.84	1.84	0.00	0.00
		Plantation	16187.84	4.36	16187.84	4.36	0.00	0.00
		Settlement	14978.45	4.03	15269.53	4.11	291.08	0.08
		Pasture	246.89	0.07	246.89	0.07	0.00	0.00
		Irrigated field	16768.98	4.51	16675.72	4.49	-93.26	-0.03
		Rainfed agriculture	26070.16	7.02	25948.45	6.98	-121.71	-0.03
		Dryland agriculture	15947.59	4.29	15907.16	4.28	-40.43	-0.01
B	Middle							
		Freshwater	658.90	0.18	685.13	0.18	26.24	0.01
		Shrub	11056.75	2.98	10750.60	2.89	-306.15	-0.08
		Forest	7529.88	2.03	7427.49	2.00	-102.40	-0.03
		Plantation	48244.96	12.98	48122.86	12.95	-122.11	-0.03
		Settlement	33281.41	8.96	33499.42	9.02	218.02	0.06
		Pasture	1178.41	0.32	1134.77	0.31	-43.65	-0.01
		Irrigated field	54355.55	14.63	54447.65	14.65	92.10	0.02
		Rainfed agriculture	24179.02	6.51	24294.39	6.54	115.37	0.03
		Rocky area	20.43	0.01	21.88	0.01	1.45	0.00
		Dryland agriculture	35784.39	9.63	35905.52	9.66	121.13	0.03
C	Lower							
		Freshwater	161.63	0.04	161.63	0.04	0.00	0.00
		Shrub	1422.62	0.38	1422.56	0.38	-0.07	0.00
		Forest	104.22	0.03	146.34	0.04	42.12	0.01
		Plantation	7765.24	2.09	7714.44	2.08	-50.79	-0.01
		Settlement	10282.07	2.77	10446.29	2.81	164.22	0.04
		Pasture	127.69	0.03	117.33	0.03	-10.37	0.00
		Irrigated field	17125.31	4.61	17127.44	4.61	2.14	0.00
		Rainfed agriculture	10199.57	2.74	10193.15	2.74	-6.42	0.00

No	Function	Land Use	Year				Conversion	
			2010		2015			
			Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
		Rocky area	0.72	0.00	1.91	0.00	1.18	0.00
		Dryland agriculture	4705.62	1.27	4563.61	1.23	-142.02	-0.04

Source: Data analysis, 2016.

In accordance to Table 2, land use change occurred in the last five years. In the upper part of Kali Madiun Sub-watershed, the area of shrub was reduced by 35.69 ha, irrigated field by 93.26 ha, rainfed agriculture by 121.71, and dryland agriculture by 40.43ha. Extended area changed into settlement area was 291.00 ha. In the middle part of Kali Madiun Sub-watershed, the land use change significantly took place.It was indicated by the change of each former land function in the middle part of Kali Madiun Sub-watershed. The changes included the extent of freshwater (26.24 ha), settlement (218.02 ha), irrigated field (92.10 ha), rainfed agriculture (115.37 ha), rocky area (1.45 ha), and dryland agriculture (121.13 ha). Meanwhile, declined total area was undergone by shrub (306.15 ha), forest (102.40 ha), plantation (122.11 ha), and pasture (43.65 ha). In the lower part of Kali Madiun Sub-watershed, the extents were obtained by forest (42.12 ha), settlement (164.22 ha), irrigated field (2.14 ha), and rocky area (1.18 ha). Declined total area in the lower part of Kali Madiun Sub-watershed occurred in shrub (0.07 ha), plantation (50.79 ha), pasture (10.37 ha), rainfed agriculture (6.42 ha), and dryland agriculture (142.02 ha).

Land use change in the upstream, midstream, and downstream will lead to a change in water quality. Also, the shift of productive into non-productive land will also affect the quality of surface water. It indicates the potential of human activities in enhancing the volume of produced wastes, which eventually augment the potential of surface water contamination. According to Yu *et al*., (2013), the nature and human activities have effects on water quality. Inappropriate land function would adversely affect the water quality.

Land use change in the upstream, midstream, and downstream might also indicate the changes of local community's activities in the last five years. The largest land conversion was settlement type. In the upper of Kali Madiun Sub-watershed, land use change from irrigated fields, dryland agriculture, and rainfed agriculture into settlements amounted to 291.08 ha. In the middle, there was total conversion of 218.02 ha from plantation, pasture, irrigated field, rainfed agriculture, and dryland agriculture. Meanwhile in the lower, there was an addition of 164.22 ha from plantation, rainfed agriculture, and dryland agriculture into settlement. According to Widyastuti and Suprayogi (2006), Gajahwong Watershed is mostly covered by settlement and paddy field.So, the land use in the study area has higher vulnerability level. It is assumed that the larger of the settlement tends to produce more domestic waste.

Nevertheless, there was a conversion of plantation into forest in the upper part of Kali Madiun Sub-watershed of 42.12 ha. It was allegedly due to the undisturbed plantation where young crops could grow and develop properly, hence, the area successfully turned into a forest. It was highly expected that this forest could balance the land use change into settlement to obtain a final result of better water quality. It was confirmed by Ozturk *et al*., (2013), that the conversion and dynamics of land use have significant impact on the hydrological status of a watershed. Hydrological condition represents the stable quantity in addition to well-maintained water quality.

b. Surface Water Quality

The quality of water surface collected in the dry season at the upper, middle, and lower

part of sub-watershed in 2010 and 2015, showed differences. The average of water quality in the Kali Madiun Sub-watershed is presented in Table 3.

Table 3. Average water quality in Kali Madiun Sub-watershed.

No	Parameter	Unit	Gov. Reg. No.82/2001				Upper		Middle		Lower	
			I	II	III	IV	2010	2015	2010	2015	2010	2015
1	TDS	mg/L	1000	1000	1000	2000	186.67	509.67	203.33	375	221.33	513.4
2	Nitrate	mg/L	10	10	20	20	0.53	1.35	0.93	0.16	1.27	0.7
3	Nitrite	mg/L	0.06	0.06	0.06	0.06	0.12	2.83	0.12	2.27	0.15	1.46
4	Phosphate	mg/L	0.2	0.2	1	5	0.27	0.12	0.37	0.09	0.5	0.22
5	COD	mg/L	10	25	50	100	15.53	16.93	16.73	24.18	16.35	20.2
6	BOD	mg/L	2	3	6	12	7.68	8.2	6.6	8.8	7.18	8.8
7	Detergents	µg/ L	200	200	200	(-)	92	316.93	305.5	261.42	431	119.28
8	Oils & greases	µg/L	1000	1000	1000	(-)	1,333.33	3,000	1,666.67	2,500	1,333.33	2,600

Source: Data analysis, 2016.

Table 3 showed the results of observation in which several parameters were classified as below the lowest quality standards (Class IV). It indicated the existence of limiting factors that hindered the water to meet the required quality standard. Parameters of nitrate and phosphate decreased, which were in Class III and IV, respectively. On the contrary to those parameters, there were six other parameters that increased from year to year. Despite TDS had fulfilled the quality standard, it gained significant increase in 2010 to 2015, both in the upstream, midstream, and downstream. Similarly, COD also increased and classified into Class II. Oils and greases, BOD, and detergents only met the standard of Class IV and they endured extreme increases during the five years of observation. However, nitrite was the only parameter that did not meet the standard of the entire classes.

The conditions of TDS, nitrate, COD, BOD, detergents, as well as oils and greases could not be separated from the impact of land use change into settlement (Table 2). Increased content of TDS was in linear with the higher numbers of settlement in the upstream, midstream, and downstream. Rahman *et al.*, (2014) asserted an increase of land use in the form of settlement potentially escalated TDS content. Likewise, an increase in nitrite content would occur. Ida (2009) and Aswadi (2006) suggested that nitrite in water bodies was caused by industrial and domestic wastes.

BOD and COD that were likely to enhance from 2010 to 2015 indicated the presence of pollution. Nugroho and Cahyorini (2007) claimed that the higher the BOD content, the higher the potential of pollution. Detergent pollution occurred particularly in the middle part of Kali Madiun Sub-watershed showed high domestic activity, in accordance with the number of settlement, which was higher than the upper and lower area. Detergent residues flowing into the water bodies caused siltation, inhibited oxygen transfer that disrupted aerobic decomposition process (Sopiah, 2004). It triggered the higher content of BOD and COD in the water since it slowed down the decomposition of wastes and garbage.

c. Water Quality Pollution Index

Water quality pollution index is used to determine the relative contamination level on the required water quality parameters (Ali et al, 2013). In Kali Madiun Sub-watershed, it was assessed based on the water quality analysis in the dry season in 2010 and 2015. The result of the analysis of water quality index in Kali Madiun Sub-watershed is presented in Table 4.

Table 4. Water Quality Index of Kali Madiun Sub-watershed.

No	Location	Year	PI 1		PI 2		PI 3		PI 4	
			Score	Class	Score	Class	Score	Class	Score	Class
1	Upper	2010	2.98	SC	1.83	SC	1.83	SC	1.8	SC
		2015	6.85	MC	6.77	MC	6.77	MC	6.68	MC
2	Middle	2010	2.86	MC	1.89	MC	1.89	MC	1.75	SC
		2015	6.53	MC	6.45	MC	6.45	MC	6.37	MC
3	Lower	2010	3.04	SC	2.32	SC	2.3	SC	2.18	SC
		2015	5.88	MC	5.75	MC	5.75	MC	5.67	MC

Source: Data analysis, 2016. Description: SC: Slightly polluted; MC: Moderately polluted.

In Table 4, the entire sections of Kali Madiun Sub-Watershed did not meet quality standard, either in Class I, II, III, or IV (PI was less than 1.00). Moreover, the pollution index showed an increase from 2010 to 2015. All of the classes could be categorised into slightly polluted in 2015. In the upper Kali Madiun Sub-watershed, the entire standards of Class I, II, III and IV were included in slightly polluted with a range from 1.80 (Class IV) to 2.98 (Class I), in 2010. However, the condition changed in 2015 where all Pollution Index could be enrolled in moderately polluted group at various class'standards of 6.68 (Class IV) to 6.85 (Class I).

Land use change in the upper part of Kali Madiun Sub-watershed from various land uses into a settlement of 291.08 ha and paddy field triggered higher amount of pollutant in the area. In addition to higher amount of domestic wastes, there were agricultural wastes and fertiliser residues. It was different with the finding in the middle of Kali Madiun Sub-watershed where most of the PI could be classified as moderately polluted. In fact, it obtained the highest score in compared with the upper and lower area due to the largest settlement area was located in the middle of Kali Madiun Sub-watershed, both in 2010 and 2015 (Table 2).

An increase of PI score in 2015 was prompted by land use change into settlement, which potentially increased pollution and furthermore could not meet the quality standard of the entire class based on Government Regulation No. 82 of 2001 on Water Quality Management and Control over Water Pollution.

In 2010, the PI score of the lower Kali Madiun Sub-watershed was in the range of 2.18 for Class IV to 3.04 for Class I and categorised as slightly polluted. However, in 2015, the PI also increased similarly with conditions in the upper and middle. It was also mainly stimulated by land conversion into settlement. Nevertheless, the PI of the lower part of Kali Madiun Sub-watershed was lower than those of the upper and middle area in the same year and class (Moderately polluted). It was allegedly due to the number of settlement in this area was lower than those in the upper and middle, in which forest was capable of lowering the PI in this area as well as the leaching of pollutants before water reached the lower area. In overall, the increase of PI from 2010 to 2015 indicated that pollution-enhanced and appropriate management is required, immediately.

d. Recommendation for Pollution Control

Investigation of pollution status in Kali Madiun Sub-watershed found out the increase of PI from year to year. Solution and strategy are required to inhibit the escalated pollution level. Several measures for pollution control are recommended as follows:

1. Regulation concerning the change of land use is required, particularly conversion into settlement and industry.

2. Domestic and industrial wastes should be managed properly before their release into water bodies, including the ban on direct disposal of both organic and inorganic wastes into water bodies.
3. Cooperation among stakeholders in addressing the pollution issue is required.
4. It is necessary to maintain and organise vegetation in adjacent to watershed or basin as a conservation effort.
5. The role and participation of the society particularly the local community is important in order to protect the environment and to reduce the pollution.

4. Conclusions

It can be concluded from this study, that the land use change in 2010 to 2015 at Kali Madiun Sub-watershed adversely affected the surface water quality and increased the pollution index of the upper, middle, and lower part of Kali Madiun Sub-watershed. Extended settlement area led to higher number of direct actions that automatically increased the amount of pollutant. Inappropriate management of domestic waste would create new pollution problems. Afforestation and appropriate pollutant management are highly recommended to reduce the level of Pollution Index.

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