The effect of land use change on water quality: A case study in Ciliwung Watershed

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Abstract. Ciliwung is the biggest river in Jakarta. It is 119 km long with a catchment area of 476 km^2. It flows from Bogor Regency and crosses Bogor City, Depok City, and Jakarta before finally flowing into Java Sea through Jakarta Bay. The water quality in Ciliwung River has degraded. Many factors affect water quality. Understanding the relationship between land use and surface water quality is necessary for effective water management. It has been widely accepted that there is a close relationship between the land use type and water quality. This study aims to analyze the influence of various land use types on the water quality within the Ciliwung Watershed based on the water quality monitoring data and remote sensing data in 2010 and 2014. Water quality parameters exhibited significant variations between the urban-dominated and forest-dominated sites. The proportion of urban land was strongly positively associated with total nitrogen and ammonia nitrogen concentrations. The result can provide scientific reference for the local land use optimization and water pollution control and guidance for the formulation of policies to coordinate the exploitation and protection of the water resource.

1. Introduction

Jabodetabek (Jakarta, Bogor, Depok, Tangerang, and Bekasi) megacity covering an area of approximately 7,000 km^2 and had a total population of more that 26.7 million in 2010. After 1981, the rate of population growth in Jakarta and surrounding cities has changed significantly. Jabodetabek area can not be separated from its upstream area in Puncak and Cianjur since the source of water for Jabodetabek comes from those two regions. Therefore, the concept of Jabodetabekpunjur (Jabodetabek, Puncak, and Cianjur) was designed to control development in the metropolitan region and upstream of the metropolitan area [1].

Ecologically, Jabodetabekpunjur coverage is the area that includes three primary watersheds (DAS), namely Ciliwung, Cisadane, and Bekasi Watershed. Ciliwung watershed is one that has a very important ecological role because it crosses several administrative areas such as Bogor Regency, Bogor City, Depok City, and Jakarta. Ciliwung River upstream located in Puncak and flows along 119 km with an average monthly discharge 882 m^3 per second (in Manggarai) toward Jakarta Bay.

Total of forest area, settlements, agricultural area, and green space in Jabodetabek from 1970-2005 has changed drastically. In the last 35 years, Jabodetabekpunjur has lost 27% of green open space.

Built area such as settlement grew more than 12 times, causing the carrying capacity of the environment to be very limited. The uncontrolled growth of settlements and urban area along the watershed, the malfunction of the canals, and the absence of an adequate drainage system caused further delays in the flow of water into the sea, resulting in Jakarta and the area along the river banks were vulnerable to flood. The other problems is the decline in the quality and quantity of river water [2].

Land cover and land use are very important elements in relation to water quality. Different types of land use and land cover affect the quality of water. Agricultural and household fertilizers have different chemicals within them, such as nitrogen and phosphorus. These chemicals can potentially run off into nearby water sources such as groundwater, streams and larger bodies of water. In turn, this could damage the nutrient content within that water supply, affecting the overall water quality itself [3].

The high population growth in Jakarta, Bogor, Depok, and surrounding areas resulted in changes of land use and land cover. Changes in land use and land cover indirectly affect water quality in Ciliwung River. This study aim is to look at the effects of changes in land use and land cover to the Ciliwung River water quality in 2010 and 2014.

2. Material and methods

2.1. Study area

Ciliwung River (figure 1) is one of 13 river that traversed in Jakarta. Drainage area of Ciliwung River approximately 42,818.74 hectares area and the main river channel is ± 119 kilometers long with an average gradient of about 10-15%. The Ciliwung River has its source at Mandalawangi in Bogor Regency with the highest peak at 3,002 m. The river flows in a northern direction passing several active volcanoes, crosses three main cities Bogor, Depok, and Jakarta before finally flowing into the Java Sea through Jakarta Bay. Ciliwung River is divided into six segments. It crosses some administrative regions such as Bogor Regency, Bogor City, Depok City, East Jakarta, South Jakarta, Central Jakarta, and North Jakarta. Mean rainfall reaches 3,125 mm, with mean annual discharge of 16 m^3/s as measured at Ciliwung Ratujaya observation station (231 km^2). With such topographical, geological and hydrological features the Ciliwung River is often overflowing and inundating parts of Jakarta [4].

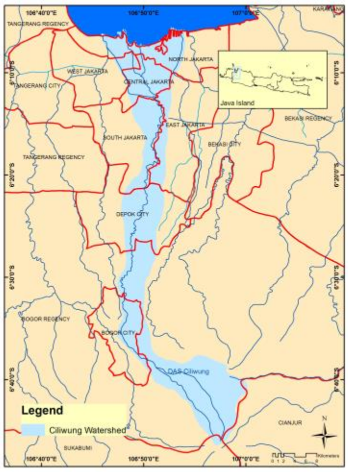

Figure 1. Study area

2.2. Sample collection and parameter measurement

A total of 12 points were sampled along the main stem of Ciliwung River. Water sampling was carried out in rainy season and dry season in 2010 and 2014. Sampling data in those two years will be used to compare the water quality from time to time and to see land cover change effect in 4 years to water quality. A combination of spatial and temporal analyses was applied to provide more robust results for the relationship between land use and water quality. Duplicate samples were taken out at each sampling site. Data of water quality were obtained from Ministry of Environment and Forestry Republic Indonesia. Sampling points along Ciliwung River can be seen in table 1.

Table 1. Ciliwung sampling points

No	Sampling Points	Location
1	Atta'awun	S 06˚41'56.2 E 106˚59'14.5"
2	Bendung Gadog	S 06˚39'12.1" E 106˚52'10.3"
3	Katulampa	S 06˚37'59.7" E 106˚50'12.6"
4	Sempur	S 06˚35'25.9" E 106˚47'56.6"
5	Pondok Rajeg	S 06˚26'43.7" E 106˚48'46.2"
6	Jembatan Panus	S 06˚24'02.4" E 106˚49'54.3"
7	Kepala Dua/Srengseng Sawah	S 06°20'56.2" E 106°50'18.2"
8	Intake PAM Condet/Kampung Gedong	S 06°17'34.2" E 106°51'12.5"
9	Sebelum Pintu Air Manggarai	S 06°12'45.7" E 106°51'28.0"
10	Jl. Kwitang	S 06°10'53.78" E 106°50'11.40"
11	Jl. Gajah Mada	S 06°09'34.64" E 106°49'08.48"
12	Jemb. Pantai Indah Kapuk/Muara Angke	S 06°07'00.04" E 106°46'23.03"

During and after sampling, six water parameters were chosen to be measured, which are important indicators of water pollution influenced by anthropogenic activities. Parameters that sampled consist of total suspended solids (TSS, mg/L), Total phosphorus (TP, mg/L), chemical oxygen demand (COD, mg/L), biological oxygen demand (BOD, mg/L), and dissolved oxygen (DO mg/L).

2.3. Spatial analysis
Landsat Thematic Mapper (TM) satellite imagery with 30 m resolution for 2010 and 2014 was obtained from Indonesian Planology Agency. The land use classes were generated using a supervised classification technique with a maximum likelihood algorithm in the Erdas Imagine 9.2 (ERDAS Corporation, Norcross, GA, USA). The Landsat images were also rectified using aerial photographs and field survey data. The overall accuracy for the classification was 88% and the kappa coefficient was 0.85 (i.e., 85% more accurate than a random classification) [5]. The land use classes were categorized into five groups: urban land, agricultural land, forest, bareland, and water body. Urban land use consists of built areas such as settlement and industry. Agricultural land including rice field, plantation, shrubs, and secondary crops field. While water bodies consist of fish pond and wetland.

3. Result

3.1. Land use site grouping and their distribution
From 2010 until 2014 urban land made up the vast majority of total area. The percentage of urban land has increased in 4 years from 66.10% to 66.85%. While agricultural land in the whole watershed showed degradation from 21.65% to 20.90% (table 2). There is no changes in total area of other land uses (bareland, forest, and water body) within those 4 years. Land use map of Ciliwung Watershed in 2010 and 2014 can be seen in figure 2.

Table 2. Land use characteristics in Ciliwung Watershed

Land Use	2010		2014	
	Area (Ha)	Percentage	Area (Ha)	Percentage
Agricultural land	9,269.15	21.65	8,947.64	20.90
Bareland	12.06	0.03	12.06	0.03
Forest	5,048.19	11.79	5,048.19	11.79
Urban	28,301.37	66.10	28,622.88	66.85
Water body	187.98	0.44	187.98	0.44
Total	42,818.74	100.00	42,818.74	100.00

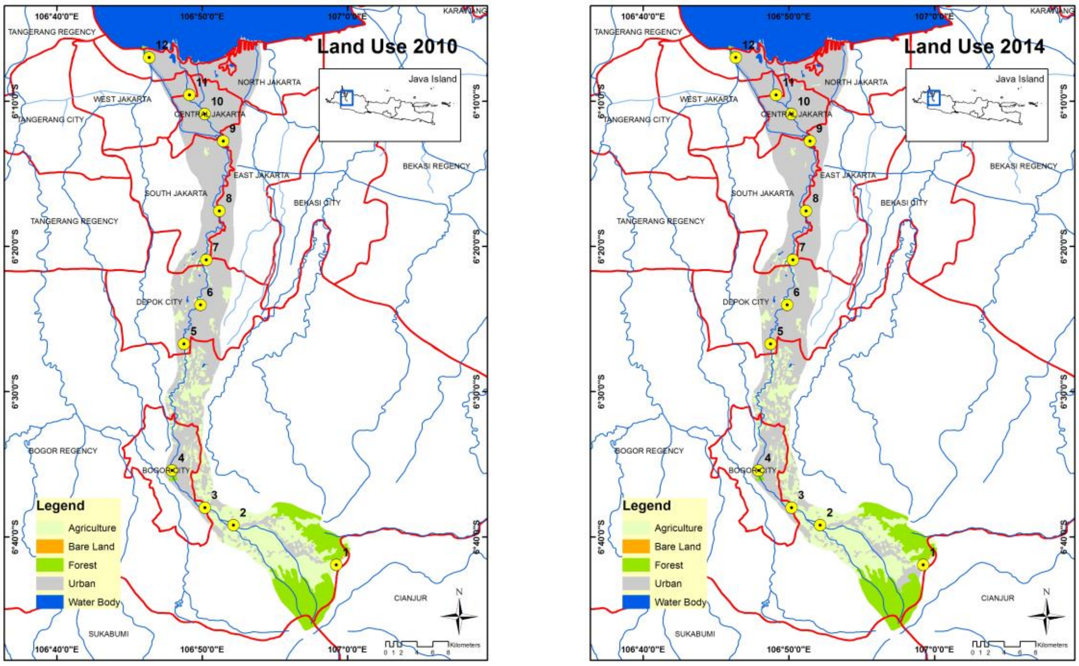

Figure 2. Land use in Ciliwung Watershed in 2010 and 2014

From the figure 2, it can be seen that land use changes from agricultural land to urban land occurred in the upstream of Ciliwung Watershed near sampling point 1. This indicates that land use changes in the Ciliwung Watershed not only occurred in an urban area or downstream of the river but also the conservation area located on the upper river. The rapid economic activity and development in Puncak is one of the factor. The land use within the watershed has great impacts on the water quality of rivers. The water quality of rivers may degrade due to the changes in the land cover patterns within the watershed as human activities increase of [6, 7]. The high attraction of Puncak as tourism object for the urban population causes local people to prefer to change agricultural land into buildings such as villas and hotels that have higher economic value than agricultural commodities. If this happens constantly then the Ciliwung upperstream would lose its function as a conservation area and ecological conditions along the Ciliwung will be degraded.

3.2. Temporal variations of water quality

The comparison of water quality in every Ciliwung sampling point in 2010 and 2014 can be seen in figure 3. According to Government Regulation No. 82/2001, Ciliwung River was categorized into water quality class 2. Indonesian Government Regulation No. 82 year 2001 stated that water quality class 2 can be used as water recreation, fish cultivation, livestock, and irrigation. The standard of water quality class 2 of each parameter can be seen from the horizontal blue line in the graphic. Based on class 2 water quality standards, the parameters of TSS, TP, BOD, and COD should be at or below the blue line while the DO parameter should be at or above the blue line.

Figure 3. Graphic of Ciliwung River water quality in 12 sampling points

TSS value at point 2, 3, 4, and 5 showed a decline from 2010 to 2014, while the rest showed an increase. At some point, the value of TSS is already at quality standards. In general, the parameter DO showed a decline from 2010 to 2014. At the point 1-8, the value of DO meet the quality standards. However, in the downstream area of the river (point 9-12) DO value is below the quality standard. The decrease of DO value from upstream to downstream indicates water quality degradation.

Similarly with DO, TP values showed a decrease in water quality from upstream to downstream. TP value showed an increase on point 9 to 12. According to NGRDC (2015) [8], the value of TP and DO has negative correlation. The more TP value, the less DO value. Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Excessive concentrations of nutrients, however, can overstimulate aquatic plant and algae growth. Bacterial decomposition of organic respiration and can use up dissolved oxygen, depriving fish and invertebrates of available oxygen in the water (eutrophication).

COD value shows an increase from upstream to downstream. Some sampling point showed a decrease COD value within 4 years. COD value at the sampling point in the downstream area is also above the quality standard of 25 mg/L. In contrast to COD, BOD value in every sampling points have already meet water quality standard for class 2 (3 mg/L). However, in general, the value of BOD in 2014 showed a decline from the 2010. This represents an improvement of water quality.

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. Chemical oxygen demand (COD) does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements take five days. Generally, water quality parameters in Ciliwung River from 2010 to 2014 has degraded.

4. Discussion

4.1. Impact of different land uses on water quality

Generally land use types related to economic activity and development negative impacts on water quality, so positive correlations exist between percentages of these land use types and concentrations of water pollutants, while undeveloped areas such as natural forest area are related to good water quality [9]. Different land use types are associated with different water pollution problems. For example, Tong and Chen (2002) [10] examined the relationships of land use and water quality on regional scale in the watershed of the Ohio State, USA. They found that TP (Total Phosphorus) was significantly positively related to commercial, residential, and agricultural lands, but non-significant relationships with forest, and BOD had a significant positive correlation with residential and commercial lands, a significant negative correlation with forest, but non-significant correlation with agricultural land [11].

4.2. Impact of urbanization on water quality

Ciliwung river water quality degradation within 4 years shows that the change in land use, in this case the increase in urban land, generally have shown that urbanization provides a real influence on the degradation of water quality in all parameters. In addition, the land utilization in Jabodetabekpunjur area has increased from upstream to downstream. Urban land has a great correlation with water quality. Urban land use was identified as the strongest contributor of pollutants in the Ciliwung Watershed. This may have been highly influenced by point source as well as non-point source pollution.

Urban land consists of various land uses such as residential, industrial, office, commercial, and other built area. Compared with other land use, urban land produces more wastewater. In addition, urbanization has expanded impervious areas, which has led to faster storm flows and greater runoff volumes [12]. Impervious storm runoff washes all types of pollutants (e.g., non-point source and point source pollutants) into rivers, which increases concentrations of nutrients and other pollutants in surface waters [13]. Besides, a shortage of wastewater treatment infrastructure in suburban areas also contributes to increased nitrogen levels [14].

5. Conclusion

Based on the Ciliwung watershed land use map in 2010 and 2014, it is known that there is a land use change of agricultural areas into urban land over 4 years period. Land use change has great impact on water quality. Generally, Ciliwung river water quality has decreased in the past 4 years. The quality of river water also decreased from upstream to downstream. This is related to the increasing urban land along the Ciliwung river from upstream to downstream. The high level of economic growth have resulted in the rise urban land. While, the rising urban land has a positive correlation with increasing concentration of pollutants in the river.

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