Water Quality Index Response of UI Cascade-Pond System on Catchment Imperviousness Temporal Variation

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Abstract. This study focuses on the water quality in a catchment area that is affected by the impervious cover. The purpose of this study is to prove the correlation analysis between impervious cover as the independent variable and the water quality index as the dependent variable by analysing the correlation and regression relationship. The study area is located in the catchment area at the campus of Universitas Indonesia, Depok, West Java. The data of the imperviousness is collected from the digital globe imagery and digitized based on identified rooftops. The water quality data is determined based on previous reports and collected manually in the pond by the author. The water collected from the pond will be put for laboratory test to be able to get the quality of the sample according to the determined parameters and then knowing the quality of the pond using the National Sanitation’s Foundation Water Quality Index (NSF-WQI) method. The targeted water quality index is determined based on water usage suitability referring to the Indonesian government regulation number 82/2001. As time goes by, the impervious cover grows and gives an effect to the water quality of the UI cascade-pond. As a tool to set a plan for future development on the catchment area of the pond system in Universitas Indonesia, it is possible to use the linear relationship between catchment area imperviousness and water quality index. After doing a linear regression analysis between imperviousness and water quality, a relationship was found that the change of impervious cover has an effect towards the water quality and is getting worse over time.

Keywords: Impervious Cover, Water Quality Index, Linear Relationship

1. Background
Universitas Indonesia campus has a cascade-pond that flows from outside the campus to Ciliwung river. The growth of imperviousness in the catchment area of KAMPUS UI cascade-pond has an influence towards the water quality. The presence of residents living in the KAMPUS UI cascade-pond area and the existence of new buildings has an effect on the water quality of KAMPUS UI cascade-pond. As time goes on there are many changes in terms of land use and the addition of the surrounding population.

In an ecosystem, each component is very influential towards the other components. In a river flow, if something happens on the upstream like pollution, it will affect the middle part and the downstream of the river. Not only it disrupts water bodies but also the overall ecological system will be disrupted. The function of the watershed as a water catchment area is to provide water for human and protect the environment including water quality, prevent flood and drought, and reduce the flow of land mass from upstream to downstream [1].
In this study, data analysis will be carried out to determine the effect of the change of landuse in the KAMPUS UI cascade-pond catchment area on the prediction of water quality in KAMPUS UI cascade-pond using correlation and regression tests. Water quality data will be gathered first by collecting water from the pond and then will be tested for quality parameters. Secondary data of impervious cover and pond water quality in UI were collected from previous research to obtain changes that occurred previous years till the present time. From the results of laboratory testing, regression analysis and correlation will be conducted to determine the changes that occur. Nine scientific parameters are tested and will by analysed which parameter is the furthest from the quality standards.

2. Material and Method

2.1 Impervious Cover Model
Water-resistant land cover or impervious cover is a surface that does not have the ability to absorb water into the soil. Examples of impervious cover are residential roofs, terraces, public buildings, commercial structures, parking lots and other watertight surfaces [2]. With the increase in excessive impervious cover, the infiltration of rainwater into the soil decreases, leading to increased rain runoff which can reduce water quality with various pollutants entering the water body. Initially the impervious cover was developed by Schueler which aims to determine how the effects of impervious cover towards various types of water and biotic quality indicators [3]. Impervious cover model is divided into 4 categories based on how much the impervious cover model influences on water bodies, namely: sensitive, impacted, non-supporting, and urban drainage.

2.2 Water Quality Index
Water quality index (WQI) is a method of simplifying the amount of water quality parameter data into a number that can describe the status of water quality so that it can be understood easily by the general public. There are three types of water quality index testing methods, namely the STORET, NSF-WQI, and CCME-WQI methods. However, in this study the NSF-WQI method is used in testing the water quality index. The National Sanitation’s Foundation Water Quality Index (NSF-WQI) method is the result of a questionnaire conducted by water experts from various United States of America that were used as respondents. The advantages of the NSF-WQI method include being able to summarize water quality data in one index value objectively, quickly and easily using it, being able to evaluate various water bodies and identifying changes in water quality, index values and can be linked to potential water designation, and can be easily understood by general public [4].

2.3 Research Location
The location for collecting water samples was carried out at eight different points of the KAMPUS UI cascade-pond catchment area. The sampling is carried out three times, which are on 16 November 2018, 29 November 2018, and 3 May 2019 at around 9:00 to 13:00 Indonesian Western Time. The following is a map of the location of the sampling points:
The samples that have been obtained will be tested according to the parameters needed at the University of Indonesia’s Laboratory of Sanitation and Environmental Engineering.

2.4 Data Collection
In knowing the relationship between changes of impervious cover and water quality, it is necessary to use the impervious cover data every year. Impervious cover data are obtained from the Geospatial Information Agency. When there are circumstances where there are years of unregistered impervious cover, there will be the interpolation of existing regression equations to obtain impervious cover data in the year for which there is no data available. When the water sample has been collected into the bottle, quality measurements are taken for their physical and chemical parameters. Measurement of these parameters was carried out at the University of Indonesia’s Laboratory of Sanitation and Environmental Engineering. The parameters measured for all of these samples are:

- pH
- Biochemical Oxygen Demand (BOD)
- Total Suspended Solids
- Temperature Change
- Fecal Coliform
- Phosphate
- Turbidity
- Nitrate
- Dissolved Oxygen (DO)

When we have obtained the impervious cover data for each year, we can compare the changes by analyzing the water quality of KAMPUS UI cascade-pond with the impervious cover data each year. From this relationship, correlation and regression can be drawn related to changes in the two variables.

2.5 Correlation and Regression
Correlation and regression analysis are used in finding the relationship between two variables, namely between changes in impervious cover as an independent variable and the status of water quality as the dependent variable. This analysis is a method to determine whether or not there is a linear relationship between those variables [5].

The data is analyzed in a nonparametric procedure because it is below 30 data [6]. The main step in a nonparametric procedure is the null hypothesis. It is a statement that indicates no difference exists between conditions, groups, or variables. At the end of the correlation analysis it can be concluded whether the null
hypothesis is rejected or not. When the null hypothesis is rejected, it means that there is a correlation between the two variables.

In this study, the author looked for the relationship between the rate of impervious cover as the independent variable and the status of water quality as the dependent variable, so the level of the relationship is called correlation. If the value of one variable increase when the other variable decreases, the two variables are negatively correlated. Conversely, if one variable increase when the other variable also increases, the two variables are positively correlated. The degree or level of relationship between two variables is measured by a correlation index called the correlation coefficient \( R^2 \). \( R^2 \) values range from 0 – 1, where the correlation is very strong if the value of \( R^2 > 0.5 \). Regression analysis is an advanced analysis of correlation to test the extent of the influence of independent variables on the dependent variable when it is known that there is a relationship between these variables. Regression analysis conducted for this study is linear regression analysis. The analysis can be formulated as follows:

\[
Y = a + bX \quad \ldots \ldots \ldots (1)
\]

Where:
- \( Y \) = Dependent Variable (Water Quality)
- \( X \) = Independent Variable (Impervious Cover)
- \( a \) = y-intercept
- \( b \) = slope of the line

Linear Regression Test was carried out using Microsoft Excel by making a graph of the impervious cover and water quality index data from year to year. Of the two series data, a Clustered Column mode graph is formed so that linear equations can be obtained from these data and \( R^2 \) values to determine the correlation of the two data.

3. Results and Discussion

3.1 Impervious Cover Percentage

This research was conducted in the KAMPUS UI catchment area. The watershed area is 7.0725808 km². From the area of the watershed, there are six different ponds so that each pond needs to be tested to determine the quality of the water. The six points are Pond Kenanga, Pond Aghatis, Pond Mahoni, Pond Puspa, Pond Ulin, and Pond Salam. The following table is the data on impervious cover from year to year:

| Pond   | Area (Ha) | 2005* | 2011* | 2015* | 2016 | 2017 | 2019 |
|--------|-----------|-------|-------|-------|------|------|------|
| Kenanga| 54.4      | 1.30% | 7.20% | 22.40%| 45.89%| 45.89%| 48.72%|
| Aghatis| 87.15     | 68.20%| 75.50%| 76.90%| 78.18%| 78.28%| 78.59%|
| Mahoni | 472.04    | 39.20%| 41.20%| 44.20%| 62.48%| 63.22%| 63.53%|
| Puspa  | 503.5     | 36.50%| 38.60%| 41.50%| 58.77%| 59.49%| 59.81%|
| Ulin   | 531.88    | 34.60%| 36.50%| 39.30%| 55.51%| 56.21%| 56.54%|
| Salam  | 578.86    | 31.80%| 33.60%| 36.20%| 51.38%| 52.05%| 52.38%|

Table 1. Catchment Area Imperviousness
The 2005, 2011, and 2015 data were collected from a previous study called “Water Quality Index for Determining the Development Threshold of Urbanized Catchment Area in Indonesia” which was written by Sutjiningsih [7]. The 2016, 2017, and 2019 data were digitized manually using the ArcGis software by the author himself. It can be seen from the table above that from time to time, the percentage of impervious cover increase.

3.2 Water Quality Index

The water quality testing uses 9 water quality parameters, namely Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), pH, Temperature Change, Turbidity, Total Suspended Solid (TSS), Total Nitrate, Total Phosphate, and Fecal Coliform using the class II quality standards based on the Indonesian Government Regulation No. 82/2001 Concerning Water Quality Management and Water Pollution Control. As the sample of the water has been tested, the author would obtain the results of the water quality for each parameter and then putting it in the WQI calculator to obtain the water quality index of each pond. The following table shows the temporal change of the water quality index from 2006 until 2019:

| Pond       | Water Quality Index | Criteria |
|------------|---------------------|----------|
|            | 2006  | 2011  | 2015  | 2016  | 2018  | 2019  |        |
| Kenanga    | 87    | 49    | 58.5  | 41.33 | 48.21 | 40.36 | Bad    |
| Aghatis    | 73    | 50    | 46.5  | 40.43 | 44.385| 38.12 | Bad    |
| Mahoni     | 87    | 50    | 56.5  | 38.65 | 48.36 | 42.39 | Bad    |
| Puspa      | 88    | 47    | 55.5  | 39.1  | 51.15 | 44.46 | Bad    |
| Ulin       | 88    | 48    | 57.5  | 33.48 | 41.905| 36.23 | Bad    |
| Salam      | 88    | 61    | 59    | 41.34 | 54.83 | 44.8  | Bad    |

It can be seen that the current water quality in UI cascade-pond is in a bad condition. The three parameters that is going to be analyzed are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Nitrates. These three parameters have a temporal change of quality as shown in the graphs below:

![Figure 2. Temporal Change of Dissolved Oxygen in UI Cascade-Pond](image-url)
Figure 3. Temporal Change of Biochemical Oxygen Demand in UI Cascade-Pond

Figure 4. Temporal Change of Nitrates in UI Cascade-Pond
Dissolved Oxygen and Biochemical Oxygen Demand has an opposite characteristic. A water quality is bad when the amount of DO is small or when the amount of BOD is much. When DO is below the quality standards, it means that the water quality is bad as shown in the graph above. But, when the amount of BOD is more than the quality standard, it means that the water quality is bad. Same like BOD, when Nitrates are above the quality standards, it means that the water quality is bad.

3.3 Analysis of Correlation and Regression Test Results

Using the null hypothesis, we can know the correlation relationship of the water quality. The following table shows the results of the null hypothesis for all sub-watershed in the UI cascade-pond catchment area.

| Sub-Watershed | Null Hypothesis       |
|---------------|-----------------------|
| KENANGA       | Accept null hypothesis|
| AGHATIS       | Reject null hypothesis|
| MAHONI        | Accept null hypothesis|
| PUSPA         | Accept null hypothesis|
| ULIN          | Accept null hypothesis|
| SALAM         | Reject null hypothesis|

If the null hypothesis is rejected, it means that there is a strong correlation between the imperviousness and the water quality. From the table above it can be said that Aghatis and Salam are the sub-watershed that has a strong correlation. After all the data are simulated by the regression results from the impervious cover and the water quality data, a correlation equation and $R^2$ values can be presented in the following table:

| Sub-Watershed | Correlation Equation | $R^2$   |
|---------------|----------------------|---------|
| KENANGA       | $y = -0.2859x + 56.543$ | 0.4111  |
| AGHATIS       | $y = -4.2213x + 369.92$ | 0.6753  |
| MAHONI        | $y = -0.5417x + 76.05$ | 0.5907  |
| PUSPA         | $y = -0.3466x + 64.702$ | 0.2945  |
| ULIN          | $y = -0.8875x + 85.902$ | 0.7075  |
| SALAM         | $y = -0.8346x + 89.069$ | 0.6567  |

When the value of $R^2 > 0.5$, the two data compared are strongly correlated. From the table above, it can be concluded that Aghatis, Mahoni, Ulin, and Salam has a strong correlation between the imperviousness and its water quality. The correlation relationship is between the imperviousness and the water quality. Aghatis watershed is correlated because it is the first pond that receives all of the waste of the catchment area. Mahoni watershed is correlated and has a bad quality because the pond directly receives waste from a restaurant called Mang Engking near the Salam pond.

However, the downstream of a cascade-pond should have the best quality because as water flows from the upstream to downstream, settling of waste will happen. In this case Salam pond has greater rate of change of water quality than Aghatis pond as shown in the graphs below:
This evidence happened because there is another inflow of waste that comes directly from outside of the campus to the inlet of Ulin pond then flows to the Salam pond and also the wastewater from the restaurant operating near the Salam pond.

4. Conclusion
As imperviousness increase temporally in a watershed, the water quality deteriorates. In a cascade-pond system, the downstream should have the best quality among all of the ponds. In this case the quality of the downstream is worse than the upstream because of having another input of waste from another drainage which is not yet observed and detected. By this evidence a suggestion of observing and detecting other drainage inputs from outside the campus area is needed so it could be known well the reason of the bad quality in the downstream of the cascade-pond.

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