Integrated water quality modelling for spatial planning

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Abstract. The main objectives of spatial planning is to ensure that the utilization of land resources is planned and implemented in an organized manner to meet the needs of present and future generation. The aim of this study is to develop an integrated water quality modelling for spatial planning. Study area is Ciliwung watershed, in the middle of Jakarta Coastal watershed. This area is ideal for such a study. Jakarta is the capital city of the Republic of Indonesia, the most-populous national capital, incorporating one of the world’s largest coastal cities. The environmental condition of Ciliwung River is very poor. In this area exist a spatial distribution of socio-economic activities and related land uses such as urban area, industry, mining, agriculture, forestry, aquaculture and fisheries, commerce, transportation, and all the human activities that generate the associated manmade pollution and other environmental issues. Water quality modelling of Ciliwung River has been used to analyse the correlation of water quality in the river body with the land use in that area. Water quality modelling was performed using the QUAL2K public domain free software. Eutrophication models were used to determine the fate and transport of organic pollutants. Correlation analysis was carried out in term of to design the optimal land use planning. Optimizing land use was intended to obtain maximum economic benefits without causing environmental pollution. Several scenario analysis was applied in this area. Based on the water quality modelling, it is can be identified, the main pollution problem in Ciliwung system is in the downstream area, due to the high load of non-point source pollutants in the area. Pollution control in the downstream of Ciliwung is very crucial in term of the sustainability of Ciliwung water resources. Ciliwung pollutant load control can be done by land use planning and build a waste treatment plant. Spatial planning is needed in this areas to get the area with minimal pollutant loads.

Keywords: Land use; spatial planning; sustainable development; water quality

1. Introduction
Spatial planning is an activity focused on the decision making that related to the location and distribution of land use activities. The main objectives of spatial planning is to ensure that the utilization of land resources is planned and implemented in an organized manner to meet the needs of present and future generation. The greater the rate of economic development, the greater the threat to environmental resources. Spatial planning requires an integrative and comprehensive planning approach in order to rationalize the appropriate land use activities.

Water quality is one of the best benchmarks used to gauge the changes in relative environmental across the several scenarios [1,2]. The flow of water in the main network serves as an integrator of many processes occurring within the watershed and all of possible effects. Water quality is an indicator of the relief and landscape characteristics and the state of the environment. Integrated water
quality modelling is one of the tools for spatial planning. By using the water quality model, it is possible to optimize the land use planning. Optimal land use is the use of land resources in the sustainable way, with the maximum benefit of social economic activities and minimum negative environmental effect.

The watershed management approach has been widely recognized as a tool for integrated spatial planning, which links ecological and socio-economic issues. It is important to think of watersheds as a whole system that is interconnected. Activities in watersheds can affect a variety of resources including beaches, bays and estuaries, near coastal waters, coral reefs and other offshore areas. What has happened in one part of a watershed can affect another part which sometimes hundreds of miles away [1,3]. If a river or stream flows through an agricultural area, it can take fertilizers, manure, and pesticides from agricultural area that flow on the ground after a rainstorm. When passing through urban and suburban areas, it may collect fertilizers that eradicate grass, untreated waste from failed septic tanks, waste water disposal from industrial facilities, sediment from construction sites, and runoff from waterproof surfaces such as parking lots [1,2,3,4]. After reaching the coast, its flow can be influenced by commercial activities and recreational boating and other activities on the beach. Spatio temporal analyses of water quality monitoring in water body are important because pollution sources vary temporally and spatially [2,4,5,6,7].

The aim of this study is to develop an integrated water quality modelling for spatial planning. Water quality will be the main indicator of the proper utilization of land resources. Based on the water quality modelling, the land use area that produces the high pollutant load can be identified. The spatial planning can be designed to optimize the land use with the minimum pollutant load.

2. Method
2.1. Study area
Study area is Ciliwung watershed, the area in the middle of Jakarta Coastal watershed (Figure 1). Jakarta Coastal Watershed is ideal for such a study due to it is one of the world’s largest coastal cities. In the Bay of Jakarta offshore lies the sequence of elongated coral islands exposed to conditions ranging from highly disturbed to relatively pristine. Jakarta is the capital of the Republic of Indonesia, the seventh national capital with the largest population which is more than ten million. Jakarta functions as a service city and industrial estate which the economic is dominated by manufacturing, and trading. Jakarta has a very limited municipal waste treatment system, most of the domestic and industrial waste is systematically discharged into the river. The environmental conditions of the Ciliwung river are very poor (Figure 2).

![Figure 1. Landsat TM7 of Jakarta coastal watershed.](image1)

![Figure 2. Environmental condition of Ciliwung main river.](image2)
In Ciliwung watershed area there is a spatial distribution of socio-economic activities and related land uses, such as industrial, mining, agriculture, forestry, aquaculture and fisheries, trade and transportation. This spatial distribution of human activity produces man-made pollution and other environmental pressures. This situation impacts on environmental stresses in the form of residues generated by populations and their economic activities, together with changes in land use.

The watershed boundaries and drainage patterns of the Jakarta coastal watershed are described based on Landsat Thematic Mapper 7 (Figure 3). The Jakarta coastal watershed is located on the north coast of Java, centred at latitude 106°50E and longitude 05°09S, consisting of 6 fluvial systems in the Cisadane River, Angke River, Sunter River, Ciliwung River, Bekasi River, and Cikarang River with combined catchment area of 4,610 km². The system is discharged to the central sector of Jakarta bay.

The Ciliwung watershed flows 125 km from upstream in Bogor and empties into Ancol, Jakarta. The fate and transportation of pollutant modelling is carried out in the main river of Ciliwung. There are 13 locations for water quality measurement in the main river of Ciliwung (Figure 4). Water quality measurement parameters are temperature, coliform, four forms of nitrogen, DO, BOD, phosphorus, two types of algae, and some conservative constituents.

2.2. Water quality modeling

Water quality modelling of Ciliwung River has been used to analyse the correlation of water quality in the river body with the land use nearby the area. Correlation analysis is carried out between water quality measured in a body of water and the pollutant load that comes from the surrounding environment. Analysis of sources of pollutants and land use in related areas was also carried out, in terms of designing optimal land use planning. Optimizing land use is intended to obtain maximum economic benefits without causing the environmental pollution. In areas that have high concentrations of pollutants and cause pollution in water bodies, must have pollution control and some scenario analysis is applied in this area.

**Figure 3.** Drainage pattern of Jakarta coastal watershed. Ciliwung watershed is in the middle of Jakarta Coastal watershed.

**Figure 4.** Point of water quality measurement in Ciliwung main river.
Water quality modelling was performed using the QUAL2K public domain free software. Eutrophication models are used to determine the fate and transport of organic pollutants. QUAL2K can simulate the migration and transformation of a wide variety of constituents including dissolved oxygen, temperature, biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrate nitrogen, total nitrogen, sediment oxygen demand, organic phosphorus, inorganic phosphorus, total phosphorus, phytoplankton and algae [10,11]. The model can also simulate some other factors such as pH, alkalinity and pathogenic bacteria.

The mass balance equation is combined with the hydrodynamic equation to produce a variable response to water quality. Water is restricted to flow from one node to another through a specified channel, advancing and spreading water quality constituents between nodes. The movement of water at the link is simulated by a hydrodynamic model with identical configurations or derived from field measurements. Hydrodynamic mathematical models in water systems based on mass balance equations are applied to these components, including advection, diffusion, inflow and outflow, and the terms sink or source (Figure 5). The mathematical model of the kinetic reaction in the water system is described as an eutrophication model (Figure 6). This model simulates temperature, coliform, four forms of nitrogen, DO, BOD, phosphorus, two types of algae, and several conservative constituents.

A general mass balance for a component concentration $c_i$ in the range of $i$ is written as shown in equation (1) [10,11]:

$$\frac{dc_i}{dt} = \frac{Q_i}{V_i} c_{i-1} - \frac{Q_i}{V_i} c_i - \frac{Q_{out,i}}{V_i} c_i + \frac{E_i}{V_i} (c_{i-1} - c_i) + \frac{E_i}{V_i} (c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i$$  (1)

In the equation (1), $c_i$, $Q_i$, $V_i$, $E_i$, and $W_i$ symbolize the component concentration of water quality, flow, volume, dispersion coefficient, and outer component load of the range $i$, respectively. $S_i$ symbolizes the sinks and sources of the component due to a large number of transformation mechanisms and reactions in the range of $i$. $Q_{out,i}$ symbolize flow abstraction in the range of $i$.

### 3. Results and Discussions

The Ciliwung water quality measurement data (Figure 7) showed at the measurement point P13, in the Depok area, 27 km from upstream, there was a significant accumulation of pollutants and a significant increase in pollutant concentrations. At this point all parameters including BOD, N, P and TDS increase significantly. At this point the TSS parameter is reduced which might because the TSS parameter has been deposited along the previous way. The DO parameter becomes zero that might cause by the accumulation of pollutants is very high that in the water system there was no more dissolved oxygen left.

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![Figure 5](image5.png) **Figure 5.** Mass balance for relevant components of the river system in reach $i$ [9,10,11].

![Figure 6](image6.png) **Figure 6.** Mathematical model of kinetic reaction in water system [8].
Validation of the Ciliwung water quality model (Figure 8) showed the number of quadratic errors was 0.153 for BOD and 0.223 for DO, respectively. The daily BOD decay rate coefficient is 12 for upstream and 3.5 for downstream. Model of Ciliwung water quality (Figure 9) shows the daily DO re-aeration rate coefficient is 20 for upstream and 0 for downstream. This study has showed that the downstream flow of the Ciliwung system has a significant concentration of pollutant load, high BOD concentration, no pollutant degradation capability, and a zero BOD decay rate. The data shows that the upper flow of Ciliwung is better than the downstream flow.

Based on the water quality model that has been developed in this study, scenario analysis is carried out with 2 scenarios, namely the upstream pollution control scenario and the downstream pollution control scenario. Upstream pollution control covers the upstream areas in Bogor to Depok, at the measurement points P1 to P13. Downstream pollution control covers the downstream areas in Depok to Ancol, at the measurement points P13 to P20. Pollution control scenarios include scenarios to eliminate the burden of point pollutant sources, non-point sources and both point sources and non-point sources.

The upstream scenario (Figure 10) showed that the scenario to minimize the burden of pollutants in the upstream area does not function to minimize the environmental impact in the Ciliwung system. The condition of Ciliwung waters remains the same as existing conditions, even though the load of pollutants has been removed from the point source, non-point source and both point and non-pollutant sources.

The downstream scenario (Figure 11) showed a scenario to minimize the burden of pollutants in the downstream area to minimize the environmental impact in the Ciliwung system. The pollutant control scenario works effectively by controlling pollutant loads, especially at non-point source loads. The pollution control scenario has not been successfully since the Ciliwung system is still the same as the original condition, if the pollutant load control is only carried out at the pollutant source point. That means the main problem of Ciliwung watershed pollution is due to the high burden of non-point pollutant sources in the area.

![Figure 7. Water quality data measurement of Ciliwung main river.](image-url)
This study shows that, the pollution problem in the Ciliwung system is in the downstream areas, which are associated with very dense urban areas. Pollutant exports by small streams tend to correlate best with land use and cover, specifically with the proportion of agricultural and urban land in the watershed.
Figure 10. Upstream scenario of Ciliwung pollution control.
DOWNSTREAM SCENARIO

EXISTING CONDITION

Point Source = 0

Non Point Source = 0

Point Source & Non Point Source = 0

Figure 11. Downstream scenario of Ciliwung pollution control.
4. Conclusion
Based on water quality modelling, it can be identified that the main pollution problem in the Ciliwung system is in the downstream area, which correlates with very dense urban areas. The main problem of Ciliwung watershed pollution is due to the high burden of non-source pollutants in the area. The pollutant loading from the ground surface associated with the land use. Pollutant exports by small streams tend to correlate best with land use and cover, specifically with the proportion of agricultural and urban land in the watershed. Pollution control in the downstream of Ciliwung is very important in terms of the sustainability of Ciliwung's water resources. Ciliwung pollutant load control can be done with land use planning and building a waste treatment plant. Spatial planning is needed in this area, which produces a high pollutant load, therefore it can be organized into areas with minimal pollutant load.

Acknowledgment
We are grateful to Dr. Bambang Edhi Leksono and Ir. Eko Harsono for their contribution in discussing and providing the secondary data and water quality analysis.

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